Waste Not, Want Not: An Environmental Impact Assessment of the Wellesley College Waste Stream and Steps for a More Sustainable Future

Credit: Richard Howard

Environmental Studies 300
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Environmental Studies Program
Wellesley College
Wellesley, MA 02481

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Acknowledgements

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List of Contributors

Academic Advisor:
Elizabeth R. DeSombre, Frost Professor of Environmental Studies

LEADERSHIP TEAM:
Project Manager: Phoebe Handler '12
Overall Text Editor: Isabella Gambill '12
Overall Data Editor: Ellen Willis-Norton '12
Project Coordinator: Pin Pravalprukskul '12

Graphics Czar: Genea Foster '12

Facilities and Administration Liaison: Natalia Ospina '12

Ruhlman Presentation Coordinator: Morgan McKinney '12

Media Contact: Dominique Hazzard '12

Webmaster: Carolyn E. Whitlock '12

Project Team Text Editors
Randelle L. Boots '13
Linda Hsu '13
Amanda Smith '12
Kelli Stephens '12
Julie Vining '12

Project Team Data/Graphics Editors
Vanessa Barrera '12
Melissa Gallant '12
Whitney Smith '12
Jessica Vandenberg '12
Florence Wangũi Kamonji '13

MATERIAL TEAMS:
Primary Materials
Amanda Smith '12 – Glass
Whitney Smith '12 – Aluminum Foil and Pie Plates
Ellen M. Willis-Norton '12 – Steel and Aluminum Cans

Paper
Vanessa Barrera '12 – Boxboard and Chipboard, Mixed Paper, and Junk Mail
Genea Foster '12 – Cardboard
Natalia Ospina '12 – Office Paper

Plastics
Phoebe Handler '12 – Plastics #4
Linda Hsu '13 – Aseptic Containers
Florence Wangũi Kamonji '13 – Plastics #6 & #7
Pin Pravalprukskul '12 – Plastics #1
Jessica Vandenberg '12 – Plastics #2
Carolyn Whitlock '12 – Plastic Bags and Wraps
(Plastics #3 & #5 were completed collectively by the Plastics Team)

Organics
Dominique Hazzard '12 – Food Waste
Kelli Stevens '12 – Disposable Compostable Dishware and Utensils
Julie Vining '12 – Yard Waste

Durable/Composite/Special Goods
Randelle Boots '13 – Personal Appliances
Melissa D. Gallant '12 – Electronic Waste
Isabella Gambill '12 – Special Recyclables
Shilpa Idnani '12 – Books, Clothing, and Institutional Durable Goods
Morgan McKinney '12 – Dishware

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Common Abbreviations

ACB: Allied Computer Brokers
Al: aluminum
Basic Input/ Output Systems (BIOS)
BOF: basic oxygen steel-making furnace
CFL: compact fluorescent light bulb
CMR- code of Massachusetts regulation
C_2H_3Cl: chemical formula of vinyl chloride
CO2: carbon dioxide
C_2H_4: methane
CPU- central processing unit
CRA: Container Recycling Alliance
CRS: Complete Recycling Solutions
CRT: Cathode Ray Tubes
DOE: United States Department of Energy
EAFA: European Aluminum Foil Association
EHS: Wellesley College's Office of Environmental Health and Safety
ES- environmental studies
EPA: United States Environmental Protection Agency
EPS: expanded polystyrene
eq: equivalents
E-waste- electronic waste
EXPS: extruded polystyrene
GHG: Greenhouse Gases
H+: hydrogen ion, a measure of acidity
H_2O: water
H_2SO_4: sulfuric acid
HCFC: Hydrochlorofluorocarbon
HDPE: High-density Polyethylene
HFC: Hydroflourocarbon
H_2O: water
IRN: International Recycling Network
km: kilometer
kg: kilogram
kJ: kiloJoules, a measure of energy
kWh: kilowatt-hours
LCA: Life Cycle Analysis
LCD- liquid crystal display
LDPE: Low-density polyethylene
MassDEP- Massachusetts Department of Environmental Protection
MAST: a type of clay
MDPE: Medium-density polyethylene
mg: milligram
Misc.: miscellaneous
MJ: megajoules
MSW: Municipal Solid Waste
N: nitrogen
NaOH: sodium hydroxide
NiCad: Nickel-cadmium rechargeable battery
NLR: Northeast Lamp Recycling
oz: ounces
PA 6.6- nylon
PbO: lead oxide
PCB- polychlorinated biphenyls
PCR: Post Consumer Recycled
PETE: Polyethylene terephthalate
PHEV: plug-in hybrid vehicle
PM: particulate matter
POP- Persistent Organic Pollutant
PO_4: phosphate
PP: Polypropylene
PSC: Phillips Services Corporation
PVC: Polyvinyl chloride
qtr: quarter
RAM- random access memory
RCRA: Resource Conservation and Recovery Act
RNA- Ribonucleic acid
ROM- read-only memory
RRF: Resource Recovery Facility
SEMASS: Waste-to-Energy incineration facility in Southeastern, Massachusetts
STARS: Sustainability Tracking and Rating System by the Association for the Advancement of Sustainability in Higher Education
SO_2: sulfur dioxide
TSDF: Transport Storage and Disposal Facility
TRACI2
µm: micrometers
UN: United Nations
UPS- United Postal Service
V: volt
W: watts
WM- waste management
WTE: Waste-to-Energy incineration facility
WHO: World Health Organization

Executive Summary

The Spring 2012 Wellesley College Environmental Studies 300 assessed the sustainability implications of the College's waste system, by estimating the total amount of waste produced annually and the material content of the waste stream, and analyzing the environmental impacts of the materials and disposal processes through a life cycle assessment (LCA).

To estimate the amount and composition of Wellesley College's waste, we completed a hands-on waste audit of a few dumpsters on campus, tallied the contents of recycling bins, examined internal waste log-books and ordering records, conducted interviews and surveys, and even visited Wellesley's waste-to-energy (WTE) and recycling facilities. We also extrapolated from EPA metrics of national waste patterns, professional LCAs, and waste assessments completed by other colleges. Once we estimated the material breakdown and total amount of Wellesley's waste, we used the TRACI2 method through the LCA software SimaPro7 to determine the environmental impacts and credits associated with how our waste is handled.

We estimate that Wellesley College produces 1,072,395.68 kg of waste annually. Of this total, 41.8% is food waste and 25% is paper waste. For our current annual waste patterns, the largest impacts come from small appliances, food, compostable dishware, and paper that are thrown in the trash. Of the current recycling stream, it is most important to recycle electronics, paper, special recyclables, and durable goods

Through an examination of the impacts per 1 kg of each material as trash or recycling, we were able to identify the best current options for waste handling. Incinerating small appliances, special recyclables, durable goods, food/compostable dishware, yard waste, and paper should be avoided. Recycling is the preferred option for paper, aluminum, steel cans, glass, small appliances, electronics, special recyclables, and durable goods. Because of their high heating value, plastics WTE incineration often results in negative impacts, which make it the preferred alternative to recycling. This finding should not be taken in isolation, however, but should consider the manufacturing impacts and recycling legislation that make recycling the preferred option for plastics after reduction.

Our primary recommendation is overall reduction of waste production, which has the greatest effect in limiting the environmental impact of our waste system. The college can build on existing successes, involving on-campus composting of yard waste, on-site mulch manufacture, and institutional durable goods reuse efforts like the Sustainable Move-Out. We also have a strong infrastructure for special recycling of electronics, small appliances, and special recyclables that would have particularly harmful impacts if thrown in the trash.

Food waste comprises the largest portion of our waste stream, and is currently treated as trash. We should work to limit the amount of food waste being generated on campus, and should assess the environmental and financial viability of a campus-scale composting program. Because of the large amount of paper waste, we recommend evaluating options to decrease use. Much of the glass waste on campus comes from the science center, where it is thrown in the trash because of contamination concerns. This practice should be re-evaluated, and alternative handling schemes that allow for lab glass recycling should be encouraged. We also encourage departmental self-audits and the creation of waste controls or bans on problematic materials.

Our LCA analyses demonstrate that our modern recycling system is convoluted, taking a plastic water bottle to three different facilities before it is actually recycled. For most materials, the market encourages overseas transport before the actual recycling happens. While market forces matter, we encourage the College to research alternative recycling handlers to localize the recycling process where possible in order to limit the transportation impacts of our waste.

1 Introduction

1.1 Framing Waste

Sustainability is an important initiative to pursue on the Wellesley College campus. To champion this cause, each year Wellesley enlists the services of the students enrolled in the Environmental Decisionmaking Class (ES 300), the capstone course required for the Environmental Studies major. Each year of ES300, students are presented with a new sustainability issue the campus would like to address, and are asked to research the problem in depth and ultimately suggest recommendations for areas of improvement based on their findings. This year our class was assigned the problem of how to reduce the environmental impacts of Wellesley College's waste stream. While this meant that at some points in our research we were quite literally up to our necks in trash, our findings were well worth the hassle. This report is a compilation of the evaluations, conclusions and general recommendations we found as a result of the campus wide waste assessment that we conducted throughout the semester.

What is the problem with waste? The problem is that there is a lot of it. Disposing of waste damages the environment as well as our health. Wellesley College would like to reduce its MSW impact for both environmental, human health, and fiscal reasons.

However, Wellesley College is only a small piece of a much larger problem. Waste disposal is a global issue and many of its causes can be found in our culture and personal habits. Marketing trends favoring planned obsolescence and societal demand for disposable convenience has resulted in the exponential increase of waste production in the United States over the past century. From 1960 to 2007 alone, the U.S nearly tripled its annual municipal solid waste stream, reaching a staggering 254 million tons of waste per year, or 4.6 pounds per person per day. With a 34 percent recycling rate, the majority of waste material winds up in a crowded landfill or contributing to atmospheric pollution in an incinerator.[1] The way waste is approached in our culture is dependent less on what the object in question is, and more on where that object is located. There are useful resources that our society is labeling as invaluable simply because they have been classified as waste and moved to a trashcan, dumpster or landfill.

[1] Municipal Solid Waste. *Environmental Protection Agency.* 2012. Web. 5 May 2012. <http://www.epa.gov/osw/nonhaz/municipal/index.htm>.

What do we label as waste? There are several categories: industrial waste (all the leftovers from the extraction and production process of materials); construction and demolition waste; special wastes (such as used medical products or sewage) and municipal solid waste (MSW). Out of all these categories, what Wellesley is most concerned with is MSW: the type of waste one would find in one's local dumpster or the garbage can in one's household. It is a broad category comprised of many different materials; the most common are cited by the EPA as paper/paperboard, food scraps, yard trimmings, plastics, metals, rubber, leather, textiles, wood and glass.[2]

It was our job to research MSW at Wellesley College and identify how the campus contributes to the global waste problem. With this report, we include what the Wellesley College community can do to reduce its waste, and encourage the campus to begin looking at the contents of its trashcans not as waste, but as resources in the wrong place.

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[2] Municipal Solid Waste. *Environmental Protection Agency*. 2012. Web. 5 May 2012. <http://www.epa.gov/osw/nonhaz/municipal/index.htm>.

1.2 Wellesley College's Waste Production

In order to estimate the environmental impacts of Wellesley's waste, we first need to know how much, and of what materials, we waste. The College did not know this basic information about its waste stream, so the first step in our project was to use a variety of methods to estimate the amount, source, and destination of Wellesley College waste. We estimated by looking at statistics from our waste hauling and recycling contracts, conducting our own waste and recycling audits and extrapolating from that process, identifying purchasing patterns, and interviewing staff members, along with other estimation tools. In calculating our estimations, we used a set of common assumptions about the number of students, when they are on campus, distances our waste travels, etc., to ensure that we were all estimating in the same way. Those assumptions can be found in Appendix A. According to our estimations, Wellesley College produces approximately 1,074,977.49 kg of waste each year.

ANNUAL STATISTICS

Unfortunately, there is no direct way of identifying the weight of the trash discarded annually by Wellesley College. Wellesley Trucking, the company Wellesley College hires to collect our trash, gathers our trash and combines it with trash from other pick-up locations, only weighing its load at the transfer facility. It is thus difficult to gauge precisely how much of the trash collected by Wellesley Trucking in one load comes from Wellesley College.

The best way we could measure patterns of waste disposal was through the 2011 compactor weights that Wellesley Trucking evaluated for the College. Out of the many dumpsters on Wellesley's campus, there are only four compactors, of which Wellesley Trucking vehicles are required to weigh. For this reason, we could only estimate the total amount of trash discarded by Wellesley by using estimates from these four compactor locations (Lulu Chow Wang Campus Center, Tower Court, Stone-Davis, and the New Dorms).[1]

Compactor data indicates that Wellesley College produced 374,102.89 kg of waste in 2011 from the aforementioned locations.[2] Our total waste disposal rate seems to peak in May, and then drops steeply in June and July, before rising once again in August and September. This fluctuation correlates with the academic year, demonstrating the highest waste disposal rates at its start in August and September, and end during May. However, every building may not follow this trend, particularly if its schedule differs from that of the academic school year. The Campus Center, for example, produced the highest amount of waste in April and November. It is possible that these times are when the largest waste-producing events are hosted in the campus center.

Figure 1.1 tracks the compacted waste collected by Wellesley Trucking in 2011, and while it does not include the complete waste stream at Wellesley College, it does offer an estimation of when the peak periods of waste disposal occur on campus.

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[1] Wellesley College Compactor Tonnage 2011. *Wellesley Trucking*. 2012. XLS file.

[2] Wellesley College Compactor Tonnage 2011. *Wellesley Trucking*. 2012. XLS file.

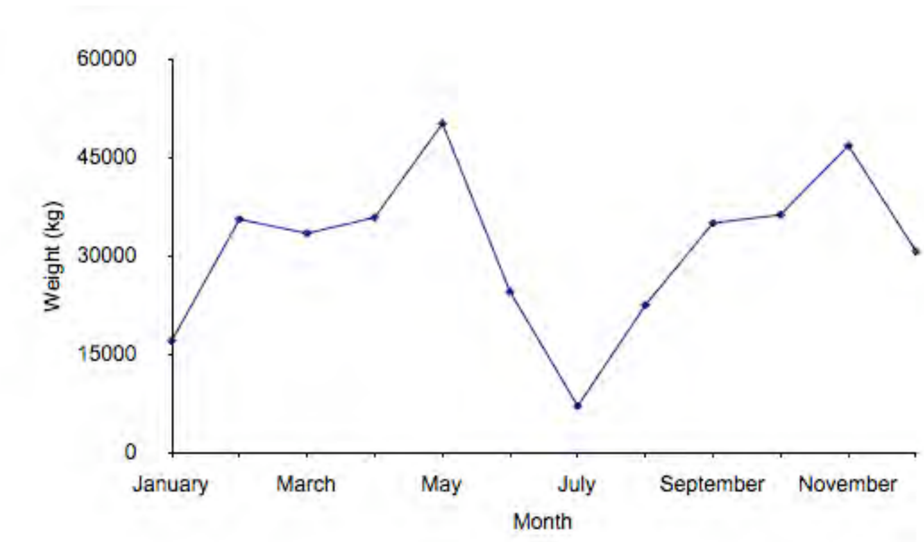

Figure 1.1: 2011 Wellesley College Compactor Tonnage. Collected by David DeBello from Wellesley Trucking from the Lulu Chow Wang, Tower Complex, Stone-Davis and the New Dorms.

Wellesley College recycling is sent to Conigliaro Industries, Northeast Lamp Recycling (NLR), and the Institutional Recycling Network through the Allied Computer Brokers (ACB) and Complete Recycling Solutions (CRS). Conigliaro Industries receives the majority of our recyclable products, including mixed paper, cardboard, metals, plastics, mixed wood, styrofoam, refrigerators, mattresses, some furniture, and computer and television cathode ray tubes. The other facilities mentioned receive our special recyclable waste (batteries and light bulbs) and electronic waste.

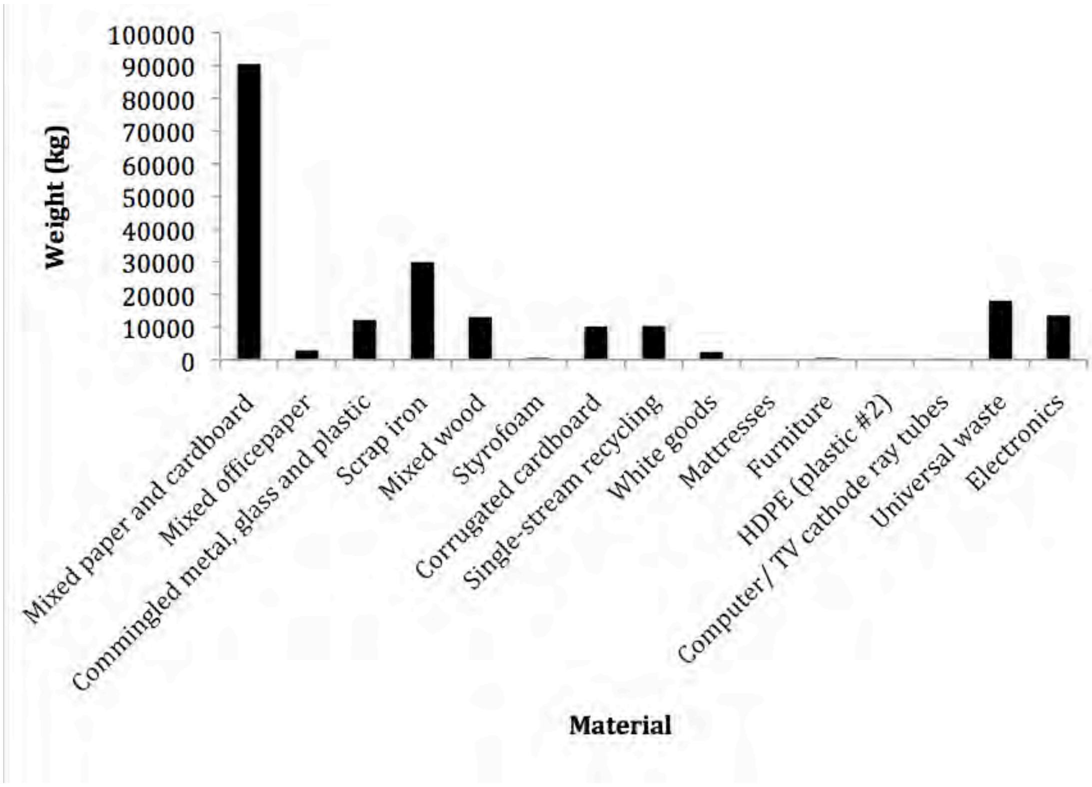

Figure 1.2: Weight of Materials Recycled in 2011 by Wellesley College. Data Obtained from Conigliaro Industries and EHS inventories.[3]

For the year 2011, Wellesley College recycled a total of 205,208 kg of waste via Conigliaro Industries and NLR. Conigliaro Industries and Wellesley College's Office of Environmental Health and Safety keep records of the weight of shipments, by material, sent to Conigliaro throughout the year.[4] In total, 173,500 kg of recyclables was sent to Conigliaro Industries in 2011, and 31,708 kg of recyclables was sent to NLR. The material that composed the largest weight of recyclables was mixed paper and cardboard, at 90,500 kg. The material that was recycled the least was HDPE (Plastic #2) at 100 kg. Other materials that account for less than 1,000 kg of waste recycled include styrofoam, mattresses, furniture, and cathode ray tubes from computers and televisions (Figure 1.2).

[3] Wellesley College 2011 Recycling Records. *Conigliaro Industries*. 2012. XLS file.; Finne, J. ES300 Universal Waste Database. 2012. XLS file; Justin Finne. Environmental Health and Safety Officer. Personal Interview 9 March 2012.

[4] Wellesley College 2011 Recycling Records. *Conigliaro Industries*. 2012. XLS file.; Finne, J. ES300 Universal Waste Database. 2012. XLS file; Justin Finne. Environmental Health and Safety Officer. Personal Interview 9 March 2012.

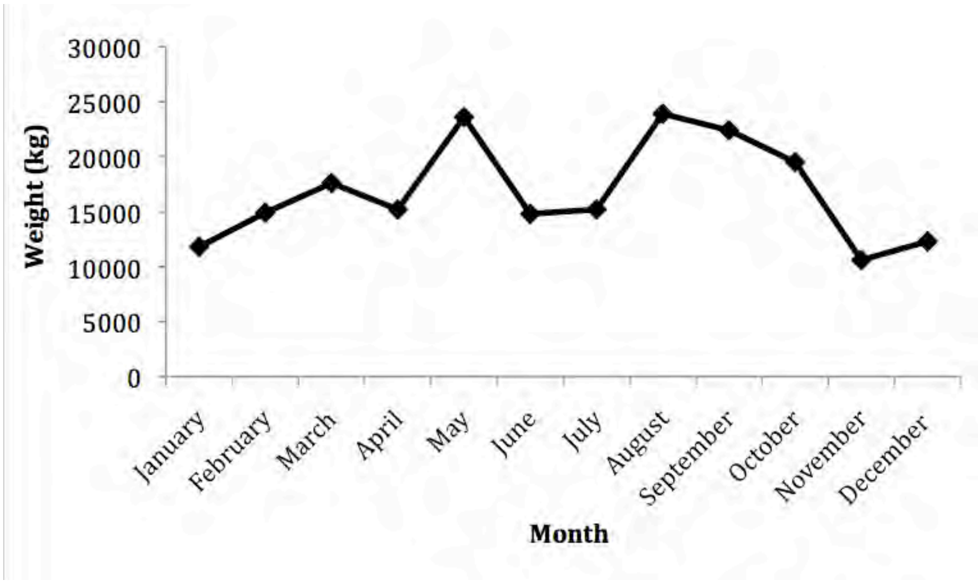

Figure 1.3: Weight of All Materials Recycled by Wellesley College by month of the 2011 school year. Materials include: Mixed Paper, Corrugated Cardboard, Mixed Office Paper, Commingled metal/glass/plastic, Scrap Iron, Mixed Wood, Styrofoam, Mattresses, Furniture, HDPE (Plastic#2), Computer/TV Cathode Ray Tubes, Special Recyclables Waste, and Electronics.[5]

At Wellesley College, there is variation in recycling rates throughout the year. As shown in Figure 1.3, most waste is recycled at Wellesley College during the months of May and August. These time periods correspond with student move-in and move-out activity. The least waste is recycled in the months of January, February, and June, which correspond with the lower student population on campus during this time of the year.

WASTE AUDIT

On February 15, 2012, we performed a waste audit to quantify the material components of the Wellesley College waste stream and investigate items that were being thrown away instead of recycled. We examined one week's worth of trash from the New Dorms residence hall complex, which consists of Bates dining hall and three residence halls (Bates, Freeman, and McAfee) that house approximately 400 students in total. The New Dorm Complex waste, still in trash bags, was transported to the Facilities Wash building, located just off-campus. There, our class split into teams, each responsible for a certain type of trash, and we donned full-body protective suits to sort the trash we found into categories (Figure 1.4).

[5] Wellesley College 2011 Recycling Records. *Conigliaro Industries*. 2012. XLS file.; Finne, J. ES300 Universal Waste Database. 2012. XLS file; Justin Finne. Environmental Health and Safety Officer. Personal Interview 9 March 2012.


Figure 1.4: Students sorting through trash during waste audit.

The bolded titles in Table 1.1 represent the general waste categories that 35 different materials were sorted into during the audit. We also had a general trash category for items that were difficult to sort and did not fall into defined groups. We based our sorting categories on both an item’s material composition and its usage. For example, plastic bottles were sorted separately from the rest of plastics even though they are made of PETE#1 plastic, and office paper was separated from mixed paper and junk mail. With usage categories included, behavioral patterns that produce specific types of waste become apparent. After organizing the waste by material type in large trash bins, we weighed the bins, and recorded the weight of waste in each category.

Table 1.1: Categories of Waste Used During the Waste Audit.

Organic Waste	**Plastics**	**Reusable Durable Goods**
Food waste	#1: Polyethylene terephthalate	Appliances, Dishware, Books
Napkins, paper plates, towels	Plastic Water Bottles	Household Items
Flowers, leaves, yard waste	#2: High-density polyethylene	
Compostable disposable products	#3: Polyvinyl chloride	
	#4: Low-density polyethylene	**Electronic Waste**
Paper	#5: Polypropylene	Cell phones, computers, etc.
Office paper	#6: Polystyrene	
Mixed paper	Styrofoam	**Special Recyclables**
Newspapers	Other Plastics (mainly #7: Polycarbonate)	Fluorescent light bulbs
Brown paper bags		Household batteries
Boxboard and chipboard	**Metal**	Inkjet cartridges
Cardboard	Aluminum cans	
	Aluminum foil, pie plates	
	Steel cans	**General Trash**
Aseptic Containers		Lids, caps, corks
Milk and juice cartons	**Glass**	Biohazards
	Bottles and jars	Composite
	Plate glass	Other

The percentage of each material category sorted during the waste audit is illustrated in Figure 1.5.

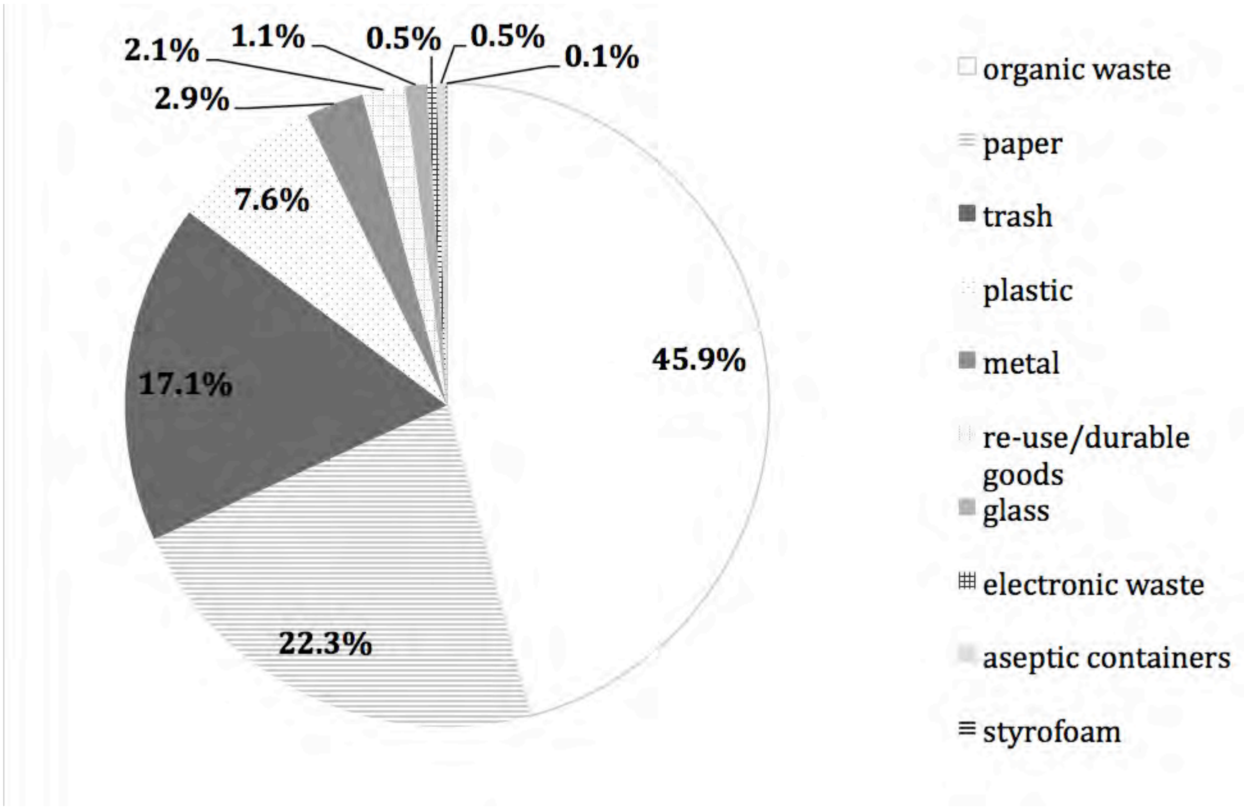

Figure 1.5: Percent of Total Waste Sorted at the Waste Audit by Material Category.

In total, 1,954 kilograms of waste from the New Dorms Complex was sorted into the above material categories. Organic waste comprised almost half of the total waste, representing 45.9 percent (Figure 1.5). Food waste was 96 percent of the organic waste category, with 860.24 kilograms of food waste weighed (Figure 1.6). Most of the organic waste was pre-consumer food waste. Additionally, considerable amounts of apparently unspoiled post-consumer food was found in the dumpster, including bread loaves, bagels, muffins, and apples.

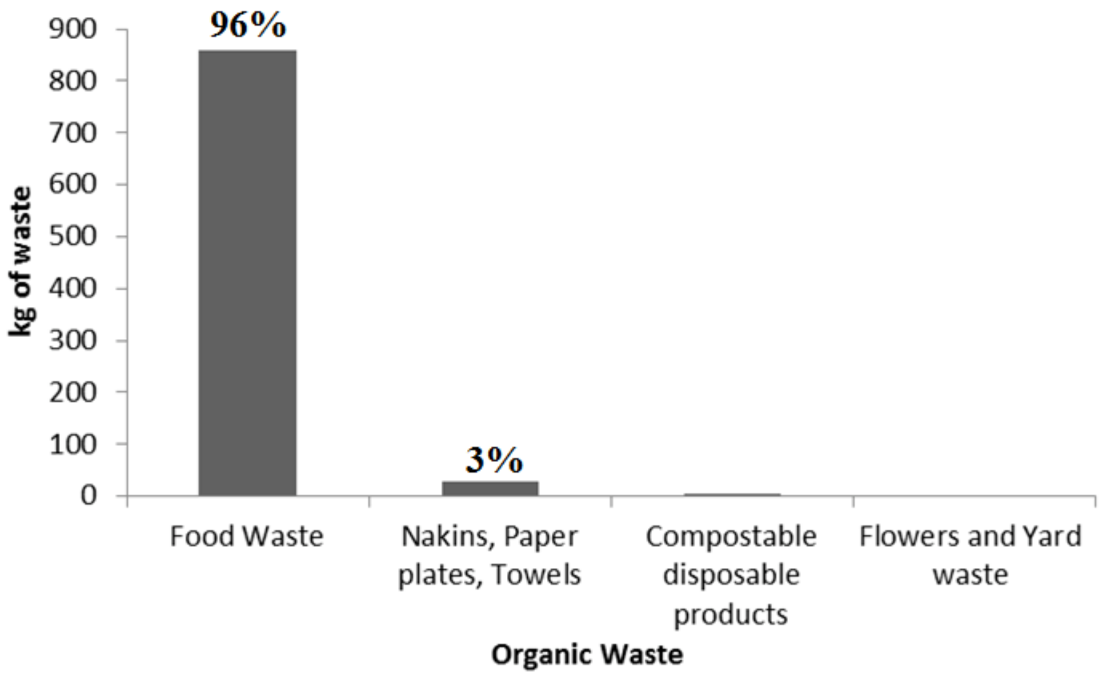

Figure 1.6: Breakdown of the organic waste category. Organic waste includes food waste, napkins, paper plates, and towels, compostable disposable products, and flowers and yard waste

The second largest waste category was paper, accounting for 22.3 percent of the total weight (Figure 1.5). Corrugated cardboard consisted of 75 percent of the paper waste category, with 327 kilograms of cardboard thrown in the trash (Figure 1.7). Most of the cardboard was used for food packaging and was seemingly disposed of by AVI Fresh (Figure 1.8). The majority of the cardboard appeared recyclable, while some packaging was contaminated with food. Mixed paper and office paper comprised a small percentage of the total waste, representing 10 and 8 percent of the paper waste category respectively (Figure 1.7). Sorters noted that student paper waste as well as newspaper waste was minimal, indicating that recycling of office papers and newspapers is occurring in the New Dorms Complex.

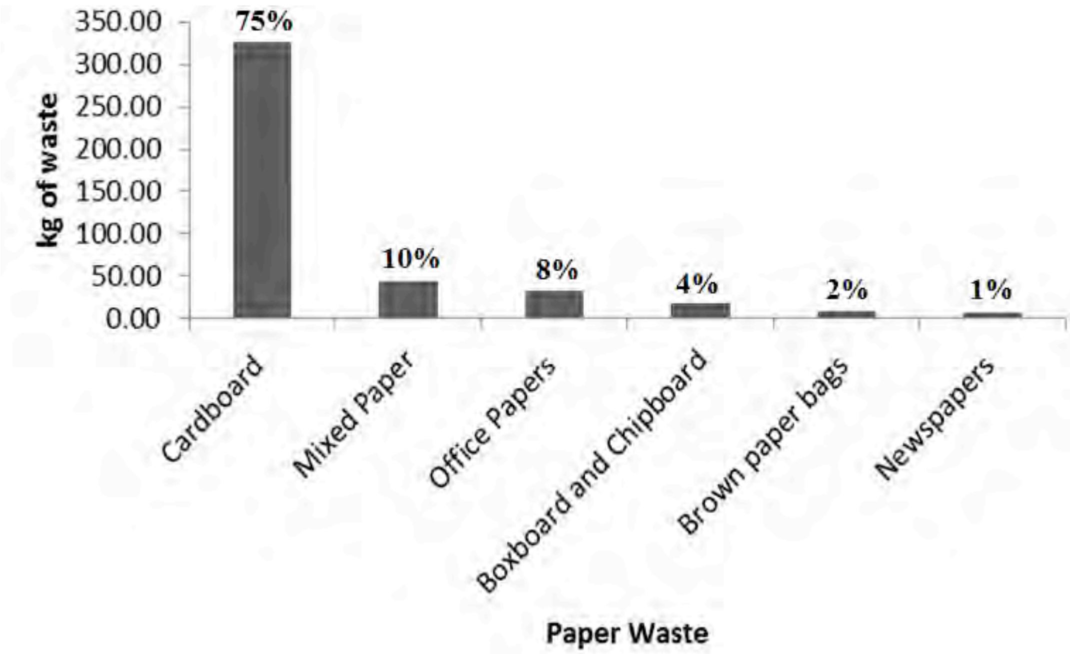

Figure 1.7: Percentage Breakdown of Paper Waste by Material.

Figure 1.8: Stack of Corrugated Cardboard After Sorting was Complete.

Plastics represented 7.6 percent of the total waste audit (Figure 1.5). Although there seemed to be a large amount of plastic waste present at the audit, plastics are extremely lightweight and therefore comprise a lower proportion of our waste stream when evaluated by weight. The seven plastic categories were roughly evenly distributed, with plastic bags and wraps having the highest percentage at 21% (Figure 1.9). Styrofoam, a subcategory of number six plastics, was mainly in the form of packing peanuts or as disposable containers for food and drinks. Many plastics were composite materials, such as toothpaste, and were therefore difficult to sort.

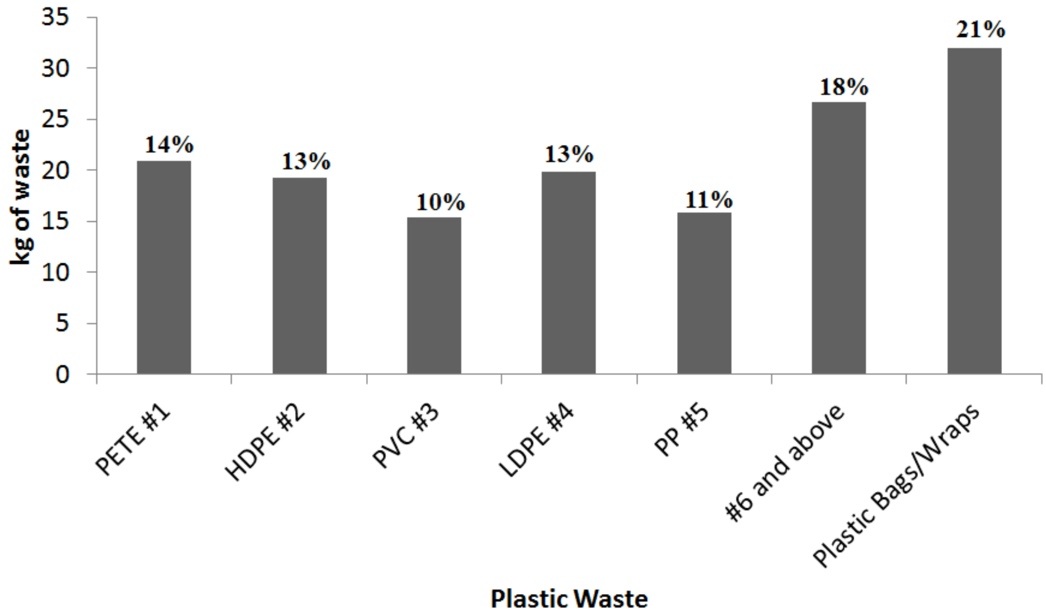

Figure 1.9: Percentage Breakdown of Plastics by Plastic Type.

The final material category involved metal waste. Metal waste represented 2.9 percent of the total waste by weight, amounting to 57.11 kilograms of waste. Steel was 91 percent of the metal waste category, mainly discarded in the form of 102 oz steel sauce cans (Figure 1.10). Aluminum foil and pie plates totaled 3.90 kilograms and aluminum cans weighed 1.18 kilograms.

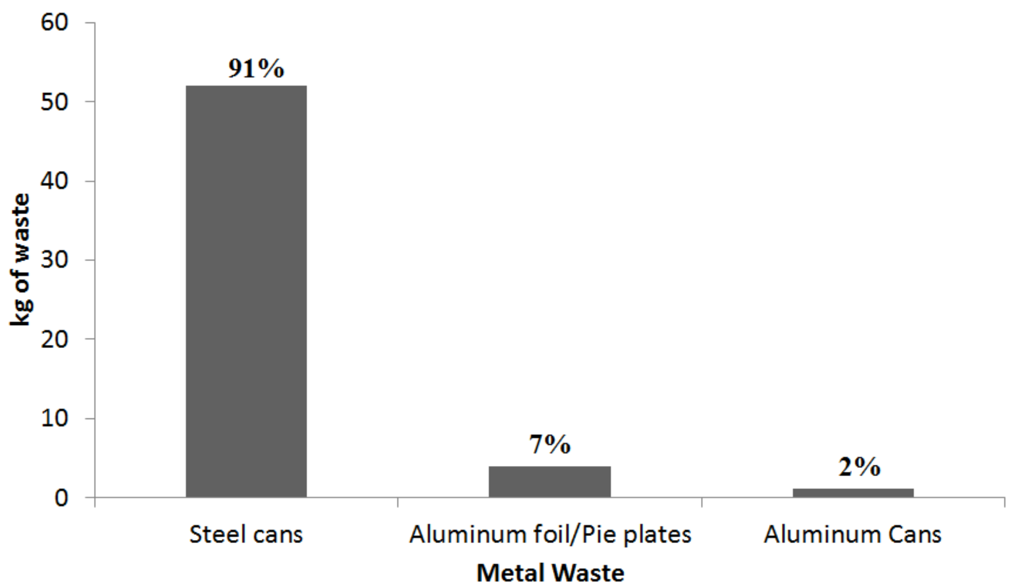

Figure 1.10: Percentage Breakdown of Metal Waste by Material.

The remaining waste categories were all individually below three percent of the total waste weighed, including re-use/durable goods, glass, electronic waste, and aseptic containers (Figure 1.5). Re-use/durable goods primarily included discarded dining hall dishware and clothing. Glass was only 1.1 percent of the total waste and was mainly found in the form of food containers, salsa, beer bottles, and juice bottles. The main trash components found at our waste audit were tissue paper, waxed paper, popcorn bags, chips and candy wrappers, and biohazards. Although trash was 17.1 percent of the total waste sorted at the waste audit, we will not be analyzing the contents of miscellaneous trash in detail for our waste assessment. We will include trash in our assessment when determining the impact of transporting Wellesley College's waste to the SEMASS incineration facility.

Generalizations

Our waste audit findings were used to estimate annual numbers for student and dining hall waste generation across campus. However, in our estimations, we had to be aware of the limitations of our waste audit. For example, the five dining halls across campus vary greatly in size and serve different numbers of students. Additionally, dining halls may have fairly different disposal practices. We also must be cognizant of the implications of the timing of our waste audit. The audit was conducted during what we considered to be a typical week at the college. The audit does not account for weeks that are close to the beginning or the end of the semester where waste production is presumably greater as students move in and out of residence halls. If the results of the waste audit were generalized to create annual waste estimates without accounting for this seasonal variation, we would underestimate our total waste generation.

Furthermore, we did not do a thorough audit of an academic building's waste. We do not therefore have the same level of detail about the materials disposed of in an academic setting. It is important to note that the waste audit provided an essential snapshot of waste generation on campus, but with a sample size of one, and a focus on residential waste habits. Any calculations based on the waste audit are estimates. Therefore, we used various tools and data to quantify the amount of waste produced on Wellesley's campus including: 1) purchasing logs 2) interviews with staff members 3) student surveys and 4) inventories of material use in academic buildings and residence halls on campus.

Despite the waste audit's limitations, the data generated was essential in calculating an average week's waste production at Wellesley College. The number of students living in the New Dorms complex is known: 400 students; therefore, a per-student waste ratio was calculated. We calculated the amount of waste produced by students in a week by multiplying the per capita student waste ratio by the number of students on campus and by the number of weeks students are on campus. We assumed that there are 2,300 students during the semester, 400 during wintersession, and 1,157 during the summer (See Appendix A). Additionally, we assumed that Bates dining hall is a typical dining hall and that all five dining halls produce a similar amount of waste. The waste produced by Bates dining hall was evident during the waste audit, as entire bags of trash were filled with materials such as organic waste, dishware, and steel food packaging cans. We can multiply the waste produced by Bates dining hall in one week by the five dining halls on campus, and by the number of weeks they are open per year. The Lulu Chow Wang is open 12 months of the year, Bates dining hall is open 9 months of the year, and the other three dining halls are open during the semester, 8 months of the year (See Appendix A).

Calendar of Waste Production

Our waste audit was done at a time of year we consider typical for waste, but we know that the disposal patterns at the college vary seasonally, with big events or special times of the year responsible for increased waste production or disposal. By breaking down the College's waste production into a general calendar of events for any given year, we can create an inventory that will enable us to also answer when certain types of waste are produced on campus.

In September, Orientation activities in many ways contribute to the generation of disposable dishware and utensils. Throughout Orientation, Wellesley College hosts outdoor lunches and info sessions for the incoming first-years and their families. To accommodate and feed a large crowd most efficiently, Dining Services uses disposable plates, cups, and utensils. Additionally, Lake Day contributes to food and disposable dishware waste on campus. The event takes place outdoors with an array of snacks and drinks offered. Dining Services provides disposable dishware, cups and utensils to feed students, and all food that is not eaten is tossed. Both Lake Day and Flower Sunday together contribute to office paper waste. In the day(s) leading up to these events, spam is sent to students' mailboxes and slid under their doors. Flower Sunday also prints out a separate program of planned performers and speakers, which is passed out to students who attend the service. The Wellesley tradition of Flower Sunday and Lake Day also generate yard waste and food waste respectively. Cut flowers (which are handed out by administrators and some upperclass students) are unable to be replanted; thus, once withered, the majority of the flowers are thrown out into the general waste stream.

In October, Homecoming Weekend and the Tanner Conference are responsible for an upsurge in paper and disposable dishware waste. Flyers are mailed out to Wellesley alums, current students, (and their families) to announce both events. During Homecoming Lunch, all dining halls (except the campus center) are closed and lunch is served outside alongside the athletic fields, and disposable dishware is provided. It is important to note, however, that although dining halls are closed, the level of food waste still does not significantly change. Food is being provided with the expectation of feeding the entire student population, but the likelihood that the entire student body will be in attendance is small, and thus food waste is created. For the Tanner Conference, booklets containing information regarding the various presentations are printed out and given to attendees. Additionally, during all coffee break and lunch sessions, disposable dishware and utensils are provided and discarded.

In November, Fall Frenzy, and many student organization events begin to take place. The amount of paper waste during this month increases with many student-organized events being advertised through the use of paper flyers. This month experiences dips in the volume of food waste produced because of the Thanksgiving holiday. Several dining areas close and the rest are open with limited hours of operation.

In December, more individual durable goods waste is produced than in any other part of the fall semester. Seniors who are graduating early, and perhaps limited by the number of items they can bring back, leave their durable belongings at the college.

In January, the volume of waste produced overall is reduced. The majority of students are not on campus, and only one dining hall is open.

February has a relatively constant waste stream; there are no special events specific to the college community that take place this month. There may be a slight increase in the amount of packaging waste due to the Valentine's Day holiday since students often receive care packages and other gifts from partners and family members.

During March three major food centric events, Yuki Matsuri, TCO Nightmarket, and the CSA & KSA Culture shows, increase the number of aluminum pans and amount disposable dishware used on campus. Due to the popularity of these events, food waste from the events is limited, but food waste from the dining halls is likely to increase due to reduced numbers of students eating in the dining halls. Spring break, during the second or third week of March, reduces the volume of all waste due to the decreased student population.

There are two events of interest that change waste volumes on campus in April: The Ruhlman Conference and Marathon Monday. During the Ruhlman Conference, all dining halls are closed for lunch. The volume of compostable single-use dishware and aluminum trays increases from the serving of food outside of the dining halls. Food waste from the dining halls likely falls as well due to the reduced food options offered around campus. The second event is Marathon Monday. During Marathon Monday, the dining halls are closed yet again. Instead there is a picnic on Munger Meadow. The volume of compostable dishware will increase as well as food packaging such as individual ice cream wrappers.

In May, due to Commencement and the Campus Wide Move-out there is a large change in the composition of waste leaving the campus. During Commencement, there is an increase in disposable dishware, cups, and utensils from campus events including the post-Commencement reception. The major composition change is during move-out. Students tend to dispose of large and small durable goods such as dining hall dishware, furniture, refrigerators, shelving, books, small electronics, and clothing.

In order to prevent these goods from going to the incinerator along with the rest of MSW from Wellesley College, the Sustainability Office has implemented a program called the "Sustainable Move-out." In each residence hall, a bright orange and wheeled collection bin is placed on the ground floor of each building. Students can leave any reusable goods in good condition in the bin. These bins are then sorted by student workers and stored in large containers for the summer months for resale in the fall when students return. During the first week of classes, reusable goods collected during the move-out are sold, heavily discounted, to students. Thus, WC prevents disposing of a large stream of durables that could be reused. During move-out, some other categories that will see increased volumes include, paper waste, from thrown out notes and assignments, and broken reusables that people are unwilling to fix.

After Commencement, in late May or early June, all residence halls house Alumnae, for Reunion weekend. All food is served on disposable dishware and from Aluminum trays. There is some food waste during this period (though it may be limited by advanced knowledge of how many people will eat each meal), and disposable dishware waste increases.

The volume of waste created on campus during the summer months decreases due to decreased numbers of students on campus. Over the summer, 8 of the 12 residential halls are occupied by a combination of college students and middle-school age campers. Recently the College farm Regeneration has collected compostable food waste during the summer from the New Dorms Complex, which houses Wellesley students taking classes and working on-campus. In each student kitchen, Regeneration's workers place covered steel containers to collect compostable non-meat related food waste. Regeneration then collects and composts the waste for use on the farm. Since all dining halls, except the Campus Center, are closed during the summer, the amount of food waste generated by college student dining halls is reduced significantly.

The other five occupied residence halls house two different groups. In the Quad (Shafer, Beebe, Pomeroy, and Cazenove), middle-school age campers are housed and fed. Munger contains another group of middle school aged students, collectively called Upward Bound, who take remedial or accelerated school classes. These students are housed and fed in residence halls as well. Since these groups are housed in dorms that do not possess dining halls during normal college operation, there will be an increase in the amount of disposable dishware and food waste.

Even though summer classes are in session, the volume of printing and copying on campus falls tremendously. The amount of paper and toner/ink cartridge wastes falls in proportion to amount of college students on-campus. In addition, during June, the Copy Center is closed for two weeks, further reducing paper and toner cartridge waste.

Finally, in addition to the activities of June and August, the Stone-Davis residence hall houses the Composers' Conference for two weeks. The Composers' eat breakfast and dinner in the living areas of the complex and lunch in the Campus Center. There is an increase in the amount of disposable dishware and aluminum trays used during this period. The Stone-Davis dining hall remains closed for the duration of the conference.

2.0 ON-CAMPUS WASTE ASSESSMENT

2.1 Waste Handling

WHERE DOES WELLESLEY'S WASTE GO?

Wellesley College disposes of waste through several different handling methods. The path each material takes is largely dependent on the composition of the waste, as well as the cost, and human effort required to dispose of it.

Wellesley is able to reuse some materials, specifically yard waste materials and durable goods, on campus.[1] Generally reusable waste is relocated from a space in which it is classified as waste to a space where it serves a purpose. For example, when a student moves out at the end of the year or graduates, durable goods such as furniture or office products can be given away or sold, and ultimately reused, by new owners. Another good example of reuse is the movement of loose brush and sticks from walkways where they impede movement and safety, to compost piles where they can decompose and return nutrients to the soil. If possible, reuse is an ideal method of disposal. It eliminates the environmental and monetary costs of the extraction and production of new materials, as well as transportation costs of sending that waste to another site for processing.

Hazardous wastes and biowastes require specific disposal procedures, as discussed in further detail below. Materials from Wellesley's Science Center, including used chemicals, some glassware, and wastewater, are categorized as hazardous wastes. The Sports Center and Health Services generate biowastes and medical wastes.[2] In order to prevent contamination, hazardous wastes cannot be disposed of through recycling or in traditional landfills. Instead, these materials are sent to facilities that are designed to dispose of hazardous materials safely, whether through incineration after the extraction of toxic components, or storage.[3] In terms of environmental impacts, the disposal of hazardous wastes through a separate, specialized facility is necessary, as it ensures that populations will not be exposed to potential health risks associated with our waste. Changes in destination for hazardous waste are less realistic than changes in amount of use on campus.

Most of Wellesley's contribution to landfills is indirect. The incineration of Wellesley's waste produces ash, which must be buried in a landfill. Landfills provide an inexpensive method of disposal, but they are often environmentally unsound. All landfills are susceptible to leakage and the land itself often cannot be safely utilized for other purposes.[4] Additionally, landfills pose a serious human health risk to surrounding

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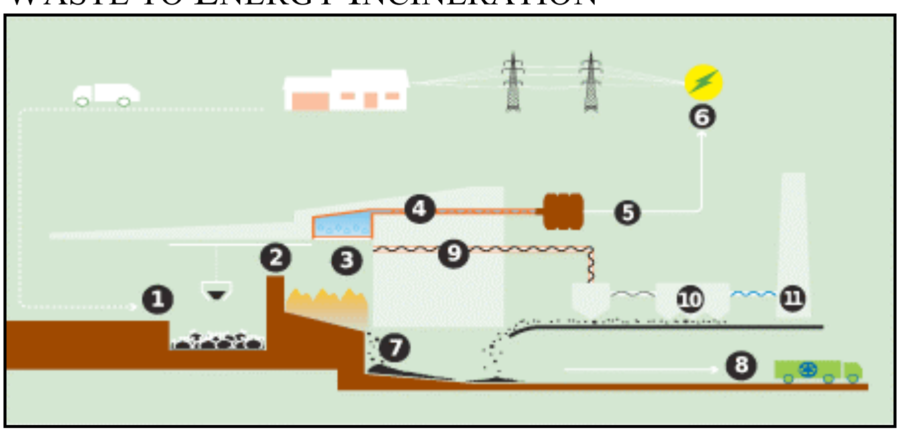
[1] Tricia Diggins. Senior Gardens Horticulturist. Personal interview. 13 Mar. 2012.
[2] Justin Finne. Environmental Health and Safety Officer. Personal interview. 9 Mar. 2012.
[3] Justin Finne. Environmental Health and Safety Officer. Personal interview. 9 Mar. 2012.
[4] Djikgraaf, E. and Vollebergh, H.R.J. Burn or Bury? A Social Cost Comparison of Final Waste Disposal Methods. *Ecological Economics* 50 (2004) 233-247. Print.

communities, and the frequent siting of landfills in minority or low-income communities can result in various types of environmental justice issues.[5]

The College provides recycling receptacles throughout campus for individual use. The types of products recycled include plastic, glass, metals, and paper. There are also two large dumpsters on campus that recycle Styrofoam. By one official estimate, Wellesley College has a recycling rate of about 32.42% including yard waste.[6] Recycling has positive consequences in that it keeps some waste from going into landfills and it also reuses some finite natural resources. There are also some negative consequences to recycling. The infrastructure that is required for recycling uses energy and can produce pollution. Trucks, which release carbon dioxide, are needed to haul the waste from the college to the recycling facility. The recycling facilities themselves may also release carbon dioxide and other emissions that contribute to air pollution and respiratory effects. Recyclables on Wellesley College Campus go to the Conigliaro Industries facility in Framingham, Massachusetts.[7]

Waste that is disposed of in as trash at Wellesley College is sent to a waste-to-energy facility called Southeastern Massachusetts (SEMASS) Resource Recovery facility.[8] There the waste is incinerated and converted in to energy. Waste incineration diverts waste from landfills and thereby avoids some of the negative externalities that landfills produce. However, waste incineration is a more expensive process than landfill use, and also contributes significantly to environmental pollution and health problems. Adverse environmental impacts as a result of SEMASS largely depend on the types of trash that are incinerated. For example, items such as bleached paper release dioxins when they burn. These dioxins are persistent organic pollutants, which negatively impact human health.[9]

WASTE TO ENERGY INCINERATION



[5] Djikgraaf, E. and Vollebergh, H.R.J. Burn or Bury? A Social Cost Comparison of Final Waste Disposal Methods. *Ecological Economics* 50 (2004) 233-247. Print.

[6] Patrick Willoughby. Director of Sustainability. Personal Interview. 9 Mar. 2012.

[7] The History of Conigliaro Industries. *Conigliaro Industries.* n.d. Web. 28 Feb. 2012 <http://conigliaro.com/corporate/index.cfm>.

[8] SEMASS Facility. *Covanta Energy Corporation*. n.d. Web. 28 Feb. 2012. <http://www.covantaenergy.com/facilities/facility-by-location/semass.aspx>.

[9] Djikgraaf, E. and Vollebergh, H.R.J. Burn or Bury? A Social Cost Comparison of Final Waste Disposal Methods. *Ecological Economics* 50 (2004) 233-247. Print.

Figure 2.1: Diagram of Waste-to-Energy Incineration Facility Processes.[10]

Waste to energy incineration is an approach to solid waste management that reduces waste volume. Solid waste is homogenized through shredding, and burned at extremely high temperatures. The heat produced converts water into steam in order to fuel heating systems or to generate electricity. The burning process leaves residual ash, which is transported to landfills, and also exerts sulfur dioxide and other gases (see Figure 2.1).[11] Some incinerators use refuse-derived fuel. Recyclable materials, such as aluminum and glass, are sorted out of the waste stream, leaving the remainder of the waste to be shredded and incinerated.[12]

In order to decrease emissions associated with incineration, pollution control technologies are used at incineration facilities. Such technologies include scrubbers, devices that use a liquid spray to neutralize acid gases, and filters, which remove tiny ash particles. This particle removal improves the air quality of the surrounding area of the incinerator.[13] Electrostatic precipitators are also used to collect heavy metals and prevent them from flowing into the air stream. Heavy metal particles cling to negatively charged plates as they flow up the gas stream and are prevented from being emitted. Removal efficiency is variable, but, on average, electrostatic precipitators are about 99% efficient.[14]

Incinerators emit many different toxins into the atmosphere, including persistent organic compounds like dioxins, furans, and polychlorinated biphenyls; heavy metals like methyl mercury, lead, cadmium, chromium and arsenic; and gases, such as sulfur dioxide and nitrogen oxide.[15] The combustion of plastics is the primary source of these toxins.[16] Incinerator emissions can therefore have severely negative impacts on both human health and the environment.[17] For example, dioxins are highly toxic and can cause cancer and neurological damage. Individuals working at incineration facilities or who live near an incinerator are highly susceptible to these effects.[18] Additionally, although there are

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[10] Understand How Waste to Energy Works. *Covanta Energy; SEMASS Covanta*. 2012. Web. 14 May 2012.

[11] Combustion | Municipal Solid Waste | Wastes | US EPA. n.d. Web. 10 Mar. 2012. <http://www.epa.gov/osw/nonhaz/municipal/combustion.htm>.

[12] Combustion | Municipal Solid Waste | Wastes | US EPA. n.d. Web. 10 Mar. 2012. <http://www.epa.gov/osw/nonhaz/municipal/combustion.htm>.

[13] Combustion | Municipal Solid Waste | Wastes | US EPA. n.d. Web. 10 Mar. 2012. <http://www.epa.gov/osw/nonhaz/municipal/combustion.htm>.

[14] Particulates - Electrostatic Precipitators (ESPs) | Air Pollution Control Orientation Course | Air & Radiation | US EPA. n.d. Web. 10 Mar. 2012. <http://www.epa.gov/apti/course422/ce6a1.html>.

[15] Pellow, D. N. Resisting Global Toxins: Transnational Movements for Environmental Justice. Cambridge: *The MIT Press*, 2007. Print.

[16] Negative Impacts of Incineration-based Waste-to-Energy Technology. n.d. Web. 11 Mar. 2012. <http://www.alternative-energy-news.info/negative-impacts-waste-to-energy>.

[17] Negative Impacts of Incineration-based Waste-to-Energy Technology. n.d. Web. 11 Mar. 2012. <http://www.alternative-energy-news.info/negative-impacts-waste-to-energy>.

[18] Negative Impacts of Incineration-based Waste-to-Energy Technology. n.d. Web. 11 Mar. 2012. <http://www.alternative-energy-news.info/negative-impacts-waste-to-energy>.

technologies aimed at reducing toxic air emissions, toxins are still present in 'bottom ash', which is a byproduct of the combustion of waste, and 'bottom ash' is often disposed of in landfills.

Many technologies have been developed to reduce toxins emitted through incineration, but it is impossible to fully eliminate the emission of toxins in the incineration process. Environmental impacts are the primary reasons incineration remains in serious disfavor among Americans, especially since the environmental justice movement has brought attention to the inequality of impact of these effects.[19]

In addition to the negative externalities of burning waste, incinerators pose problems by burning exhaustible raw materials, such as plastics, that could be recycled into usable materials. Burning reusable materials in order to create 'cheap fuel' creates a disincentive to reuse materials in a time when raw materials, such as petroleum, are near exhaustion.[20] Looking at waste-to energy incineration as a sustainable source of energy is misleading as it depreciates the value and necessity of recycling.

Waste-To-Energy power plants do, however, provide electricity, and therefore decrease the harms from energy provided in other ways. This waste management system offers a significant reduction in greenhouse gas emissions, which have been estimated generally at 1 ton of carbon dioxide per ton of trash combusted rather than landfilled.[21] With the rates of MSW disposal in the United States steadily increasing, half of all U.S. states use the MSW to fuel WTE power plants within their borders. On average, the combustion of MSW produces 600 kWh of electricity per ton combusted, which in terms of oil, equates to one barrel.[22] Furthermore, the U.S. Department of Energy (US DOE) recognizes WTE power plants as a source of renewable energy and classifies the facilities as a type of biomass.[23]

Rates of recycling in WTE communities have been estimated to be 17.8 percent higher than the US EPA reported average national recycling rate. This trend of increased recycling rates in WTE communities has been true for at least the last decade in the USA.[24]

WTE power plants can last 30 years or more with proper maintenance.[25] These facilities require much less land than landfills to process the same amount of waste. Moreover, unlike new landfills, new WTE power plants can be built on the same site as

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19 Pellow, D. N. Resisting Global Toxins: Transnational Movements for Environmental Justice. Cambridge: *The MIT Press*, 2007. Print.

20 Cradle to Cradle: Transitioning from Waste Incineration to Beneficial Materials | CATALYST - Strategic Design Review. n.d. Web. 10 Mar. 2012. <http://catalystsdr.com/2010/02/cradle-to-cradle-transitioning-from-waste-incineration-to-beneficial-materials/>.

21 Psomopoulos, C.S., Bourka, A. and Themelis, N.J. Waste-to-Energy: A Review of the Status and Benefits in USA. *Waste Management* 29 (2009): 1718-1724. Print.

22 Psomopoulos, C.S., Bourka, A. and Themelis, N.J. Waste-to-Energy: A Review of the Status and Benefits in USA. *Waste Management* 29 (2009): 1718-1724. Print.

23 Psomopoulos, C.S., Bourka, A. and Themelis, N.J. Waste-to-Energy: A Review of the Status and Benefits in USA. *Waste Management* 29 (2009): 1718-1724. Print.

24 Psomopoulos, C.S., Bourka, A. and Themelis, N.J. Waste-to-Energy: A Review of the Status and Benefits in USA. *Waste Management* 29 (2009): 1718-1724. Print.

25 Psomopoulos, C.S., Bourka, A. and Themelis, N.J. Waste-to-Energy: A Review of the Status and Benefits in USA. *Waste Management* 29 (2009): 1718-1724. Print.

existing ones. This not only saves green space from being developed into waste management systems, but also saves WTE companies' money by reducing their capital cost for land in the new facility to zero.[26] The US EPA has acknowledged WTE power plants' relatively low environmental impact in comparison to other sources of electricity, and the WTE facilities now only account for less than 1% of the US emissions of dioxins and mercury.[27]

SEMASS

Waste discarded at Wellesley College as trash is sent to the Southeastern Massachusetts Resource Recovery Facility (SEMASS RRF). The SEMASS waste-to-energy facility is operated and managed by the SEMASS Partnership through Covanta SEMASS, L.P.[28] The 95-acre facility serves 60 communities in Massachusetts, incinerating over 1 million tons of waste per year or around one-fifth of the state of Massachusetts' total municipal solid waste (MSW).[29] The facility uses the electricity generated from waste incineration to run its operations, and sells the remaining electricity to the grid (84 megawatt-hours, powering around 75,000 homes).[30]

Wellesley Trucking transports Wellesley College's waste to a transfer station in Holliston, MA, approximately 10.7 miles away from Wellesley College. Waste from open containers leave in a 70-yard trailer truck (with a fuel efficiency of 5.5 to six miles/gallon), and waste from compactors from the Tower Complex, the Stone-Davis Complex, the Bates-Freeman-McAfee Complex, and the Lulu Chow Wang Campus Center are sent in a different truck (with a fuel efficiency of six miles/gallon).[31]

Trucks from the transfer station in Holliston deliver Wellesley College's waste to SEMASS, which is around 50 miles away from Wellesley. Part of the waste may be delivered to another Covanta facility in Haverhill when the Haverhill facility has a low waste supply. It is estimated that around 10% of our overall waste is diverted to Haverhill, which is 44.3 miles away from Wellesley.[32]

The SEMASS facility operates on the expectation that households, institutions, and industry all recycle. Legally, the facility cannot accept glass, wood, metal, sheet rock, narrow plastic, paper, or lead acid batteries. Therefore, waste loads composed of more than 50 percent construction demolition material, or more than 20 percent of banned materials that cannot be easily sorted by the facility, are deemed unacceptable and turned

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[26] Psomopoulos, C.S., Bourka, A. and Themelis, N.J. Waste-to-Energy: A Review of the Status and Benefits in USA. *Waste Management* 29 (2009): 1718-1724. Print.

[27] Psomopoulos, C.S., Bourka, A. and Themelis, N.J. Waste-to-Energy: A Review of the Status and Benefits in USA. *Waste Management* 29 (2009): 1718-1724. Print.

[28] Facilities: About Covanta SEMASS. *Covanta Energy,* 2012. Web. 28 Mar 2012. <
http://www.covantaenergy.com/en/facilities/facility-by-location/semass/about.aspx>.

[29] Covanta Energy SEMASS: Waste Characterization Study in Support of Class II Recycling Program. *Mid Atlantic Solid Waste Consultants.* 11 Feb 2011. Print.; Will Campbell. Personal Interview. 14 Mar 2012.

[30] Will Campbell. Covanta Energy. Personal Interview. 14 Mar 2012.

[31] David DeBello. Wellesley Trucking. Personal Interview. 28 Feb 2012.

[32] David DeBello. Wellesley Trucking. Personal Interview. 28 Feb 2012.

away.[33] Once loads are accepted, the facility has no sorting mechanism, excluding a step in pre-combustion where some ferrous metals are recovered using a rotating magnet.

Prior to combustion, waste is shredded and homogenized into 4 by 4 inch pieces. 80 percent of ferrous metals are recovered at this stage. The shredded waste is then combusted in boilers at extremely high temperatures, and two standard efficiency steam turbines (54 megawatt-hours and 30 megawatt-hours) convert the energy generated into electricity. Metals are also recovered from the bottom ash; nearly 50,000 tons of recyclable metals are recovered annually from both ash and the pre-combustion stage. The ash and scrubbers are disposed of in the Carver/Marion/Wareham landfill.[34]

To reduce environmental impacts (in many cases to below federally mandated levels), the SEMASS facility uses a combination of practices. The facility makes use of carbon injection to control mercury and dioxin emissions, lime slurry injections to control sulfur dioxide emissions, and fabric filters to control the emission of particulate matter. Additionally, the facility attempts to improve energy efficiency where possible by increasing the energy output of incineration and the general energy efficiency of the SEMASS facility.[35]

Figure 2.2: ES300 Class on a Tour of the SEMASS Facility.

RECYCLING

Recycling is a method by which unwanted materials are re-processed into similar (or in some cases the same) materials instead of being discarded as waste into a landfill or incinerator. Recycling can help reduce the need for primary resources, land filling or incineration, energy (in both the extraction and manufacturing processes,) and solid waste collection.[36] Recycling can save energy and reduce greenhouse gas emissions depending on what gets recycled. For example, a recycled aluminum can takes much less energy to make than a can made from virgin materials; so much less, in fact, that a TV could be

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[33] Covanta Energy SEMASS: Waste Characterization Study in Support of Class II Recycling Program. *Mid Atlantic Solid Waste Consultants.* 11 Feb 2011. Print

[34] Will Campbell. Covanta Energy. Personal Interview. 14 Mar 2012.

[35] Will Campbell. Covanta Energy. Personal Interview. 14 Mar 2012.

[36] Porter, R.C. Economics of Recycling; The Economics of Waste. *Resources for the Future.* Washington, DC: 2002. 133-43. Print.

powered for three hours with the energy saved. Similarly, if a three-foot tall stack of newspaper is recycled, one fewer tree needs to be cut down, and recycled glass contributes 50% less to water pollution.[37] Recycling also helps the economy by providing more jobs, as it is more labor intensive than either landfill or incineration, and it adds value to the recyclable material.[38] People also experience a psychological benefit when they recycle; they feel happy, proud, or at least that they are doing the right thing,[39] which can lead to a domino effect in encouraging environmentally beneficial behavior

Although recycling is often associated with overall environmental benefits, there are several reasons why recycling remains the last of the 'three R's.' First of all, not every material can be recycled efficiently. For instance, less than seven percent of the plastic used in the United States can be fully recycled,[40] meaning that the vast majority of plastic produced must be either landfilled or incinerated. Many goods that are "recyclable" are actually downcycled, or transformed into goods of lesser value such as turning old water bottles into traffic blockers. Other goods, like electronics waste have so many harmful components that recycling, although still a better option than incineration or landfilling, has negative social and environmental effects. Addionally, collecting and sorting recyclables is costly in terms of labor, energy, and capital.[41] Finally, studies have shown that people's decision to recycle can effect their future actions. While some recyclers are motivated to do more environmentally friendly behaviors, others will experience the opposite effect. For example, some recyclers believe that recycling their bottles and newspapers fulfills their quota for environmentally friendly behavior when, in reality, much larger lifestyle shifts are required. Recycling is undoubtedly a necessary tool for preserving resources and reducing solid waste generation, but it is not a 'silver bullet.' Reducing consumption is still preferable to increasing recycling.

Conigliaro Industries

The Conigliaro Industries Facility, to which most Wellesley College recycling is sent, is located in Framingham, Massachusetts, approximately 6.9 miles from the Wellesley College campus. Recyclable materials from the College are transported weekly in a Freightliner Swaploader medium-sized truck (a College vehicle).[42]

Conigliaro Industries recycles a variety of materials, including paper (corrugated cardboard, newsprint and magazines, computer and mixed paper), comingled steel, glass, aluminum, plastic, drink and food containers, scrap metal, mattresses, furniture, and what

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[37] Recycling Pros and Cons. *AlternativeConsumer.* 2012. Web. 3 Mar 2012. <http://www.alternativeconsumer.com/2009/11/16/recycling-pros-and-cons/>.

[38] Murray, M. Benefits of Recycling. *Californians Against Waste.* 2011. Web. 3 Mar 2012. <*http://www.cawrecycles.org/living_green/benefits_of_recycling*>.

[39] Myers, T. Eco-Fads: King County Says Recycling WillMake You 'A Good Person'. *RedCounty.* 2010. Web. 1 April 2012. <http://www.redcounty.com/content/eco-fads-king-county-says-recycling-will-make-you-good-person>.

[40] Recycling Pros and Cons. *AlternativeConsumer.* 2012. Web. 3 Mar 2012. <http://www.alternativeconsumer.com/2009/11/16/recycling-pros-and-cons/>.

[41] Porter, R.C. Economics of Recycling; The Economics of Waste. *Resources for the Future.* Washington, DC: 2002. 133-43. Print.

[42] Patrick Willoughby. Director of Sustainability. Personal interview. 28 Feb. 2012.

the company labels as "difficult materials", such as computers, electronics, laboratory plastics and glass, batteries, light bulbs, ballasts, and cathode ray tubes (CRTs).[43] Despite the option of processing "difficult materials" at Conigliaro Industries, much of Wellesley's hazardous or special recyclable waste is sent elsewhere. Special recyclables, computers, and electronics, for example, are all sent to Northeast Lamp Recycling in Connecticut.[44] After 18 years of operation, Conigliaro Industries currently serves 550 industrial, institutional, and municipal clients including 42 school systems, 22 colleges and universities, 40 hospitals, 20 cities and towns, and 150 industrial plants.[45] Materials from these sites are transported there daily for sorting and processing.

Conigliaro Industries receives approximately 80 tons of waste each day, with only 10 percent (8 tons) of waste that cannot be processed on site. This 10 percent of unprocessed waste is thrown out and becomes a part of the Municipal Solid Waste stream. Most recyclable waste at Conigliaro Industries is collected, sorted, baled, and sent elsewhere for the manufacturing of new products. Metals are sorted on site and shipped elsewhere for processing, usually based on where offers the best price. Roof shingles are reused as base material in road construction, and rubber sheets are reused as weed suppressors in gardening and landscaping. Foam board is collected and shipped out to places that make picture frames, baseboards, and other products. Mattress materials are reused for several products. For example, mattress fibers can be reused to make carpet, and wooden bed frames can be used to make synthetic logs. Special recyclables such as household batteries and compact fluorescent light bulbs are collected by Conigliaro Industries and sent to a processing facility in New Hampshire for recycling.[46]

Conigliaro Industries strives to connect wholesale, consumers, construction, and manufacturing industries in order to have a fully communicating supply chain. As a business, Conigliaro's strategy is to increase the value of the waste the company processes to make recycling cost-effective and accessible to their clients. Conigliaro has also demonstrated a commitment to environmental interests with the installation of solar panels to run balers and shredders on site whenever possible.[47]

Recent upgrades at Conigliaro Industries encourage the creative use of recyclable materials for on-site manufactured products, to then be sold for profit. For example, thanks to equipment expansions made possible by the Recycling Investment Reimbursement and Department of Environmental Protection grants, Conigliaro Industries is now producing over 100 tons of mixed plastic aggregate per month, and uses it to manufacture Conigliaro products on site to be sold for profit. Mixed plastics are ground, washed if necessary, and used to make composite products. For example, plastics are used in a concrete-sand-plastic mix, allowing production in excess of 10,000 buckets

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[43] Total Recycling Services at Schools, Colleges, and Universities. *Conigliaro Industries*, n.d. Web. 14 Mar 2012. < http://conigliaro.com/recycling/school.cfm>.

[44] Patrick Willoughby. Director of Sustainability. Personal interview. 28 Feb. 2012.

[45] Total Recycling Services at Schools, Colleges, and Universities. *Conigliaro Industries*, n.d. Web. 14 Mar 2012. < http://conigliaro.com/recycling/school.cfm>.

[46] Richard Garrison. Manager of Conigliaro Industries. Personal Interview and Tour of Conigliaro Facilities. Mar 9, 2012.

[47] Richard Garrison. Manager of Conigliaro Industries. Personal Interview and Tour of Conigliaro Facilities. Mar 9, 2012.

of asphalt cold patch per month.[48] Glass from windows and colored sources is ground into small sand-sized pieces, to then be used for decorative landscaping, known as "tumbled glass aggregate."[49]

Some plastic aggregate is used to make "Plas-crete", a novel type of concrete produced from mixed plastics. A silo and batching plant was added to the site at Conigliaro Industries in order to mix sand (from glass), plastic, and water for Plas-crete blocks. The market for Plas-crete has exceeded the company's expectations, pouring 50 to 80 blocks per day; up to 15,000 pounds of mixed plastic is going into Plas-crete alone each day at Conigliaro Industries.[50]

Since Conigliaro Industries downcycles many of the recyclable products it receives, it may not represent the most efficient and environmentally friendly recycling facility option for handling Wellesley's recyclable waste. Conigliaro's focus on the success of on-site manufactured products like Plas-crete prevents received materials from being recycled as completely as possible. For example, plastics are not fully sorted before processing, and glass, an almost infinitely recyclable material, is used to make Plas-crete blocks instead of being melted down to make more glass products. Additionally, due to the pricing of goods on domestic and international markets, Conigliaro Industries sends many recyclable products long distances for processing and recycling, meaning that our transportation impact for many recyclables remains quite high. Despite Conigliaro's stated commitment to environmental interests, it may not be the most efficient or sustainable recycling facility available for Wellesley College.

Figure 2.3: Weighing Station at Conigliaro Industries.

[48] Technical Report #14: Determining the Best Formulation for a Unique Asphalt Cold Patch Product made with #3-7 Rigid Plastic Aggregate. *Chelsea Center for Recycling and Economic Development*, University of Massachusetts. Jan 2000. Web. Mar. 15 2012, <http://www.chelseacenter.org/pdfs/TechReport14.pdf>.

[49] Richard Garrison. Manager of Conigliaro Industries. Personal Interview and Tour of Conigliaro Facilities. Mar 9, 2012.

[50] Technical Report #14: Determining the Best Formulation for a Unique Asphalt Cold Patch Product made with #3-7 Rigid Plastic Aggregate. *Chelsea Center for Recycling and Economic Development*, University of Massachusetts. Jan 2000. Web. 15 Mar 2012, <http://www.chelseacenter.org/pdfs/TechReport14.pdf>.

Hazardous, Chemical, and Biological Waste Disposal

Hazardous, chemical and biological waste all fall under separate regulations for handling and disposal. None of these wastes can legally be included in the regular municipal solid waste (MSW) stream. Wellesley College produces all of these special wastes and the Office of Environmental Health and Safety (EHS) along with a few other key players in the Science and Health Centers, Motor Pool staff, and Facilities Department oversee their handling and disposal.[51]

Hazardous Waste

The U.S. Environmental Protection Agency (EPA) categorizes hazardous waste as follows:[52]

- Listed Waste: Waste determined as hazardous by EPA, including from industrial and manufacturing processes (F-list), from specific industries (K-list) and from commercial chemical products (P- and U-lists).
- Characteristic Wastes: Wastes not included among listed waste but that are ignitable, corrosive, reactive or toxic.
- Universal Wastes: Batteries, pesticides, mercury-containing products and lamps (including light bulbs).
- Mixed Wastes: Waste that contains both radioactive and hazardous components.

The handling of hazardous waste is controlled by the Resource Conservation and Recovery Act (RCRA), which regulates the lifecycle impacts of a hazardous product from generation, transport, treatment, storage and disposal.[53]

Wellesley College is considered a "small quantity generator" of hazardous waste, and is thereby limited to producing 2,200 lbs (997.9 kg) of hazardous waste per month. The EHS Office estimates that on average, Wellesley College only produces about 85 percent of its maximum allowance, approximately 848.2 kg per month. Listed and characteristic waste produced on campus, largely in the science center, is collected monthly by Phillips Services Corporation (PSC) which takes it to a Treatment, Storage and Disposal Facility (TSDF) in Providence, Rhode Island. This waste is largely incinerated, a very little is landfilled, and ignitable substances are used for fuel blending.[54]

Universal waste is collected in special locations around campus, including residential and institutional buildings, by EHS. This waste is picked up every 3 to 4 months by Northeast Lamp Recycling (NLR), which also processes electronic waste produced on campus. Universal waste is partially processed at the NLR site in East

[51] Justin Finne. Environmental Health and Safety Officer. Personal Interview. 9 Mar 2012.
[52] Waste Types. *Environmental Protection Agency*. 6 Mar 2012. Web. 10 Mar 2012. <http://www.epa.gov/osw/hazard/wastetypes/index.htm>.
[53] Summary of the Resource Conservation and Recovery Act. *Envrionmental Protection Agency*. 24 Feb 2012. Web. 10 Mar 2012. <http://www.epa.gov/lawsregs/laws/rcra.html>.
[54] Justin Finne. Environmental Health and Safety Officer. Personal Interview. 9 Mar 2012.

Windsor, Connecticut and some electronic waste is sent to Allied Computer Brokers (ACB) in Amesbury, Massachusetts.[55]

Waste produced at Motor Pool from automobile repair and servicing, mostly oil, is collected separately from the Trade Shops as needed.[56]

Chemical Waste

Chemical waste produced in the Science Center and other buildings around campus is considered to be a separate category from hazardous waste, but is still regulated under RCRA. Phillips Services Corporation (PSC) also collects chemical waste on its monthly pick-up. Containers that held non-hazardous chemical waste are regulated and collected by PSC. The majority of these materials are incinerated.[57]

Biological Waste at Wellesley College

Dry biological waste is produced in the Science Center, Health Services and Sports Center. Stericycle, an Illinois-based company, collects dry biological waste monthly. Non-dry waste, including cell cultures and other liquid laboratory wastes, is generally bleached and deposited down the drain by Biology Department preparatory staff.[58]

HOW MUCH DOES WELLESLEY'S WASTE COST?

Wellesley College's trash is disposed of through Wellesley Trucking Service, Inc. in Framingham, MA. The college pays Wellesley Trucking Service, Inc. per time period (every 15 days) for its services, which includes pickup, hauling and disposal of our trash to the disposal facility. In 2011, the College paid a total of $299,701.70 to dispose of our waste, for an average of $3.49 per kg.

The College was actually charged $309,669.40 during this year to dispose of our waste but due to a recycling credit within our contract with Wellesley Trucking Service, Inc. we received a discount of $9,967.70. We receive a recycling credit because we do not pay Wellesley Trucking Service, Inc. per weight for its service. The College negotiated this recycling credit because of how the current contract works: since we pay for the service of trash removal, Wellesley Trucking would remove however much trash we dispose of. If we put waste into the recycling stream, then it becomes waste that Wellesley Trucking does not have to bear the cost of removing. We therefore get a credit for the waste that is recycled, rather than sent through the trash pickup process.

Wellesley pays for recycling by material. Coniglario Industries receives a variety of material loads from us. In 2011, these loads included mixed and office paper; commingled plastic metals and glass; scrap iron; mixed wood; durable goods such as mattresses, couches and refrigerators; and styrofoam. When loads have been mixed, they

[55] Justin Finne. Environmental Health and Safety Officer. Personal Interview. 9 Mar 2012.
[56] Justin Finne. Environmental Health and Safety Officer. Personal Interview. 9 Mar 2012.
[57] Justin Finne. Environmental Health and Safety Officer. Personal Interview. 9 Mar 2012.; Raymond Keegan. Science Center Stock Room. Personal Interview. 08 Mar 2012.
[58] Justin Finne. Environmental Health and Safety Officer. Personal Interview. 9 Mar 2012.; Raymond Keegan. Science Center Stock Room. Personal Interview. 08 Mar 2012.

are accepted as single stream loads, for which we are charged approximately $20/ton. Depending on the material, we are offered one of three rate options: no charge, charge, or credit. These rates are dependent on the market, and there are even periods when we are not charged, and then given a credit for it once the market value for that material improves. Wellesley currently receives a market-dependent credit for iron scrap metal, baled corrugated cardboard, office paper, and mixed paper, but this credit (or which materials it applies to) may change from year to year.

The current annual cost of disposing of recycling with Conigliaro Industries is approximately $660. This relatively low cost is due to the amount of waste we recycle that Conigliaro either does not charge us for, or gives the College a credit for. For example, in 2011 we were not charged for the 1,400 lbs (635.03 kg) of Styrofoam the College sent. On the other hand, we received a credit of over $2.6 million for Wellesley's scrap iron, but were charged an equivalent amount for the mixed wood we sent to the facility.

2.2 Measuring Our Impact

To evaluate the full scope of impacts associated with waste on the Wellesley College campus, we relied upon a life-cycle analysis (LCA) of the products that leave the campus as waste. A life-cycle analysis (or assessment; the two terms are used interchangeably) assesses the environmental, economic and social consequences of product use, manufacture, and disposal over the entire life cycle of a product – from "cradle to grave."[1] Our assessment of the impacts associated with the life cycle of a given material or product at Wellesley are analyzed with specific series of impact factors, ranging from contributions to climate change, to consequences to human health and disruption of biodiversity.

In order to evaluate impacts, we have split up our analysis into two parts. In part one, we look at the per-kilogram impacts of our material at the 'cradle', as it is extracted from raw materials, transported, and manufactured. We will rely mostly on aggregate industry data for this step. In addition, if the product uses other resources during its lifetime, such as water or electricity, then we add in the impact of these additional resources during this step. In part two, we turn to the 'grave' and examine the consequences of disposal per one kilogram of the product, observing what happens to the substance as it is transported and recycled, reused or incinerated. If recycled, we calculate a recycle credit based upon the impact assessment of manufacturing the substance that it is recycled into entirely from virgin materials, and if incinerated, we calculate the energy credit gained from burning the product.

1 Impact Assessment; The A to Z of Corporate Social Responsibility. *Credo Reference*. Hoboken: Wiley, 2007. Web. 15 Mar 2012. <http://books.google.com/books/about/The_A_to_Z_of_Corporate_Social_Responsib.html?id=woqEDQQzGp0C>.

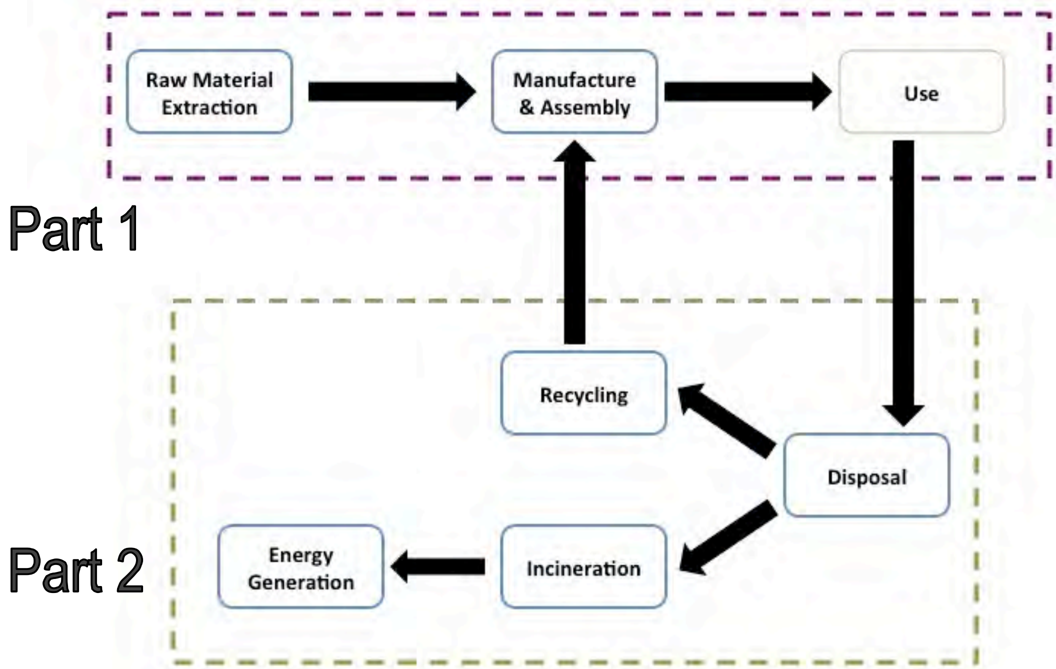

Figure 2.4: A Flowchart of a Product's Life Cycle, with Parts One and Two of our LCA Marked by the Boundaries of the Dotted Lines.

We then determine the impact across each of our impact factors for a product in a given year by adding the impacts of both stages, and multiplying by the total mass of the substance disposed of at the College each year. We discuss the specific factors used for our impact in more detail in the next section; however, we discuss both quantitative measures, such as kilograms of carbon dioxide equivalents released into the atmosphere, and qualitative impacts, such as the relative contribution to permanent land disruption on a scale from 0-5.

Although our process is thorough, there are several things that our analysis cannot encompass. For example, we do not account for sunk environmental and economic costs, such as the impact of a factory that was purchased forty years ago, except as a factor in some of the industry data that we will examine. Relying on industry data also means that our data, in some ways, lacks specificity; although we know precisely which facilities process the waste from our college for the second part of our LCA, our data on the impacts for manufacturing in part 1 come from industry aggregate sources, which might not take into account the specific sources of the materials that ultimately comprise our waste on campus.

This lack of specificity also lends uncertainty to our impact factor analysis. Pollution is context-specific; for example, the effect of eutrophication on a stream can be very different depending upon how many other sources feed nitrogen into the water. Moreover, we simply lack a good quantitative measure for many of the impacts we want to assess, such as biodiversity disruption, beyond ranking the damage on a scale of one to five.

None of these difficulties, however, are enough to seriously detract from our LCA process. The qualitative measures that we do have are solid analytical tools and are well discussed in other analyses. Our analysis is therefore compatible with other assessments, allowing our assessment both to inform and be informed by other people's work on life-cycle analysis. Even though we lack a good quantitative measure for many of our environmental and social impacts, it is important that we think about and include these impacts in the first place, even if we can only compare the relative impacts to each other.

Finally, our focus only on the inputs that go directly into making a product or material allows us to cut down our analysis to a reasonable size, and lets us narrow in on the parts of a product's life-cycle that are most meaningful to Wellesley College. Since Wellesley bears the cost of disposing goods, Wellesley has the most motive to intervene in the disposal process, rather than at manufacturing. Additionally, since Wellesley College only has control over activities that take place on-campus, it makes sense to focus our efforts on the parts of a product's life cycle that the College has the potential to influence.

IMPACT FACTOR EXPLANATION

As mentioned previously, we determined the impacts of Wellesley College's waste per kg of waste by material, both for the manufacturing process and its final destination. The impact factors chosen to quantify the impacts of our waste are global warming, acidification, eutrophication, and human health effects (carcinogens, non-carcinogens, and respiratory effects). The SimaPro7 LCA software and the Tools for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI2) database were used to calculate the emissions of different substances from various stages of a material's life cycle. TRACI2 provides a base unit of comparison for each impact factor analyzed, thus making it easy to compare impacts across different material categories and processes. We also analyzed additional ecosystem impacts that we could not quantitatively measure, but whose effects we nonetheless wanted to consider using a 0-5 ranking system. Analyzing various impact factors throughout the life cycle of a particular material allows for a comprehensive estimate of its aggregate economic, environmental and social effects. Ultimately, this information can be used to inform choices regarding the handling and disposal of waste generated on the Wellesley College campus.

Global Warming Potential

Global warming potential is an estimate assessing Wellesley College's contribution to climate change by way of current available waste disposal methods on campus. Global warming potential also identifies greenhouse gas emissions associated with the life cycle of each material in Wellesley College's waste stream. Climate change, or the warming of the earth's atmosphere due to increases in greenhouse gases (GHG), is one of the most pressing environmental issues of the 21st century. Increases of atmospheric temperature may have severe environmental, social, and economic cost, including but not limited to: decreased water availability, species extinction, sea level rise due to thermal expansion of ocean water, and human mortality as a result of floods, heat waves, and drought.[2] Hundred's of universities have made commitments to reducing net greenhouse gas emissions from particular campus operations, like waste disposal.[3] Reducing greenhouse gas emissions associated with waste disposal will decrease Wellesley's contribution to global warming and improve the college's environmental image.

The amount and types of greenhouse gas emissions vary by material (e.g. plastic #4 vs. organic waste) and disposal method (e.g. incineration vs. recycling). We calculated the emissions of greenhouse gases like methane (CH4), nitrous oxide (N2O), carbon dioxide (CO2), and fluorinated gases such as chlorofluorocarbons (CFCs) during the transportation and final disposal of each material in Wellesley College's waste stream. Then we measured and quantified the various types of GHG emissions as carbon dioxide (CO2) equivalents. The metric measure of carbon dioxide equivalency compares the cumulative radiative forcing effects from the emission of a unit mass of gas over a specified time horizon, relative to the effects from the emission of a unit mass of carbon dioxide (CO2).[4] Using the standard metric unit of carbon dioxide equivalency allows us to identify which materials and which disposal methods have the largest contribution to climate change.

Acidification

Acidification measures the increase in acidity or hydrogen ion (H+) concentrations in water and soil.[5] Acidification can be used to measure the air pollution associated with sulfur dioxide (SO2), ammonia (NH3), nitrogen oxides (NOx) and volatile organic compounds (VOCs).[6] In the United States, two-thirds of all sulfur dioxide and one-quarter of all nitrogen oxides are produced as a result of fossil fuel combustion.[7] When gases such as sulfur dioxide and nitrogen oxide react with water, oxygen, and other chemicals in the atmosphere, acid rain occurs. Acid rain causes acidification of water ecosystems and negatively affects plant growth and healthy soil. Acid rain also causes the pH of water to decrease, results in the death of many aquatic species and an overall decrease in biodiversity.[8] In addition, acid rain accelerates the decay in building materials and paints,[9] leading to further environmental pollution and

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[2] Mann, M.E. and Kump, L.R. Dire Predictions: Understanding Global Warming. New York: *Daniel Kaveney*, 2008. Print

[3] Presidents Climate Commitment. *American College & University Presidents' Climate Commitment (ACUPCC),* 2007. Web. 12 Mar 2012. <www.presidentsclimatecommitment.org>.

[4] Glossary of Climate Change Terms. *Environmental Protection Agency*. 2 Nov 2011. Web. 12 Mar 2012. <http://epa.gov/climatechange/glossary.html>.

[5] Penningtown, D.W., *et al.*, Life Cycle Assessment Part 2: Current Impact Assessment Practice. *Environment International*. 2004. Web. 15 Mar 2012. <http://www.sciencedirect.com/science/article/pii/S0160412003002551>.

[6] Acidification and Trans-Boundary Air Pollution: Causes and Impact. *Netherlands Environmental Assessment Agency*. Web. 12 Mar 2012. <http://www.mnp.nl/mnc/i-en-0178.html>.

[7] What is Acid Rain? *Environmental Protection Agency*. Jun 2007. Web. 14 Mar 2012 <http://www.epa.gov/acidrain/what/index.html>.

[8] Effects of Acid Rain. *Environmental Protection Agency*. Dec 2008. Web. 12 Mar 2012. <http://www.epa.gov/acidrain/effects/surface_water.html>.

[9] Effects of Acid Rain. *Environmental Protection Agency*. Dec 2008. Web. 12 Mar 2012. <http://www.epa.gov/acidrain/effects/surface_water.html>.

poor human health. Acidification potential is a useful impact category because it helps analyze what effects different materials have on the health of aquatic and terrestrial ecosystems.

Acidification potential of particular materials is calculated using hydrogen ions or H+ equivalents, which is the base unit of comparison used by the TRACI2 database.

Eutrophication

Eutrophication is an important impact category to include in our life-cycle analyses since it measures the health of aquatic ecosystems and water sources. Eutrophication occurs when there is a high concentration of nutrients such as phosphates, nitrates, and other select organic compounds in a specific body of water.[10] These substances not only accelerate algae growth, but also promote the excessive growth of algae. As algae die and decompose, high levels of organic matter and decomposing organisms deplete the water of oxygen. Low levels of oxygen in water lead to the death of various organisms,[11] including fish. Although eutrophication is a natural process, human activity often expedites the process leading to harmful consequences for aquatic ecosystems. Eutrophication is recognized as one of the most important factors contributing to habitat change, and therefore it is a good indicator by which to assess the impact of our waste on aquatic ecosystems.[12]

The first step to calculate eutrophication potential for different materials is to find the emissions of the various nutrients that cause eutrophication, by keeping track of the mass emitted and the receiving environment it is emitted in (air, water, soil). The compounds emitted should be expressed using a common unit, to compare across all substances. In the case of eutrophication, the base unit of comparison is nitrogen (N) or N-equivalents. Eutrophication is estimated using N-equivalents because it is the unit that is included in impact assessment methodology developed by the EPA Tools for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI2) method.[13]

Human Health Impacts

Human health impact as defined by the World Health Organization, is a state of complete physical, social and mental well-being, and not merely the absence of disease or infirmity.[14] The physical, social and mental well-being of humans can be negatively impacted by our waste and its method of disposal, as well as by the extraction and manufacturing of the materials that are, eventually, disposed of. While in our impact

[10] Eutrophication. *Toxic Substances Hydrology Program, US Geologic Survey*. n.d. Web, 10 Mar 2012, <http://toxics.usgs.gov/definitions/eutrophication.html>.

[11] Eutrophication. *Toxic Substances Hydrology Program, US Geologic Survey*. n.d. Web, 10 Mar 2012, <http://toxics.usgs.gov/definitions/eutrophication.html>.

[12] Glibert, P.M. et al. The Role of Eutrophication in the Global Proliferation of Harmful Algal Blooms. *Oceanography* 18: 2, Jun 2005, Web. 10 Mar 2012. <http://www.chnep.wateratlas.usf.edu/upload/documents/EutrophicationAndHABs.pdf>.

[13] Monica Higgins. Postdoctoral Fellow in Environmental Studies Program. Personal Interview. 15 Mar 2012.

[14] Health Promotion Glossary. *World Health Organization*. 1998. Web. 12 Mar 2012. <http://www.who.int/hpr/NPH/docs/hp_glossary_en.pdf>.

assessment it is difficult to quantify impacts on human health in terms of social and mental well-being, we were able to quantify the impact potential of each waste category and its destination on human physical well-being. Our human health impact potential comprises three metrics.[15] They are:

Carcinogens, in Benzene equivalents
Non-carcinogens, in Toluene equivalents
Respiratory effects, in PM2.5 equivalents

Carcinogens are substances that have the potential to cause cancer. Carcinogens are cancer-causing because they can disrupt cellular processes all over the body and ultimately change a cell's DNA. Examples of carcinogenic substances include chromium, arsenic, benzene and dichloroethene.

Non-carcinogens are substances that are toxic to humans, but do not cause cancers. A wide array of substances falls under this category including heavy metals, dioxins, and some organic chemicals, making this category one of the biggest in our analysis of waste impacts. Non-carcinogens can be produced at all the stages of a material's life cycle and are present in extraction, manufacture, transportation, recycling, and incineration processes.

Particulate matter comprises airborne dust, gases, and other liquids with the potential to cause harm to respiratory organs.[16] Particulate matter with a diameter smaller than 2.5μm is not effectively captured in the nasal passages because of its small size and can therefore lodge deep in the lungs, thereby increasing the risk of lung disease and other respiratory health problems.[17] Long exposure to small sized particulate matter also has the potential to cause structural damage to the lungs.[18] Examples of particulate matter include sulfur and nitrogen oxides. In the production stage of a material's life cycle, particulate emissions are likely to be produced in the extraction of raw materials, especially those that involve mining; in the transport of raw materials to processing centers; in the processing stage; and in the transport of the final products to their destinations. The disposal stage might also produce particulate emissions during the transportation of materials to various recycling centers, or to SEMASS for incineration. Additionally, the recycling and incineration processes both produce particulate emissions.

Human health is important both for our own safety as well as for the sake of avoiding the economic cost of health care provision (or alternatively avoiding the loss of the economic potential of sick workers). In using these three metrics for human health impacts, we are able to quantify the varying health effects that our waste will have depending on its manufacture and destination, as well as to compare among the waste categories.

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[15] Krebs, K. et al. Climate Change and Recycling. 5 Aug 2008. Web. Mar 12 2012. <http://yosemite.epa.gov/r10/ecocomm.nsf/programs/wcf/$file/301-1-presentation.pdf>.
[16] Pollutants: Particulate Matter. *Environmental Protection Agency*. 27 Mar 2012. Web. 7 May 2012. <http://www.epa.gov/pm/>.
[17] Fine Particles- Questions and Answers. *Department of Health*, *New York State*. Feb 2011. Web. 7 May 2012. <http://www.health.ny.gov/environmental/indoors/air/pmq_a.htm>.
[18] Pollutants: Particulate Matter. *Environmental Protection Agency*. 27 Mar 2012. Web. 7 May 2012. <http://www.epa.gov/pm/>.

Additional Ecosystem Impacts

Ecosystems represent a community of animals and plants interacting with one another and with their physical environment. They provide a variety of services collectively known as ecosystem services without which life on earth would be difficult, if not impossible.[19] The resilience and functioning of these ecosystems can be affected by changes in land use, pollution and climate change, all of which waste and its disposal play a part.[20]

For the purposes of our study, additional ecosystem impacts assessed include soil erosion, permanent land disruption, water use, biodiversity disruption and whether the resource used is renewable or not (resource use). The contribution of each waste material to each additional ecosystem impact category is estimated on a low-medium-high scale with 0 being the lowest impact, 0.5 medium, and 1 being the highest impact. The values for each impact category are then added to estimate a total ecosystem impact score for each waste material's manufacture from cradle to factory gate out of 5. An example is provided below.

Table 2.1: Ecosystem Impacts from the Manufacture of Material X

Erosion	Permanent Land Disruption	Water Use	Resource Use	Biodiversity Disruption	Total Score (Out of 5)
1	0	1	0.5	1	**3.5**

In the example above, the hypothetical material does not cause the permanent disruption of land and only uses some non-renewable energy. However, the manufacture of this material causes soil erosion, uses a lot of water, and disrupts biodiversity in releasing substances that are toxic to ecosystems, for example.

In using the aggregate value from the 5 impact factors, we approximate whether any category of material has an overall major, medium, or low impact on ecosystems. In the example above, the aggregate impact that the manufacture of the material has on ecosystems is 3.5/5. This is a medium to high impact score.

Finally, the analysis of cradle to gate ecosystem impacts informs our understanding of the environmental impacts that are avoided from not manufacturing a material with virgin materials if, for example, they are made from recycled content instead.

WHAT DO THE IMPACT FACTORS REALLY MEAN?

The numbers we produce in our analysis may be comprehensible to specialists, but it can be difficult to understand how much of an effect the measurements we produce actually have on the environment. That is especially true because we need to remember that all the impact factors are measured on different scales; we cannot simply assume that

[19] Ecosystem Services Fact Sheets. *Ecological Society of America*, n.d. Web. 13 Mar 2012. <http://www.esa.org/ecoservices/comm/body.comm.fact.ecos.html>.
[20] Naeem, S. et al. Biodiversity and Ecosystem Functioning: Maintaining Natural Life Support Processes. *Issues in Ecology.* 4:4, 1999. Print.

one unit more of one impact factor is equivalent to one unit more of another impact factor.

We have therefore gathered information to help contextualize the magnitude of effects from different types of measurements, in units that may be understandable to the non-specialist. Table 2.2 shows the types of effects that would be experienced by different amounts of the units we use for our comparison for each impact factor.

Table 2.2: "Real World" Equivalence of Each Impact Factor.

Impact Factor	Net Difference	"Real World" Equivalence
Global Warming	3,165.59 kg CO2 eq or 135.8357 kg CO2 eq or 100 kg CO2 eq	Driving a midsize car 4,300 miles.[21] = Driving a midsize car 100 miles = Driving a midsize car 73.62 miles
Acidification	12,255.27 H+ moles eq 10,000 H+ moles eq	Roughly three bathtubs of hydrochloric acid[22], [23] 2.4479 bathtubs full of hydrochloric acid.
Eutrophication	1000 kg N eq	Same Amount of Nitrogen as the Manure of 13.158 dairy cows.[24]
Carcinogens	1 kg benzene eq	Same Amount of Benzene in 17,778 Cigarettes or the Total Cancer Risk of Smoking 8,888 Cigarettes. (Benzene in Cigarettes accounts for 50% of their Cancer Risk) [25]
Non Carcinogens	1 kg toulene eq	If ingested, enough to kill 19.23 people within 30 minutes. (Lethal Dose = 60 mL[26] Density = .8669 g per mL (Wikipedia))
Respiratory Effects	1 kg PM2.5 eq	If released into the air of the building with the World's largest internal volume[27] it increases the risk of death by 45.11% annually[28].

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[21] Carbon Footprint Calculator. *The Nature Conservancy*. n.d. Web. 2012. <http://www.nature.org/greenliving/carboncalculator/index.htm>.

[22] pH: The Power of Hydrogen. *Coastwide Laboratories*. n.d. Web. 9 Apr 2012. <http://www.coastwidelabs.com/Technical%20Articles/ph__the_power_of_hydrogen.htm>.

[23] Big Help for Small Bathrooms. *This Old House*. Web. 5 Apr 2012. <http://www.thisoldhouse .com/toh/article/0,,191441-3,00.html>.

[24] Smith, K.A. and Frost, J.P. Nitrogen Excretion by Farm Livestock with Respect to Land Spreading Requirements and Controlling Nitrogen Losses to Ground and Surface Waters; Part 1: Cattle and Sheep. *Bioresource Technology*. 2000. Web. 17 Apr 2012. <http://www.sciencedirect.com/science/article/pii/S0960852499000619>.

[25] Public Health Statement: Risks and Exposure to Benzene. *CDC*. n.d. Web. 17 Apr 2012. <http://www.atsdr.cdc.gov/toxprofiles/tp3-c1.pdf>.

[26] 2-Health Effects of Toluene: OSH Answers. *Canadian Centre for Occupational Health and Safety*. n.d. Web. 18 Apr. 2012. <http://www.ccohs.ca/oshanswers/chemicals/chem_profiles/toluene/health_tol.html>.

[27] Boeing: Future of Flight Aviation Center & Boeing Tour - Background Information. n.d. Web. 18 Apr 2012. <http://www.boeing.com/commercial/tours/background.html>.

[28] Verrier, R. and Mittleman, M. Air Pollution: An Insidious and Pervasive Component of Cardiac Risk. *Air Pollution.* n.d. Web. 18 Apr. 2012. <http://circ.ahajournals.org/content/106/8/890.full>.

2.3 Primary Materials

This chapter on primary materials includes an in depth analysis of glass, aluminum products (including pie plates, cans, and foil), and steel cans. A brief background is given for each material, as well as estimations of the materials' use on the Wellesley College campus. Each material section ends with an analysis of the life cycle impacts associated with that material. These primary materials were combined into one chapter because they are all comprised of virgin materials manufactured to form basic products for consumer use. They also are all materials that allow for closed loop recycling, meaning that they can be recycled endlessly without downcycling.

GLASS

Glass Background

Glass is an inorganic, solid material primarily made of sand (silicon dioxide, or SiO_2), limestone (calcium carbonate, or $CaCO_3$), and sodium carbonate (Na_2CO_3).[1] Other elements are added to certain types of glass to make them more refined or to enhance their reflectivity, such as lead in crystal.[2] Glass is usually transparent or translucent in appearance. It is hard, brittle, and impervious to natural elements. Glass has been used for thousands of years for practical, as well as decorative items.[3]

Uses of Glass at Wellesley College

At Wellesley College, glass is commonly used for windows, as well as food and beverage containers. Glass is also used as laboratory equipment in academic settings, such as in Chemistry classes or research labs. The majority of glass that enters the waste stream on a daily basis is from food and beverage containers.

Activities and Behaviors Producing Glass Waste at Wellesley College

Beakers, slides, and other miscellaneous laboratory equipment are used by students and faculty when performing experiments; this type of glass is frequently broken through use and handling error, creating glass waste. Many social events on campus, including those held at the pub, serve alcohol in glass bottles, which also produces glass waste. Additionally, glass waste is created by students living on campus in the form of discarded light bulbs, broken glassware, and glass perfume bottles.

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[1] "Glass." *Encyclopædia Britannica. Encyclopædia Britannica Online Academic Edition*. Encyclopædia Britannica Inc., 2012. Web. 22 Feb. 2012. <http://www.britannica.com/EBchecked/topic/234888/glass>.

[2] Graziano, J H. "Lead exposure from lead crystal." *Lancet* 337.8734 (1991): 141. Web. 29 Feb. 2012. <http://www.sciencedirect.com/science/article/pii/014067369190803W>.

[3] "Glass." *Encyclopædia Britannica. Encyclopædia Britannica Online Academic Edition*. Encyclopædia Britannica Inc., 2012. Web. 22 Feb. 2012. <http://www.britannica.com/EBchecked/topic/234888/glass>.

Amount of Glass Produced at Wellesley College

The amount of glass waste produced annually at Wellesley College is estimated as 10,096.35 kg annually, as indicated in Table 3.1, and graphically in Figure 3.1.

Table 3.1: Estimated Annual Glass Waste at Wellesley College.

Material	.Weight Per Unit (kg/unit)	# Units (Per 1 kg)	# Units Produced Annually	Produced Annually (kg)
Laboratory Glassware	10	0.10 collection box	225 recycle boxes	2,100
Residential Glassware	0.20	5 bottles	22,912.50 bottles	4,582.50
Pub Glassware	0.20	5 bottles	12,480 bottles	2,496
Miscellaneous	-	-	-	917.85
Total				**10,096.35**

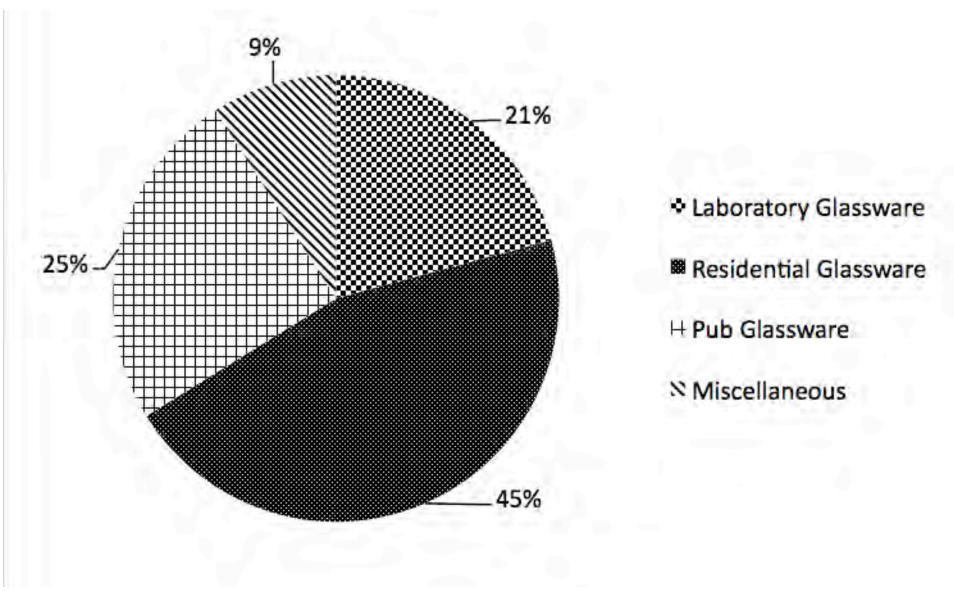

Figure 3.1: Relative breakdown of the glass discarded on campus. The majority of glass discarded on campus is produced in the residence halls.

Wellesley College supplies 70 laboratory glass collection boxes throughout the science center.[4] We estimated the weight of each glass collection box to be 10 kg on average. When they are full, these collection boxes are sealed and disposed of in the dumpster at the Science Center loading dock. They are discarded into the general waste stream of Science Center trash. The boxes are not weighed, they are simply discarded, and replaced by a new box.[5] We assume that the boxes fill up and are discarded three times a semester. Since we are estimating, a miscellaneous category representing 9 percent of overall glass waste was added to our total amounts to account for discrepancies that may exist. The total amount of laboratory glassware discarded annually is therefore estimated to be 2,310 kg.

The amount of residential glassware in the Wellesley College waste stream, consisting of mostly bottles and jars, was calculated based on our waste and recycling audit results. The weight of an empty glass bottle was estimated to be 0.2 kg, meaning that 5 bottles comprise 1 kg of glassware waste. Including a 10% error to account for any discrepancies, the total amount of residential glassware discarded annually is 5,040.75 kg.

The pub orders roughly 20 cases of 24 glass bottles per week during the academic year. Since the weight of an empty glass bottle was estimated to be 0.2 kg, 5 bottles comprise 1 kg of glass. Including a 10% error to account for any discrepancies, the total amount of pub glassware disposed of annually is about 2,745.60 kg.

The total amount of glass waste on campus is approximately 10,096.35 kg. This is a small portion of the overall campus waste production. Of the total glassware waste, residential glassware accounts for 49.93% of the glass waste, while the other uses, pub bottles and laboratory glassware, collectively account for 50.07% of glass waste. Therefore, residential glassware use is the primary activity producing glass waste on campus.

Handling of Glass Waste at Wellesley College

The distribution of how glass is handled when disposed of on campus is displayed in Table 3.2.

Table 3.2: Estimated Handling of Glass Waste at Wellesley College.

Material	% Recycled	% Thrown in Trash
Laboratory Glassware	-	100%
Residential Glassware	50.21%	49.79%
Pub Glassware	100%	-
TOTAL	**50.07%**	**49.93%**

[4] Keegan, Raymond. Wellesley College Stockroom Manager. Personal interview. 31 Mar. 2012.
[5] Keegan, Raymond. Wellesley College Stockroom Manager. Personal interview. 31 Mar. 2012.

Despite waste ban regulations implemented by the Massachusetts Department of Environmental Protection that ban glass from MSW,[6] glass is still discarded in the Wellesley College waste stream as trash and sent to the incinerator. All glass bottles purchased by the pub are sent back to the distributor for a discount on the next purchase.[7] This system allows for a 100% recycling rate of pub glass bottles. Exceptions are if customers remove glass bottles from the pub. Based on our waste and recycling audit data, along with information supplied from the pub, we estimate that about 50% of glassware is thrown in the trash and about 50% is recycled.

Destination of Glass Waste

The portions of glass waste sent to recycling, MSW, and glass waste handling facilities are estimated in Table 3.3.

Table 3.3: Destination of Glass Waste by Percentage.

	Conigliaro	SEMASS	Burke
% of Waste	22.88%	49.93%	27.19%
Weight of Waste (kg)	1,260.19	6,090.56	2,745.60

Glass products that are handled as recycling on campus are sent to the Conigliaro Industries recycling facility. We estimate that 22.88% of glass waste from Wellesley College, or about 1,260.19 kg, is sent to Conigliaro Industries annually.

Glass products discarded in the trash are incinerated at SEMASS. We estimate that 49.93% of glass waste, or 6090.56 kg of glass, is sent to SEMASS annually.

All glass bottles used at the pub are sold back to Burke Distribution Corporation, located in Randolph, MA. The distributor retrieves the empty bottles from the college by truck.[8] We estimate that 27.19% of glass waste produced at Wellesley College, or 2,745.60 kg, is collected by Burke Distribution Corporation annually.

Abridged Life Cycle of Glass Waste Produced at Wellesley College

At Wellesley College, glass is primarily found in residential glassware in the form of bottles used for the delivery of liquids like soda or beer. An abridged life cycle diagram for bottles from production to disposal is displayed in Figure 3.2.

[6] Your Municipality and Waste Ban Compliance. *Massachusetts Department of Environmental Protection*, Nov. 2011. Web. 14 Mar. 2012. <http://www.mass.gov/dep/recycle/solid/wbanmuni.pdf>.

[7] Samantha, Crowell. Pub Staff Employee. Personal interview. 13 Mar. 2012.

[8] Samantha, Crowell. Pub Staff Employee. Personal interview. 13 Mar. 2012.

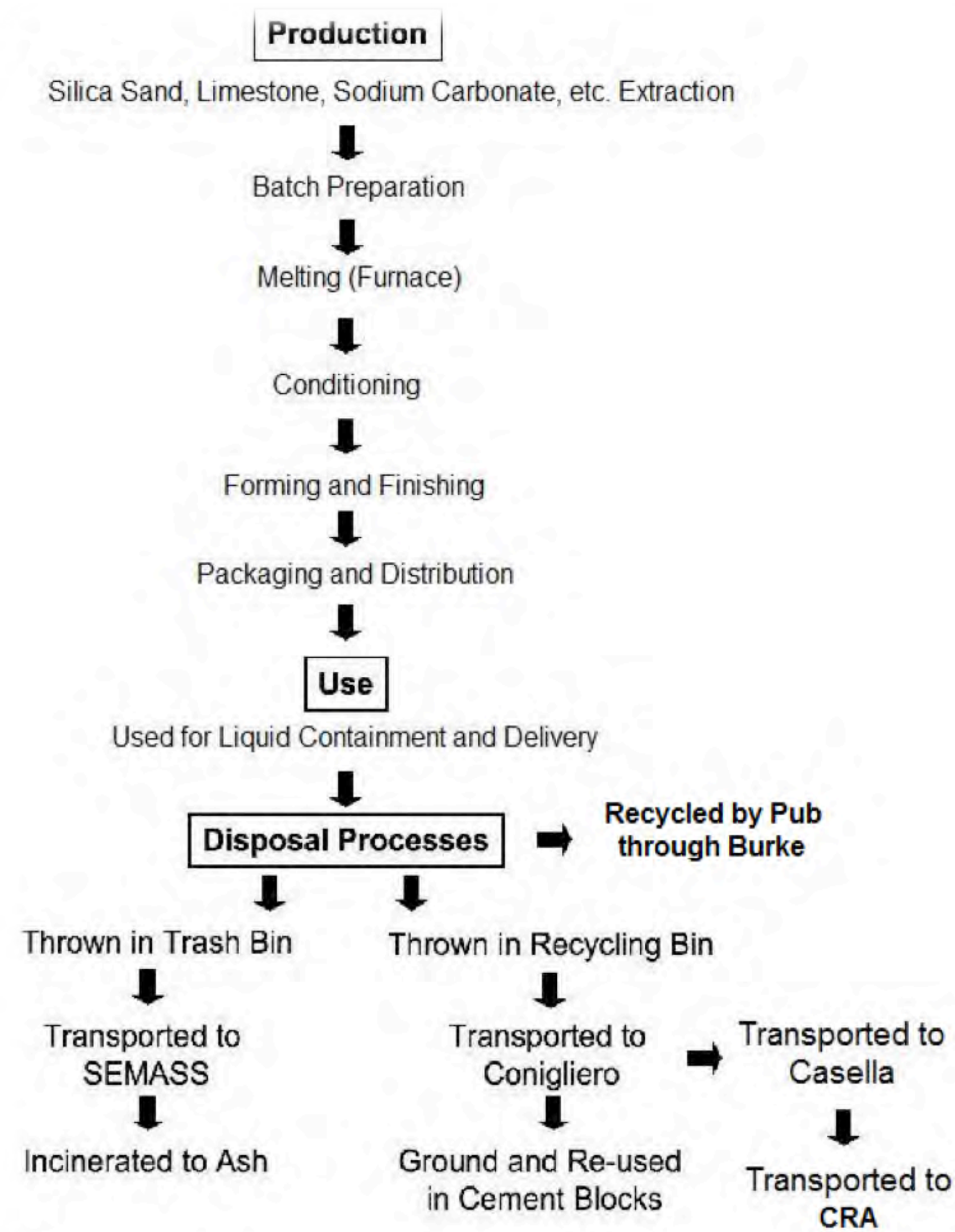

Figure 3.2: Abridged Life Cycle for Glass Bottles.

Glass Source Background

Glass in its commercial form is made from three main substances: silica sand (silicon dioxide, or SiO_2), limestone (calcium carbonate, or $CaCO_3$), and sodium carbonate (Na_2CO_3), also known as soda ash.[9] Other elements are added to certain types of glass to make them more refined, enhance their reflectivity, or change their color.[10] Stripping the overburden (a type of

[9] "Glass." *Encyclopædia Britannica. Encyclopædia Britannica Online Academic Edition*. Encyclopædia Britannica Inc., 2012. Web. 22 Feb. 2012. <http://www.britannica.com/EBchecked/topic/234888/glass>.

[10] Graziano, J H. "Lead exposure from lead crystal." *Lancet* 337.8734 (1991): 141. Web. 29 Feb. 2012. <http://www.sciencedirect.com/science/article/pii/014067369190803W>.

surface mining also known as “strip mining”), conducting wet and gravity separation,[11] and quarry blasting are used in the extraction of necessary materials and in the production of glass.[12]

Silica sand, which makes up approximately 60-70 percent of the glass batch,[13] is extracted by stripping the overburden with machines, such as bulldozers and scrapers. Next, wet separation is conducted by washing the sand and passing it through screens to remove roots and other organic matter. After that, gravity separation is conducted to separate silica sand from regular sand. Finished silica sand is then transported by truck to plants for processing, while oversized materials and residual clay are returned to the mine pits.[14] The extraction of silica sand causes air pollution,[15] erosion, and loss of habitat.[16]

Limestone is extracted by blasting in quarries.[17] The extraction process scars the land and makes it unusable for agriculture, grazing, or recreational use.[18] After extraction from quarries, limestone is transported to crush plants by trucks or rail. At crush plants it undergoes the calcination process, which involves heating the limestone in a kiln at temperatures up to 900 degrees Celsius. This process emits CO_2 and calcium oxide (lime) in the process.[19]

Sodium carbonate is extracted using tracked excavators to dig trenches. The wet ore is then dumped to the side of the trench, where it is moved by dozers to form thin layers. These layers are left to dry in the sun. Trucks haul the dried material to the processing plants.[20] These trenches permanently disrupt the land.[21]

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[11] "Processing of Silica Sand." *Outotec*. (2011): n.d. Web. 28 Mar. 2012. <http://www.outotec.com/14581.epibrw>.

[12] Irvine, James. "C1aL4 Extraction of Limestone." *Leeds City College*. n.d. Web. 28 Mar. 2012. <http://www.jirvine.co.uk/Chemistry_GCSE/C1A/c1al4.htm>.

[13] "Processing of Silica Sand." *Outotec*. (2011): n.d. Web. 28 Mar. 2012. <http://www.outotec.com/14581.epibrw>.

[14] Tam, K. and Pinderhughes, R. "Glass." *San Francisco State University* (2003): 90. Web. 28 Mar. 2012. <http://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0CDIQFjAA&url=http%3A%2F%2Fonline.sfsu.edu%2F~raquelrp%2Fprojects%2FGlass.ppt&ei=8EF2T8TvHOHc0QHm5Zy_DQ&usg=AFQjCNGkLgMqiHArMrOrVcq4loiQ1DcYhg>.

[15] "Sand mining surges in Wisconsin." *WisconsinWatch.org*. Wisconsin Journal of Investigative Journalism, 31 Jul. 2011. Web. 13 Apr. 2012. <http://www.wisconsinwatch.org/2011/07/31/sand-mining-surges-in-wisconsin/>.

[16] Lucía, A, et al. "Gully Erosion on Silica Sand and Arkose Slopes in Central Spain." *IV International Symposium on Gully Erosion* (2007): Web. 13 Apr. 2012. <http://webcache.googleusercontent.com/search?q=cache:X_UQDpKAx7QJ:ggyma.geo.ucm.es/proyectos/carcavas/329815-5SEPT.pdf+&cd=2&hl=en&ct=clnk&gl=us>.

[17] Irvine, James. "C1aL4 Extraction of Limestone." *Leeds City College*. n.d. Web. 28 Mar. 2012. <http://www.jirvine.co.uk/Chemistry_GCSE/C1A/c1al4.htm>.

[18] "Strip Mining of Coal: Environmental Solutions." Energy Citations Database. n.d. Web. 30 Mar. 2012. <http://www.osti.gov/energycitations/product.biblio.jsp?osti_id=7357651>.

[19] Tam, K, and Pinderhughes, R. "Glass." *San Francisco State University* (2003): 90. Web. 28 Mar. 2012. <http://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0CDIQFjAA&url=http%3A%2F%2Fonline.sfsu.edu%2F~raquelrp%2Fprojects%2FGlass.ppt&ei=8EF2T8TvHOHc0QHm5Zy_DQ&usg=AFQjCNGkLgMqiHArMrOrVcq4loiQ1DcYhg>.

[20] "US Borax Trona Mine Owens Lake, California." *Mine-Engineer.Com*. n.d. Web. 1 Mar. 2012. <http://www.mine-engineer.com/mining/tronamine.htm>.

[21] "Strip Mining of Coal: Environmental Solutions." Energy Citations Database. n.d. Web. 30 Mar. 2012. <http://www.osti.gov/energycitations/product.biblio.jsp?osti_id=7357651>.

Manufacturing of Glass

Silica sand, limestone, sodium carbonate, and cullet (recycled glass or broken glass) are kept dry and cool in batcher houses and are held in silos or compartments. They are then mixed and weighed in proper proportions and sent to the furnaces in hoppers. The furnaces are operated by natural gas.[22] Natural gas is a non-renewable resource formed from the decomposition of organic matter in high temperature and pressure conditions for thousands of years. The extraction of natural gas causes habitat destruction, erosion, landslides and loss of soil productivity.[23] The glass mixture is then heated to between 1300-1600 degrees Celsius, where it enters a softened or molten state.[24]

Once heated, the mixture is placed in molds by pressure from compressed air or metal plungers. The process is completed by the primary mold being blown with compressed air to the shape of the final mold. The finished glass product is removed, packaged, and distributed.[25]

Manufacturing and Use Impact Assessment for Glass

The ecological impact of manufacturing glass is summarized by impact category in Table 3.4. The major contributors to each impact category score are outlined in Table B.1 found in Appendix B.

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[22] Tam, K, and Pinderhughes, R. "Glass." *San Francisco State University* (2003): 90. Web. 28 Mar. 2012. <http://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0CDIQFjAA&url=http%3A%2F%2Fonline.sfsu.edu%2F~raquelrp%2Fprojects%2FGlass.ppt&ei=8EF2T8TvHOHc0QHm5Zy_DQ&usg=AFQjCNGkLgMqiHArMrOrVcq4loiQ1DcYhg>.

[23] Lepoutre, Priscilla. “The Manufacture of Polyethylene.” *The New Zealand Institute of Chemistry*. n.d. Web. 25 Apr. 2012. <http://www.google.com/search?q=Lepoutre%2C+Priscilla.+%E2%80%9CThe+Manufacture+of+Polyethylene.%E2%80%9D+The+New+Zealand+Institute+of+Chemistry.&ie=utf-8&oe=utf-8&aq=t&rls=org.mozilla:en-US:official&client=firefox-a>.

[24] Tam, K, and Pinderhughes, R. "Glass." *San Francisco State University* (2003): 90. Web. 28 Mar. 2012. <http://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0CDIQFjAA&url=http%3A%2F%2Fonline.sfsu.edu%2F~raquelrp%2Fprojects%2FGlass.ppt&ei=8EF2T8TvHOHc0QHm5Zy_DQ&usg=AFQjCNGkLgMqiHArMrOrVcq4loiQ1DcYhg>.

[25] Cattane, J. "Environmental Overview Complete Life Cycle Assessment of North American Container Glass." *Glass Packaging Institute*. n.d. Web. 27 Mar. 2012. <http://www.gpi.org/downloads/lca/N-American_Glass_Container_LCA.pdf>.

Table 3.4: Total impact values for glass bottle material extraction and manufacture per 1 kg of material.

Impact Category	Total Impacts per 1 kg	Total Impacts per 10,096.35 kg	Unit
Global Warming	0.03	302.89	kg CO2 eq
Acidification	0.01	100.96	H+ moles eq
Eutrophication	0.000057	0.58	kg N eq
Carcinogens	0.000043	0.43	kg benzene eq
Non-Carcinogens	0.35	3,533.72	kg toluene eq
Respiratory effects	0.000034	0.34	kg PM2.5 eq

The additional ecosystem impacts of steel can manufacturing are quantified in Table 3.5.

Table 3.5: Additional Ecosystem Impacts for the Manufacture of Glass.

Erosion	Permanent Land Disruption	Water Use	Resource Use	Biodiversity Disruption	Total Score
1	1	0	1	0.5	**3.5**

As glass is mainly a product of silica sand, soda ash, and limestone, the majority of the ecosystem impacts from the manufacture of glass are a result of silica sand, soda ash, and limestone extraction through overburden stripping, quarry blasting, and trench digging. These processes require intensive landscape modifications and permanent land disruptions, which cause air pollution,[26] erosion, and loss of habitat.[27] Resource use during the manufacturing process of glass is ranked high because of resource demanding processes during the manufacturing phase, such as heating in the furnace using natural gas, a non-renewable resource.[28] The total

[26] "Sand Mining Surges in Wisconsin." *WisconsinWatch.org*. Wisconsin Journal of Investigative Journalism, 31 Jul. 2011. Web. 13 Apr. 2012. <http://www.wisconsinwatch.org/2011/07/31/sand-mining-surges-in-wisconsin/>.

[27] Lucía, A, et al. "Gully Erosion on Silica Sand and Arkose Slopes in Central Spain." *IV International Symposium on Gully Erosion* (2007): Web. 13 Apr. 2012. <http://webcache.googleusercontent.com/search?q=cache:X_UQDpKAx7QJ:ggyma.geo.ucm.es/proyectos/carcavas/329815-5SEPT.pdf+&cd=2&hl=en&ct=clnk&gl=us>.

[28] Lepoutre, Priscilla. "The Manufacture of Polyethylene." *The New Zealand Institute of Chemistry*. n.d. Web. 25 Apr. 2012. <http://www.google.com/search?q=Lepoutre%2C+Priscilla.+%E2%80%9CThe+Manufacture+of+Polyethylene.%E2%80%9D+The+New+Zealand+Institute+of+Chemistry.&ie=utf-8&oe=utf-8&aq=t&rls=org.mozilla:en-US:official&client=firefox-a>.

ecosystem impact score for glass is 3.5. This relatively high ecosystem impact score indicates the manufacture of glass is moderately harmful to ecosystems.

Recycling Overview of Glass

Glass can be endlessly recycled into a range of glass products, including: bottles and jars, plates, bowls, home decorating supplies, artwork, glass doorknobs and vases. Recovered glass is crushed into cullet and used as raw material to make new glass.[29]

Recycled residential glassware from Wellesley College is sent to Conigliaro Industries, where 40% of it stays on site and is ground into small pieces.[30] The resultant ground glass is used as an additive to cement in the manufacture of cement retaining wall blocks sold by the company. In this way, part of Wellesley's glass recycling is being downcycled. By not reintroducing the glass into recycling stream, it is permanently removed from the resource stream. In trapping glass in cement blocks, more silica sand, limestone, and sodium carbonate must be extracted in order to create new glass products. The other 60% of the glass sent to Conigliaro Industries is sent off site by the company to Casella Waste Systems, Inc.[31]

GLASS INCINERATION IMPACTS

Figure 3.3: Glass disposed of in the trash. Picture captured during our February waste audit of the New Dorms.

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[29] Cattane, J. "Environmental Overview Complete Life Cycle Assessment of North American Container Glass." *Glass Packaging Institute*. n.d. Web. 27 Mar. 2012. <http://www.gpi.org/downloads/lca/N-American_Glass_Container_LCA.pdf>.

[30] Conigliaro Industries. Personal interview. 29 Mar. 2012.

[31] Conigliaro Industries. Personal interview. 29 Mar. 2012.

Transportation Impacts: SEMASS

Glass waste sent to SEMASS for incineration is transported in a large, diesel-powered combination truck. We calculated the impact factors for this method of transport using the SimaPro7 database through the TRACI2 method. These impacts factors were generated for a large, diesel-powered, combination truck from the US carrying 1 kg for 1 km. These values were then multiplied by the distance to SEMASS, 98.16 km, and by the weight of glass waste sent to the facility annually, 6,090.56 kg.

Facility Impacts for Glass Handling: SEMASS

Inert materials, such as glass, are completely transmitted to slag ash in the incineration process.[32] Since it is inert, glass will not pollute soil, water or air. Therefore, there are no impacts associated with glass incineration. Glass will not burn, it will only melt at high temperatures; most incinerators require sorting of glass to prevent operational problems.[33]

Facility Credit for Glass Handling: SEMASS

Unlike some materials such as paper, glass does not provide any heat energy for making steam or electricity. In waste-to-energy facilities, like SEMASS, glass just melts. Value cannot be recovered from landfilling glass either. SEMASS receives no credit for incinerating glass.[34] The impact values for transporting 1kg of glass to SEMASS are displayed in Table 3.6. The cumulative facility impacts for sending 6,090.56 kg of glass waste to SEMASS are presented in Table 3.7.

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[32] Hellweg, S., Hofstetter, T. and Hungerbühler, K.. "Modeling waste incineration for life-cycle inventory analysis in Switzerland." *Environmental Modeling and Assessment* 6 (2001): 219–235. Web. 3 Apr. 2012. <http://www.springerlink.com/content/j0786101473h5mg1/fulltext.pdf>.

[33] "Recycable and Non-Recycable Materials." *Waste Management Alternatives*. Alaska Native Tribal Health Consortium, 2002. Web. 3 Apr. 2012. <http://www.anthc.org/cs/dehe/sustops/rasc/upload/Appendix%204.pdf>.

[34] "Glass." New York State Department of Environmental Conservation, 2012. Web. 3 Apr. 2012. <http://www.dec.ny.gov/chemical/45171.html>.

Table 3.6: Impact per 1 kg for Glass Sent to SEMASS.

Impact category	Transport Impact per 1 kg	Facility Impact	Facility Credit	Total Impact per 1 kg	Unit
Global warming	0.02	-	-	0.02	kg CO2 eq
Acidification	0.0066	-	-	0.0066	H+ moles eq
Eutrophication	6.26E-06	-	-	6.26E-06	kg N eq
Carcinogens	6.45E-06	-	-	6.45E-06	kg benzene eq
Non Carcinogens	0.14	-	-	0.14	kg toluene eq
Respiratory effects	7.51E-06	-	-	7.51E-06	kg PM2.5 eq

Table 3.7: Cumulative Impacts for 6,090.56 kg Glass Sent to SEMASS.

Impact category	Transport Impact for 6,090.56 kg	Facility Impact	Facility Credit	Total Impact for 6,090.56 kg	Unit
Global warming	55.70	-	-	55.70	kg CO2 eq
Acidification	18.40	-	-	18.40	H+ moles eq
Eutrophication	0.02	-	-	0.02	kg N eq
Carcinogens	0.02	-	-	0.02	kg benzene eq
Non Carcinogens	383	-	-	383	kg toluene eq
Respiratory effects	0.02	-	-	0.02	kg PM2.5 eq

GLASS RECYCLING IMPACTS

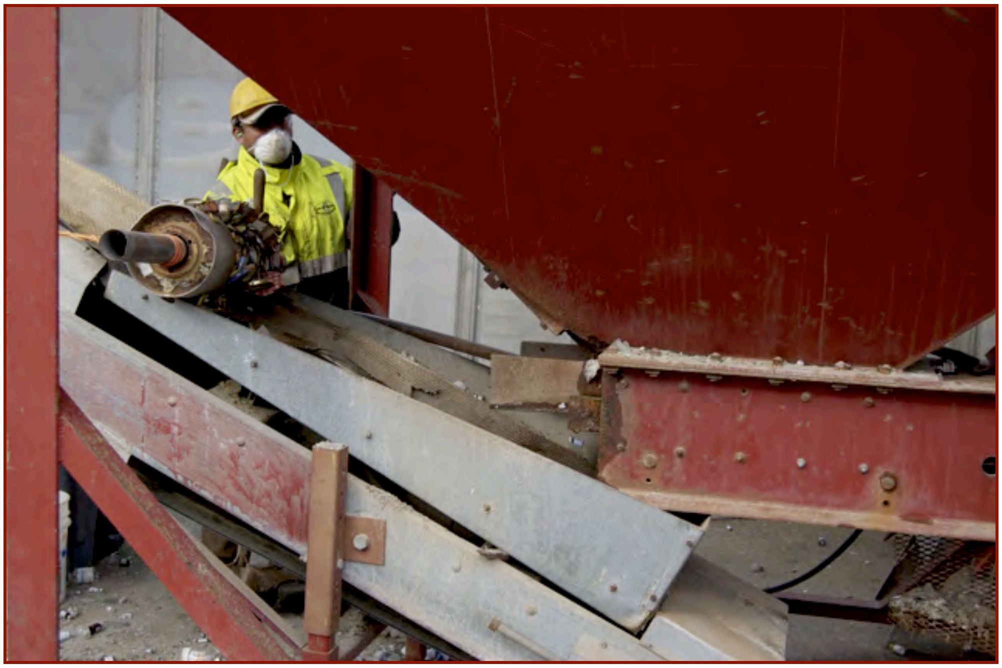

Figure 3.4: Glass-grinding machinery at Conigliaro Industries.

Transportation Impacts: Conigliaro & Casella

Glass waste handled as recycling from Wellesley College is first sent to Conigliaro in a medium, diesel-powered, single-unit truck from the US, where 40% of the glass waste is removed for on-site use. After Conigliaro, 60% of the glass waste is sent to Casella in a similar vehicle. Based on data from SimaPro7, impacts were generated for carrying 1 kg for 1 km with the previously mentioned vehicle. These values were multiplied by the distance to Conigliaro (212.45 km), and similarly for the distance to Casella (50.69 km) and by the weight of glass waste sent to the facility annually (Conigliaro: 504.08 kg; Casella: 756.11 kg). The impacts from transporting 1 kg of glass waste are displayed in Table 3.8. The impacts from transport of 1kg of glass waste from Conigliaro to Casella are displayed in Table 3.10.

Facility Impacts for Glass Handling: Conigliaro & Casella

To calculate the impacts for glass waste sent to Conigliaro, we estimated that the machine used to crush and tumble glass is equivalent to a rock crusher. To calculate the impacts for glass sent to Casella, we estimated that the machine used to sort glass is equivalent to a machine used to package and organize cement blocks within a given facility. The facility impacts for crushing and tumbling 1 kg of glass waste at Conigliaro are displayed in Table 3.8. The impacts of sorting 1kg of glass waste at Casella are displayed in Table 3.10.

Facility Credit for Glass Handling: Conigliaro & Casella

Conigliaro receives a credit for reusing glass waste as part of their cement retaining wall blocks and reducing the amount of cement needed to make the blocks. To calculate the credit for Conigliaro, we estimated the machine used to create cement blocks is equivalent to a machine used to make an aerated concrete block. We estimate that 10% of the cement blocks are composed of glass waste. Therefore, we multiplied the impact factors from the above machine by 10%. These impacts were calculated using data from the SimaPro7 database through the TRACI 2 method; the credit for recycling 1 kg of glass at Conigliaro is shown in Table 3.8.

Casella does not receive a credit based on the chosen impact factors since glass is merely sorted at this facility. The glass sorting process does not directly reduce the amount of emissions released from glass use, manufacture, or disposal.

The cumulative facility impacts for Conigliaro are presented in Table 3.9, and in Table 3.11 for Casella.

Table 3.8: Impacts per 1 kg of Glass Sent to Conigliaro, first step in the recycling process.

Impact category	Transportation Impacts	Facility Impacts	Facility Credit	Total	Unit
Global warming	0.00187	2.36E-08	-0.000092	0.0018	kg CO2 eq
Acidification	0.000547	5.24E-09	-8.19E-06	0.00054	H+ moles eq
Eutrophication	5.82E-07	1.09E-07	-1.79E-08	6.73E-07	kg N eq
Carcinogens	-	1.49E-10	-2.36E-08	-2.35E-08	kg benzene eq
Non Carcinogens	-	1.05E-06	-0.000084	-0.000083	kg toluene eq
Respiratory effects	5.45E-07	7.40E-11	-2.20E-08	5.23E-07	kg PM2.5 eq

Table 3.9: Cumulative Impacts for 504.08 kg of Glass Sent to Conigliaro, first step in the recycling process.

Impact Category	Transport Impact Total	Facility Impact Total	Facility Credit Total	Total Impact	Unit
Global warming	0.94	0.000012	-0.047	0.89	kg CO2 eq
Acidification	0.28	2.64E-06	-0.0041	0.027	H+ moles eq
Eutrophication	0.00029	5.50E-05	-9.02E-06	0.00034	kg N eq
Carcinogens	-	7.50E-08	-0.000012	-0.000012	kg benzene eq
Non Carcinogens	-	5.31E-04	-0.043	-0.042	kg toluene eq
Respiratory effects	0.00028	3.73E-08	-0.000011	0.00026	kg PM2.5 eq

Table 3.10: Impacts per 1 kg for Glass Sent to Casella, second step in the recycling process.

Impact Category	Transport Impacts	Facility Impact	Facility Credit	Total Impact	Units
Global Warming	0.011	3.80E-06	-	0.011	kg CO2 eq
Acidification	0.0031	1.19E-06	-	0.0031	H+ moles eq
Eutrophication	3.32E-06	2.02E-08	-	3.34E-06	kg N eq
Carcinogens	-	4.83E-08	-	4.83E-08	kg benzene eq
Non-Carcinogens	-	0.00055	-	0.00055	kg toluene eq
Respiratory Effects	3.11E-06	5.95E-09	-	3.12E-06	kg PM2.5 eq

Table 3.11: Cumulative Impacts for 756.11 kg of Glass Sent to Casella, second step in the recycling process.

Impact Category	Transport Impacts	Facility Impact	Facility Credit	Total Impact	Units
Global warming	8.06	0.0029	-	8.06	kg CO2 eq
Acidification	2.36	.0009	-	2.36	H+ moles eq
Eutrophication	0.0025	.000015	-	0.0025	kg N eq
Carcinogens	-	0.000037	-	0.000037	kg benzene eq
Non Carcinogens	-	0.42	-	0.42	kg toluene eq
Respiratory effects	0.0024	4.50E-06	-	0.0024	kg PM2.5 eq

Transportation Impacts: Container Recycling Alliance

After the glass waste is sorted at Casella, it is transported to Container Recycling Alliance (CRA). We calculated the transport based on its use of a medium, diesel-powered, single-unit truck from the US. Impact factors, generated through the SimaPro7 database using the TRACI2 method, were generated for carrying 1 kg for 1 km in the aforementioned vehicle. This number was multiplied by the distance to CRA (61.47 km) and by the weight of glass waste sent to that facility annually (756.11 kg). The impacts for transporting 1 kg of glass waste to CRA are displayed in Table 3.12.

Facility Impacts for Glass Handling: Container Recycling Alliance

In order to calculate the impacts for glass sent to CRA, we estimated that the machine used to melt and recycle glass is equivalent to a machine used to temper flat glass. These impacts were calculated utilizing data from the database SimaPro7 through the TRACI 2 method, in order to analyze the specific impact factors included in Table 3.12.

Facility Credit for Glass Handling: Container Recycling Alliance

CRA received an energy credit equal to the amount of emissions released from the production of 1 kg of glass from virgin materials multiplied by the number of kilograms sent to the facility annually. This is because the glass waste sent to the facility is recycled and reused, which eliminates the need for new glass to be made for that purpose. The facility credit for 1kg of glass processed at CRA is displayed in Table 3.12.

The cumulative facility impacts for Conigliaro are presented in Table 3.13.

Table 3.12: Impacts per 1 kg for Glass Sent to CRA, third step in the recycling process.

Impact category	Transport Impact	Facility Impact	Facility Credit	Total	Unit
Global warming	0.011	0.031	-0.045	-0.0038	kg CO2 eq
Acidification	0.0031	0.89	-0.013	0.88	H+ moles eq
Eutrophication	3.32E-06	35.4	-0.000091	35.4	kg N eq
Carcinogens	-	3.85E-07	-0.00028	-0.00028	kg benzene eq
Non-Carcinogens	-	0.0045	-7.02	-7.02	kg toluene eq
Respiratory Effects	-	-	-0.000044	-0.000044	kg PM2.5 eq

Table 3.13: Cumulative Impacts for 756.11 kg of Glass Sent to CRA.

Impact category	Transport Impact Total	Facility Impacts Total	Facility Credit Total	Total	Unit
Global warming	8.06	23.40	-34.30	-2.84	kg CO2 eq
Acidification	2.36	671	-10.10	663.26	H+ moles eq
Eutrophication	0.0025	26,800	-0.069	26,800	kg N eq
Carcinogens	-	0.00029	-0.22	-0.22	kg benzene eq
Non Carcinogens	-	3.42	-5,310	-5,306.58	kg toluene eq
Respiratory effects	0.0024	0.00026	-0.034	-0.03	kg PM2.5 eq

Cumulative Impacts of Recycling Glass: Conigliaro, Casella, and CRA

The cumulative impacts of placing glass in the recycling (Conigliaro, Casella, CRA) per 1 kg are described in Table 3.14. The cumulative impacts of placing glass in the recycling (Conigliaro, Casella, CRA) are described in Table 3.15.

Table 3.14: Impacts per 1 kg Glass Recycling Waste at Wellesley College (Conigliaro, Casella, CRA)

Impact Category	Transport Total	Impact Total	Credit Total	Total	Unit
Global Warming	0.02	0.03	-0.05	0.01	kg CO2 eq
Acidification	0.01	0.89	-0.01	0.88	H+ moles eq
Eutrophication	0.00	35.40	0.00	35.40	kg N eq
Carcinogens	-	4.33E-07	-0.00028	-0.00028	kg benzene eq
Non-Carcinogens	-	0.01	-7.02	-7.02	kg toluene eq
Respiratory Effects	6.77E-06	3.55E-07	-0.000044	-0.000037	kg PM2.5 eq

Table 3.15: Overall Impacts of Recycling 1,260.19 kg glass at Wellesley College (Conigliaro, Casella, CRA)

Impact Category	Transport Total	Impact Total	Credit Total	Total	Unit
Global Warming	17.06	23.40	-34.35	6.16	kg CO2 eq
Acidification	5	671.00	-10.10	665.89	H+ moles eq
Eutrophication	0.01	26,800.00	-0.07	26,799.94	kg N eq
Carcinogens	-	0.00033	-0.22	-0.22	kg benzene eq
Non-Carcinogens	-	3.84	-5,310.04	-5,306.20	kg toluene eq
Respiratory Effects	-	-	-0.03	-0.03	kg PM2.5 eq

Transportation Impacts: Burke Distribution Corporation

Glass waste sent to Burke Distribution Corporation is transported in a medium, diesel-powered, single-unit truck. The impact factors for this method of transport were generated by the SimaPro7 database, through the TRACI2 method, for such a vehicle carrying 1 kg for 1 km. These values were multiplied by the distance to Burke (31.38 km) and by the weight of glass waste sent to that facility annually (2,745.60 kg). The impact values for 1kg of glass transported to Burke are displayed in Table 3.14.

Facility Impacts for Glass Handling: Burke Distribution Corporation

We estimated that glass sent to Burke did not have a facility impact based upon our impact factors. This is because glass sent to Burke is in the form of glass bottles that are reused, meaning that instead of being recycled, they are rinsed and refilled for redistribution.

Facility Credit for Glass Handling: Burke Distribution Corporation

Burke received a credit equal to the amount of emissions released from the production of 1 kg of glass from virgin materials multiplied by the number of kilograms sent to the facility annually. This is because glass bottles sent to the facility are rinsed and reused, eliminating the need for new bottles to be made to replace them. This energy credit is displayed in Table 3.14.

The cumulative impacts of placing glass in the recycling (Burke) per 1 kg are described in Table 3.16. The cumulative impacts of placing total glass in the recycling (Burke) are described in Table 3.17.

Table 3.16: Impacts per 1 kg for Glass Sent to Burke Distribution Corporation.

Impact category	Transport Impact	Facility Impacts	Facility Credit	Total	Unit
Global warming	0.0054	-	-0.045	-0.04	Kg CO2 eq
Acidification	0.0016	-	-0.01	-0.012	H+ moles eq
Eutrophication	1.69E-06	-	-0.000091	-0.000090	kg N eq
Carcinogens	-	-	-0.00029	-0.00029	kg benzene eq
Non Carcinogens	-	-	-7.03	-7.03	kg toluene eq
Respiratory effects	1.59E-06	-	-0.000044	-0.000043	kg PM2.5 eq

Table 3.17: Cumulative Impacts for 2,745.60 kg of Glass Sent to Burke Distribution Corporation.

Impact category	Transport Impact Total	Facility Impacts Total	Facility Credit Total	Total	Unit
Global warming	14.82	-	-123.55	-108.73	Kg CO2 eq
Acidification	4.39	-	-27.46	-23.07	H+ moles eq
Eutrophication	0.0046	-	-0.25	-0.25	kg N eq
Carcinogens	-	-	-0.80	-0.80	kg benzene eq
Non Carcinogens	-	-	-19,301.57	-19,301.57	kg toluene eq
Respiratory effects	0.0044	-	-0.12	-0.12	kg PM2.5 eq

GLASS DISPOSAL CONCLUSIONS

The impacts of throwing 1kg of glass in the trash or the recycling are compared in Table # and the cumulative impacts of Wellesley College's glass waste being thrown in the trash or placed in the recycling is compared in Table 3.19.

Table 3.18: Comparison of Impacts for Placing 1kg of Glass in the Trash or in the Recycling.

Impact Category	Impact per 1kg Thrown in Trash	Impact per 1kg Recycled (Conigliaro, Casella, CRA)	Impact per kg Recycling (Burke)	Unit
Global Warming	0.02	0.01	-0.04	kg CO2 eq
Acidification	0.0066	0.88	-0.01	H+ moles eq
Eutrophication	6.30E-06	35.4	-0.00009	kg N eq
Carcinogens	6.30E-06	-0.00028	-0.00029	kg benzene eq
Non-Carcinogens	0.14	-7.02	-7.03	kg toluene eq
Respiratory Effects	7.50E-06	-0.000037	-0.000043	kg PM2.5 eq

Table 3.19: Comparison of Total Impacts for Placing Glass in the Wellesley College Trash or Recycling Waste Stream (Conigliaro, Casella, CRA), or Recycling Stream at the Pub (Burke)

Impact Category	Trash Total	Recycling Total (Conigliaro, Casella, CRA)	Total Recycling (Burke)	Unit
Global Warming	55.70	6.12	-109	kg CO2 eq
Acidification	18.40	665.89	-32.10	H+ moles eq
Eutrophication	0.02	26,799.94	-0.25	kg N eq
Carcinogens	0.02	-0.21	-0.78	kg benzene eq
Non-Carcinogens	383	-5,306.20	-19,300	kg toluene eq
Respiratory Effects	0.021	-0.03	-0.12	kg PM2.5 eq

Critical Areas in the Life Cycle of Glass

The majority of glass's impacts occur during the extraction of raw materials. Raw material extraction involves permanent land transformation during strip mining and quarry blasting. If glass is recycled, the effects of extraction can be reduced, even eliminated. Recycled glass cullet limits the need for virgin materials to be extracted, thereby reducing the impact associated with the use of glass.

Assessment of Wellesley College's Handling of Glass

Given the current available options for handling glass waste at Wellesley College, recycling glass is less harmful for the environment and human health compared to throwing glass in the trash. Glass discarded in Wellesley's MSW is sent to SEMASS where it provides no energy,[35] but simply melts. Melted glass causes machine complications and transforms into slag

[35] "Recycable and Non-Recycable Materials." *Waste Management Alternatives*. Alaska Native Tribal Health Consortium, 2002. Web. 3 Apr. 2012. <http://www.anthc.org/cs/dehe/sustops/rasc/upload/Appendix%204.pdf>.

ash, which then takes up space in landfills.[36] When glass recycling and trash are compared, recycling proves to be the better option in all impact categories. For glass materials whose shape can be retained, a method of rinsing and reusing, like bottles at Burke Distribution Corporation, is preferred. Reusing glass not only completely eliminates the need for raw materials, but also reduces the energy needed to melt and reform the glass. Recycling glass actually possesses negative global warming, carcinogen, non-carcinogen, and respiratory impacts because the environmental impacts of raw material extraction are eliminated from the life cycle.

The Wellesley College Science Center does not currently recycle glass discarded in its laboratories. Many people think that it is recycled since it is separated into cardboard boxes, but this assumption is wrong. The Science Center glass waste is sealed in plastic bags and placed in the dumpster near the loading dock where it is then sent to SEMASS to be incinerated.[37] Glass is discarded in this way because it is potentially contaminated.[38] This is alarming since SEMASS does not accept our hazardous waste. Science Center glass waste is an important concern and is something that can be significantly improved at Wellesley College.

Since laboratory glass waste is being discarded in the trash, the first step for the college is to identify specific contamination concerns and use areas. After this, separate bins for contaminated and uncontaminated glass can be established to divide the glass waste stream from the Science Center. The uncontaminated glass can then be recycled and the contaminated glass can be disposed of as hazardous waste in an appropriate manner.

ALUMINUM CANS

Aluminum Cans Background

Aluminum cans are used solely for beverage storage, primarily juices, alcoholic beverages, and sodas.[39] Aluminum cans are formed from a pure aluminum sheet and are available in 8 oz., 12 oz., 16 oz., 24 oz. and 32 oz. sizes.[40]

Uses of Aluminum Cans at Wellesley College

Aluminum cans are mainly purchased outside of Wellesley College and brought on campus by students, faculty, and staff. The only two places aluminum soda cans are sold on campus are in a vending machine on the second floor of the Science Center and in El Table, a student-run café. All other vending machines and auxiliary food providers sell soda in plastic bottles rather than aluminum cans. Faculty and staff may bring in aluminum juice or soda cans for their personal lunches. Students mainly use aluminum cans when purchasing beer off-

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[36] Hellweg, S., Hofstetter, T. and Hungerbühler. K. "Modeling waste incineration for life-cycle inventory analysis in Switzerland." *Environmental Modeling and Assessment* 6 (2001): 219–235. Web. 3 Apr. 2012. <http://www.springerlink.com/content/j0786101473h5mg1/fulltext.pdf>.

[37] Keegan, Raymond. Wellesley College Stockroom Manager. E-mail Interview. 30 Mar 2012.

[38] Howard, Suzanne. Wellesley College Director of Environmental Health and Safety. E-mail Interview. 11 Apr 2012.

[39] "Aluminum | The Aluminum Can". *The Aluminum Association*, 2008. Web. 01 Mar. 2012, <http://www.aluminum.org/Content/NavigationMenu/TheIndustry/PackagingConsumerProductMarket/Can/default.htm>.

[40] Life Cycle Impact Assessment of Aluminum Beverage Cans. *PE Americas.* Tech. Boston: PE International, 21 May 2010.

campus. Students bring the cans into residence halls and dispose of the cans in waste or recycling bins.

Activities and Behaviors Producing Aluminum Can Waste at Wellesley College

Aluminum can waste is produced when students, faculty, and staff consume beverages stored in aluminum cans on campus.

Amount of Aluminum Can Waste Produced at Wellesley College

The amount of aluminum can waste produced annually at Wellesley College is estimated as 1,043.12 kg, as shown in Table 3.20.

Table 3.20: Estimated Annual Aluminum Can Waste at Wellesley College.

Source	#Units (cans) Produced Annually	Total kg produced annually
Sage Lounge Vending Machine	540	8.10
Sports Center Vending Machine	540	8.10
El Table	384	5.76
Harambee House	192	2.88
Student off-campus purchasing	24,603.05	369.05
Faculty/staff off-campus purchasing	36,960	554.40
Miscellaneous	-	94.83
Total		**1,043.12**

The amount of aluminum can waste produced annually at Wellesley College was calculated using data from informal audits of on-campus vendors of aluminum cans, along with waste and recycling audit data. We assumed that aluminum cans purchased on-campus were not found in the waste audit because the residence hall where the audit took place is not located near any on-campus aluminum can vendors. The Sage Lounge and Sports Center vending machines are both maintained by the same company, NextGeneration, and hold ninety aluminum cans each. We estimated that the vending machines are re-filled every two months by NextGeneration. This assumption was based on the date the first comment card was placed on the vending machine; comment cards are used for filing complaints if the vending machine did not return a consumer's money. One aluminum can weighs 15 grams.[41] Therefore, the two vending machines are each responsible for 81 kg of aluminum can waste annually, or 540 aluminum cans.

An El Table member reported the number of aluminum cans ordered by the cooperative each month and an Ethos member estimated how many aluminum cans are purchased for use in Harambee house. El Table purchases 384 cans annually, at a weight of 5.7 kg, and Harambee House uses 192 cans annually, which collectively weigh 2.88 kg.

The amount of off-campus aluminum can waste was calculated for students using the results of the New Dorm Complex's waste and recycling audit. During the waste audit, 1.18 kg

[41] Shields, Susie. "The Secret Life of A Cola." *Oklahoma Sierran* 4 (July 2003): 1

of aluminum can waste, equivalent to 78.67 aluminum cans, were sorted and 32 cans were found in the New Dorm Complex's recycling. We then established a per person ratio of aluminum can waste and multiplied by the total number of Wellesley students on campus. We calculated that 24,603.05 aluminum cans are disposed of annually, or 369.05 kg of waste. Faculty and staff purchasing of off-campus aluminum cans was also calculated using data from an audit of recycling bins and trash cans in Green Hall. Forty-one aluminum cans were found in recycling bins and one aluminum can was found in a trash bin. The number found after one day of work was used to calculate the annual number of aluminum cans faculty and staff dispose of, 36,960 cans or 554.4 kg. This number is probably an overestimate because Green Hall is one of the largest of the 20 academic buildings.

Handling of Aluminum Can Waste at Wellesley College

The distribution of how aluminum cans are handled when disposed of at Wellesley College is shown in Table 3.21.

Table 3.21: Estimated Handling of Aluminum Can Waste at Wellesley College.

Material	% recycled	% thrown in trash
Sage Lounge Vending Machine	70%	30%
Sports Center Vending Machine	70%	30%
El Table	90%	10%
Harambee House	90%	10%
Student off-campus purchasing	28.91%	71.09%
Faculty/staff off-campus purchasing	98%	2%
Total	**74.49%**	**25.52%**

We estimated a 70 percent recycling rate of aluminum cans purchased in Sage Lounge and the Sports Center. We assumed a high recycling rate because aluminum can recycling bins are available near the vending machines, making aluminum cans an easy-to-recycle item in these locations. The estimated that recycling rates of aluminum cans at El Table and Harambee House were even higher, at 90 percent, with only 10 percent of aluminum can waste from the two locations being thrown in the trash, mainly because there are clearly visible metal recycling bins. Student, faculty, and staff disposal of aluminum cans purchased off-campus was estimated based on the ratio of cans in the trash and the recycling bins during the recycling and waste audits. We calculated a 28.91 percent recycling rate for students, while the recycling rate for faculty and staff was significantly higher, at 98 percent. However, the recycling rate for faculty and staff may be an overestimate because Wellesley College employees may dispose of aluminum can waste into their personal trash bins, rather than walking down the hall to dispose of their waste.

Destination of Aluminum Can Waste

The weight of aluminum can waste sent to recycling and MSW handling facilities is estimated in Table 3.22.

Table 3.22: Destination of Aluminum Can waste by Weight.

	Conigliaro Industries	**SEMASS**
% of Waste	74.49%	25.52%
Weight of Waste (kg)	777.02	266.15

We found that 74.49 percent of the total aluminum waste produced at Wellesley College is recycled and transported to Conigliaro Industries. Annually, 777.02 kg of aluminum can waste is transported to Conigliaro Industries for recycling. The aluminum can waste disposed of in the trash, representing 25.52 percent of the total aluminum can waste, is sent to SEMASS and incinerated. We estimate 266.15 kg of aluminum can waste is sent to SEAMASS annually.

ALUMINUM FOIL & PIE PLATES

Aluminum Foil and Pie Plates Background

Aluminum foil and pie plates are two of the many products made from aluminum. Aluminum foil has a variety of uses; it is used as structural reinforcement in aircrafts,[42] but is more commonly used in food preparation.

Aluminum foil's widespread usage can be attributed to its low density and high capacity to protect consumer and medical products. Aluminum foil is lightweight, making it inexpensive and accessible for extensive use, and its ability to protect products from light, gases, water, and bacteria makes it ideal for packing, storage, and other industrial and household needs.

Uses of Aluminum Foil and Pie Plates at Wellesley College

At Wellesley College, aluminum foil can be found in building insulation reflecting heat and moisture, in almost all electronics functioning as electrical capacitors, and in air conditioning units acting as a heat exchanger. Aluminum foil is also used in the science center laboratories to protect equipment from light, and in the art department as aluminum craft paper.

Most commonly, aluminum foil and pie plates are used in food-related production or packing at Wellesley. Wellesley Fresh uses aluminum foil for cooking purposes and food storage. Wellesley Fresh uses both family size and individual aluminum pie plates for cooking, especially for the production of desserts. Outside of dining services, food catering is another source of aluminum foil and pie plate usage at Wellesley. Academic Departments, student organizations, and individual students order catered food that is delivered in aluminum containers.

Activities and Behaviors Producing Aluminum Foil Waste at Wellesley College

Quick food preparation and easy clean-up are the main motivators for aluminum foil and pie plate waste created by Wellesley Fresh. Wellesley Fresh uses non-durable aluminum products, which are thrown away after one use, rather than cleaned and reused or recycled. The single use and disposal of these products saves employees time and effort.

[42] "EAFA-The Home of Aluminum Foil." *The European Aluminum Foil Association*. n.d. Web 27 Feb 2012. <http://www.alufoil.org/home.html>

The desire for prepared or catered foods is major motivator of aluminum pie plate waste. The time required to prepare food is much higher than ordering catering, thus students and organizations order catering that is delivered in aluminum pans.

Amount of Aluminum Foil and Pie Plate Waste Produced at Wellesley College

The amount of aluminum foil and pie plate waste produced annually at Wellesley College is estimated at 425.36 kg, as indicated in Table 3.23.

Table 3.23: Estimated Annual Aluminum Foil Waste produced by Wellesley College.

Material	Weight per unit (kg/unit)	# Units per kg	# Units Produced Annually (containers)	Total Produced Annually (kg)
Wellesley Fresh Foil	1.30	770'x 12" of foil	32	41.60
Wellesley Fresh Pie Plate Waste	.004	250 containers	32,000	128
Half Pan Catering Containers	0.03	30.30 containers	3,000	90
Full Pan Catering	0.11	9.09 containers	945	103.95
Science Center Foil	1.30	770'x 12" of foil	3	3.90
The Hoop & El Table	1.3	770'x 12" of foil	16	20.80
Miscellaneous	-	-	-	37.06
Total				**425.31**

The percentage of annual aluminum foil and pie plate waste by usage is represented in Figure 3.5.

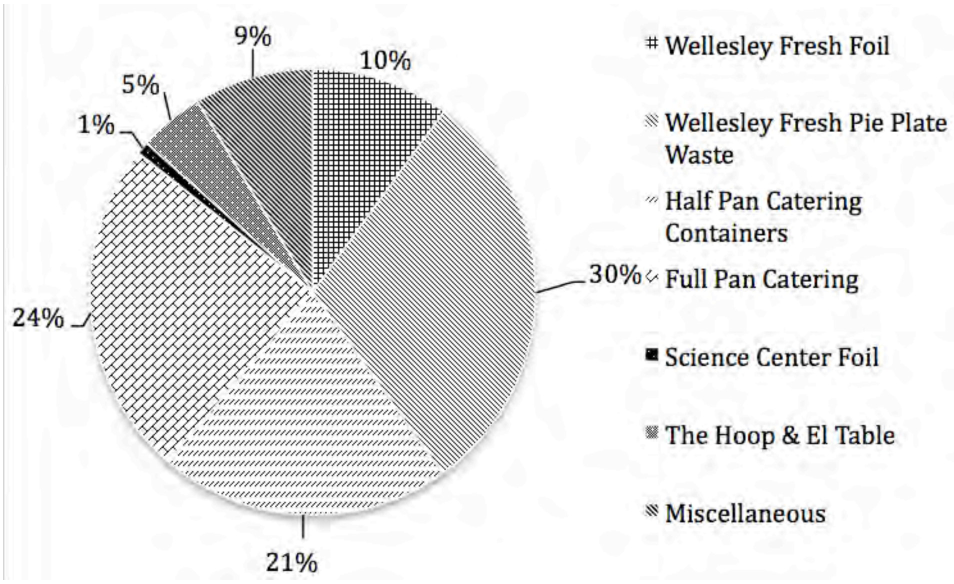

Figure 3.5: Relative breakdown of aluminum foil and pie plate waste Discarded on campus.

The amount of aluminum foil and aluminum pie plate waste produced by Wellesley Fresh was estimated by extrapolating from our waste audit data of Bates dining hall. We found a total of 3.39 kg of aluminum foil and aluminum pie plate waste during our audit. About 85% of the 3.39 kg was pie plate waste and 15% was foil waste, which breaks down to 2.88 kg of pie plate waste and 0.51 kg of foil waste respectively. Roughly 400 students live in the New Dorm Complex, meaning that Wellesley Fresh produces approximately 2.88 kg of aluminum pie plate waste and 0.51 kg aluminum foil waste to feed 400 students per week.

The majority of the aluminum pie plate waste was in the form of mini plates (4 x ½"), weighing 0.004 kg each, where 250 mini plates comprise 1 kg.[43] Since mini plates represent the majority of the aluminum pie plate waste, the weight of these plates were used in all calculations to determine aluminum pie plate waste of Wellesley Fresh. One 1000'x 12" roll of aluminum foil is 1.3 kg, with 770' x 12" rolls comprising 1 kg.[44] Approximately 0.51 kg of aluminum foil comprises 25% of a 1000'x 12" roll. Since 400 students live in the New Dorms complex and 0.51 kg of foil were found in the audit, Wellesley Fresh uses one 1000'x 12" roll of aluminum foil for 400 students every four weeks. The total annual weight of aluminum foil and pie plate waste disposed of by Wellesley Fresh is 170.60 kg.

As mentioned earlier, The Wellesley Events Calendar provides an overview of all programs that have been scheduled using 25Live. Using this calendar, we estimated that approximately 75 small scale catering events, serving 20 to 50 people, happen per month, 3 medium scale events, serving 75 to 125 people, happen per month, and 5 large scale special occasion events occur per semester. An example of a small-scale event is a department hosting a lecture with a lunch provided or organizational lunch and dinner meetings. We estimated 5 half-pan aluminum containers (12x10x4 inches) weighing 0.033 kg are used at each small-scale

[43] Aluminum foil containers. *Alufoil Products* PVT. LDT, 2010. Web. 10 March 2012. <http://www.alufoilindia.com/foil_containers.html>.

[44] Aluminum foil containers. *Alufoil Products* PVT. LDT, 2010. Web. 10 March 2012. <http://www.alufoilindia.com/foil_containers.html>.

event, where 30.30 containers comprise 1 kg.[45] Medium scale events include campus-wide dinner dialogues. We estimated 8 full pan aluminum containers (20x12x3 inches), weighing 0.11 kg each are used at each medium scale event, where 9.09 containers comprise 1 kg.[46] Large-scale special occasion events include Lake Day and Tanner Conference. We estimated 75 full pan aluminum containers (12x10x4 inches), weighing 0.11 kg are used at each large scale event, where 9.09 containers comprise 1 kg.[47] After extrapolating based on approximate number of events per academic year, we therefore estimate that the annual total weight of aluminum pans disposed of through catering at Wellesley College is 193.95 kg.

The Hoop and El Table also produce aluminum foil waste. El Table uses approximately one 770'x 12" foil role per month[48] and eight per year. We estimated that the Hoop uses the same amount of foil because it is also a student cooperative and serves similar food items. Thus, El Table and the Hoop produce approximately 16 770'x 12" foil roles per year.

Less commonly, aluminum foil serves to protect sensitive instruments or items from moisture or light in the Science Center. We estimate that one and a half 1000'x 12" rolls of aluminum foil are used per year in the Science Center. This was estimated from an informal survey of students in the sciences, who claimed that they rarely used aluminum foil and when they did it was in very small quantities. [49] The weight of 1 roll is 1.30 kg, where 770' x 12" of a roll comprises 1kg. The total amount of aluminum foil annually disposed of in the Science Center is therefore 3.90 kg.

Handling of Aluminum Foil and Pie Plate Waste at Wellesley College

The distribution of disposal of aluminum foil and pie plate waste is displayed in Table 3.24.

Table 3.24: Estimated Handling of Aluminum Foil and Pie Plate Waste Plastic Waste at Wellesley College.

Material	% Recycled	% Thrown in Trash
Wellesley Fresh Foil Usage	0%	100%
Hoop and El Table Foil Usage	0%	100%
Catering Pans	3%	97%
Science Center Foil	25%	75%
TOTAL	**7%**	**93%**

Aluminum foil used by Wellesley Fresh and for catered events is usually thrown in the trash because of food residues left on containers. We estimate that about 100% of aluminum foil used by Wellesley Fresh is discarded in the trash.

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[45] Aluminum foil containers. *Alufoil Products* PVT. LDT, 2010. Web. 10 March 2012. <http://www.alufoilindia.com/foil_containers.html>.

[46] Aluminum foil containers. *Alufoil Products* PVT. LDT, 2010. Web. 10 March 2012. <http://www.alufoilindia.com/foil_containers.html>.

[47] Aluminum foil containers. *Alufoil Products* PVT. LDT, 2010. Web. 10 March 2012. <http://www.alufoilindia.com/foil_containers.html>.

[48] Carter, Asha. Personal Interview. 17 April 2012.

[49] Kahill Loran; Ekeh, Ijeoma; West, Wedy , Personal Interview 12 March 2012

Aluminum foil used in the Science Center is disposed of in the trash and in recycling.[50] We estimate that 25% of aluminum foil is thrown in the recycling, because there are recycling bins available in the common spaces in the Science Center, but not in the classrooms where individuals are more likely to discard their aluminum waste in the trash.

Destination of Aluminum foil and Pie Plate Waste

The portions of aluminum foil and pie plate waste sent to Conigliaro Industries for recycling and SEAMASS for incineration are estimated in Table 3.25.

Table 3.25: Destination of Aluminum Foil and Pie Plate Waste by Percentage.

	Conigliaro	SEMASS
% of Waste	7%	93%
Weight of Waste (kg)	29.78	395.53

Recycled aluminum foil and pie plates enter a single stream recycling flow and are sent to the Conigliaro Industries recycling facility in Framingham, MA. We estimate that 7% of aluminum foil waste from Wellesley College, or 29.78 kg, is sent to Conigliaro Industries annually.

Aluminum foil and pie plates products disposed of in the trash are sent to SEMASS, where they are incinerated. We estimate that 93% of waste, or 395.53kg of aluminum foil is sent to SEMASS annually.

Abridged Life Cycle of Aluminum Cans, Foil and Pans Produced at Wellesley College

Aluminum cans, foil, and pans are all extracted from the same primary material and manufactured in similar manners. We conducted one Life Cycle Assessment for these aluminum products, which is inclusive of Wellesley's aluminum can waste (1,043.17 kg) and Wellesley's aluminum foil and pan waste (425.31 kg). Thus, the Life Cycle Assessment reflects the total impacts of 1,468.48 kg of aluminum waste produced at Wellesley College annually. An abridged lifecycle diagram for aluminum production to disposal is displayed in Figure 3.6.

[50] Nikerson, Deborah. Personal Interview. 15 March 2012

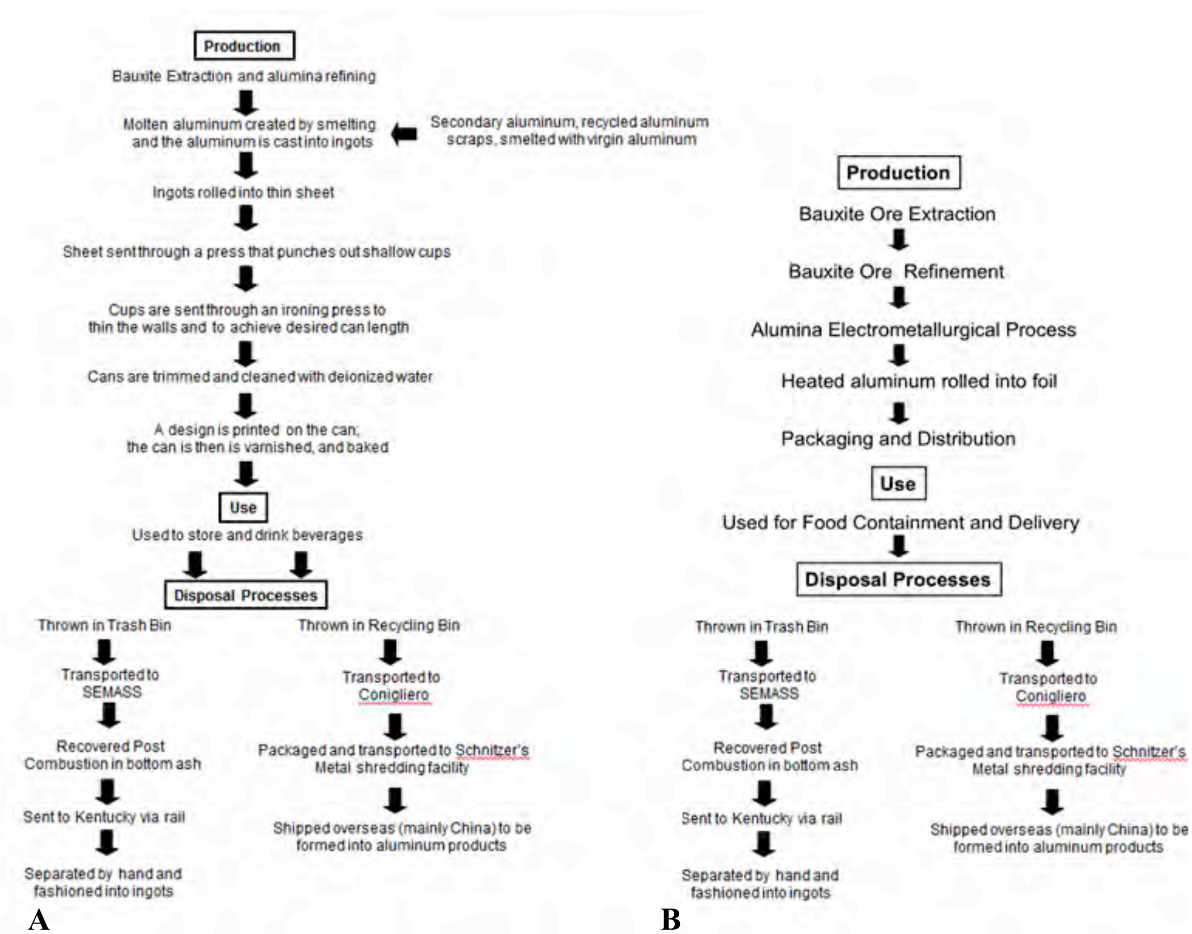

Figure 3.6: Abridged Life Cycle for A) Aluminum Cans and B) Aluminum Foil and Pie Plates.

Aluminum Source Background

Aluminum is produced from Bauxite, a mixture of aluminum oxides, silicon, and iron oxides.[51] Bauxite ore is extracted from strip or open pit mines. Explosives are used to loosen the deposits found in the mines.[52] Once obtained, bauxite ore is crushed, ground, and washed with water to remove impurities.[53] The crushing and grinding process produces dust emissions, affecting respiratory systems in nearby communities.[54] Bauxite mines use large amounts of water to control dust emissions and remove impurities.[55] Additionally, strip and open pit mining result

[51] Willson, J. "The Environmental Impact of Bauxite Mining." *Helium*. 02 Jul. 2010. Web. 27 Mar. 2012, <http://www.helium.com/items/1878788-effect-of-bauxite-mining-on-the-environment>.
[52] Willson, J. "The Environmental Impact of Bauxite Mining." *Helium*. 02 Jul. 2010. Web. 27 Mar. 2012, <http://www.helium.com/items/1878788-effect-of-bauxite-mining-on-the-environment>.
[53] Life Cycle Impact Assessment of Aluminum Beverage Cans. *PE Americas.* Report. Washington D.C.: Aluminum Association, 2010.
[54] Jamaica Bauxite Case (BAUXITE). n.d. Web. 26 Mar. 2012, <http://www1.american.edu/TED/bauxite.htm>.
[55] Life Cycle Impact Assessment of Aluminum Beverage Cans. *PE Americas.* Report. Washington D.C.: Aluminum Association, 2010.

in intensive land use and removal of topsoil.[56] Bauxite is mainly shipped to North America for aluminum can production from Brazil, Guinea, and Jamaica.[57]

Manufacturing of Aluminum

The bauxite is refined to aluminum oxide, known as alumina, through the Bayer Process, where bauxite is digested into a sodium aluminate solution. [58] This solution is filtered, causing the aluminum hydrate particles to crystallize, precipitate, and calcinate to alumina. Filtering of solid impurities produces red mud, a mixture of solid and metallic oxide-bearing impurities. The mud is highly alkaline, and contains low levels of iron, titanium, and gallium.[59]

The alumina is smelted, producing molten aluminum and carbon-dioxide,[60] using an electric current.[61] This electrometallurgical process is energy intensive, taking 15.7 kWh of electricity to produce one kilogram of aluminum from alumina, [62] which results in greenhouse gas emissions. The aluminum is then rolled into thin sheets.

Aluminum can manufacturing begins with a press that punches out shallow cups from the aluminum sheet.[63] An ironing press forms the shallow cup into the beverage can's body by reducing the thickness of the shallow cup.[64] The inside of the can is smoothed with a trimmer and the can is then cleaned with a series of water rinses.[65] The outside of the can is painted, varnished, and baked to dry the paint.[66] Finally, the cans' diameter is reduced at top, in a process known as necking, and shipped to customers.[67]

Aluminum foil manufacturing consists of aluminum sheets passing though heated rollers to create tin roles of foil. [68] To create aluminum plates and pans, the aluminum sheet first passes

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[56] Jamaica Bauxite Case (BAUXITE). n.d. Web. 26 Mar. 2012, <http://www1.american.edu/TED/bauxite.htm>.

[57] Life Cycle Impact Assessment of Aluminum Beverage Cans. *PE Americas.* Report. Washington D.C.: Aluminum Association, 2010.

[58] Alumina Refining; About Aluminum. *International Aluminium Institute.* n.d. Web. 1 Apr. 2012, <http://www.world-aluminium.org/About Aluminium/Production/Alumina refining>.

[59] Aluminum recycling and processing for energy conservation. *The Minerals Information Society*. (2007). Print. Materials Park, OH: John A. S. Green.

[60] Aluminum recycling and processing for energy conservation. *The Minerals Information Society*. (2007). Print. Materials Park, OH: John A. S. Green.

[61] Smelting; About Aluminum. *International Aluminium Institute*. n.d. Web. 1 Apr. 2012, <http://www.world-aluminium.org/About Aluminium/Production/Smelting>.

Smelting; About Aluminum. *International Aluminium Institute*. n.d. Web. 1 Apr. 2012, <http://www.world-aluminium.org/About Aluminium/Production/Smelting>.

[63] How Are Aluminum Cans Made? *Earth911*. 2012. Web. 26 Mar. 2012, <http://earth911.com/recycling/metal/aluminum-can/how-are-aluminum-cans-made/>.

[64] How Are Aluminum Cans Made? *Earth911*. 2012. Web. 26 Mar. 2012, <http://earth911.com/recycling/metal/aluminum-can/how-are-aluminum-cans-made/>.

[65] How Are Aluminum Cans Made? *Earth911*. 2012. Web. 26 Mar. 2012, <http://earth911.com/recycling/metal/aluminum-can/how-are-aluminum-cans-made/>.

[66] How Are Aluminum Cans Made? *Earth911*. 2012. Web. 26 Mar. 2012, <http://earth911.com/recycling/metal/aluminum-can/how-are-aluminum-cans-made/>.

[67] How Are Aluminum Cans Made? *Earth911*. 2012. Web. 26 Mar. 2012, <http://earth911.com/recycling/metal/aluminum-can/how-are-aluminum-cans-made/>.

[68] The Aluminum Association. *The American Aluminum Association*. 2008. Web. 27 Feb 2012. <http://www.aluminum.org/>; EAFA-The Home of Aluminum Foil. *The European Aluminum Foil Association*. nd. Web 27 Feb 2012. <http://www.alufoil.org/home.html>.

through a heated roller and then a press stamps out the body of the aluminum pan to the desired shape. [69]

Manufacturing and Use Impact Assessment for Aluminum

The ecological impact of the manufacture of aluminum, per 1 kg of material, is summarized by impact category in Table 3.26. The major contributors to each impact category score are outlined in Table B.2 found in Appendix B.

Table 3.26: Total Impact Values for Aluminum Material Extraction and Manufacture Per 1kg of Material and for the Total kg of Aluminum Produced at Wellesley College Annually, 1,468.48 kg.

Impact category	Impact for 1 kg	Total impact for 1,468.48 kg	Unit
Global warming	3.18	4,669.77	kg CO2 eq
Acidification	0.71	1042.62	H+ moles eq
Eutrophication	2.66E-04	.39	kg N eq
Carcinogens	.21	219.06	kg benzene eq
Non-Carcinogens	241	353,903.68	kg toluene eq
Respiratory effects	2.83E-03	4.16	kg PM2.5 eq

The additional ecosystem impacts of aluminum can manufacturing are quantified in Table 3.27.

Table 3.27: Additional Ecosystem Impacts for the Manufacture of Aluminum.

Erosion	Permanent Land Disruption	Water Use	Resource Use	Biodiversity Disruption	Total Score
1	.5	.5	.5	.5	**3**

The majority of ecosystem impacts resulting from aluminum manufacturing are consequences of the bauxite extraction process, resulting in an overall additional ecosystem impact score of four. The topsoil from mine sites is removed entirely before a Bauxite mine is opened.[70] Erosion on mining sites is prevalent, significantly reducing the soil's water retention capabilities.[71] Therefore, aluminum manufacturing from primary materials received a high erosion impact score. Although open pit and strip mining devastates the natural landscape, significant efforts have been made to rehabilitate mined land, such as restoring forests, in Brazil and Jamaica.[72] Restoration projects led to a medium impact permanent land disruption score. Aluminum manufacturing received a medium water use score because bauxite mining relies on water to remove impurities and control dust emissions, but some of the water is recycled and

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[69] The Aluminum Association. *The American Aluminum Association*. 2008. Web. 27 Feb 2012. <http://www.aluminum.org/>; EAFA-The Home of Aluminum Foil. *The European Aluminum Foil Association*. nd. Web 27 Feb 2012. <http://www.alufoil.org/home.html>.

[70] Jamaica Bauxite Case (BAUXITE). n.d. Web. 26 Mar. 2012, <http://www1.american.edu/TED/bauxite.htm>.

[71] Jamaica Bauxite Case (BAUXITE). n.d. Web. 26 Mar. 2012, <http://www1.american.edu/TED/bauxite.htm>.

[72] Jamaica Bauxite Case (BAUXITE). n.d. Web. 26 Mar. 2012, <http://www1.american.edu/TED/bauxite.htm>.

reused.[73] Additionally, the tailings, or materials left over from alumina production, form an alkaline mud that leaches into surface water and underground aquifers, contaminating the water supply.[74] Bauxite ore is not renewable, but it is prevalent in many regions; thus, aluminum manufacturing received a medium impact score for resource use.[75] Even with possible reforestation after a mine's closure, there is significant biodiversity loss with the opening of a bauxite mine.[76] Aluminum manufacturing using primary materials was given a medium biodiversity impact score. Aquatic species cannot live in the contaminated water; all vegetation life is initially destroyed and many plants cannot be easily re-grown because of erosion; and animal life is removed from the site and may suffer from noise pollution, due to the nearby explosions.[77] As noted previously, restoration projects can restore natural habitats, increasing biodiversity in the footprint of the mines.

Recycling Overview of Aluminum

Aluminum products usually undergo closed-loop recycling. Recycled aluminum, often referred to as secondary aluminum, is added to a furnace and smelted with virgin aluminum, producing molten aluminum. The energy used to melt and remold aluminum is 95% less when using secondary aluminum than when producing aluminum from virgin materials.[78]

The aluminum that is recycled on campus is packaged at Conigliaro Industries and sent to Schnitzer's Metal Shredding Facility in Worcester, MA.[79] Schnitzer's sends scrap aluminum to domestic and international aluminum manufactures, primarily in China. If aluminum cans are thrown in the trash, they are sent SEMASS and recovered post-combustion.[80] The post-combustion aluminum is then sent to Kentucky via rail where it is separated by hand and fashioned into ingots.[81] If secondary aluminum was used for all aluminum manufacturing, the additional ecosystem impacts of aluminum would reduce to .5 because the majority of the impacts are due to the extraction of bauxite. The only medium impact score would be water use from using water to rinse newly formed aluminum.

73 PE Americas. *Life Cycle Impact Assessment of Aluminum Beverage Cans*. Rep. Washington D.C.: Aluminum Association, 2010.
74 "Jamaica Bauxite Case (BAUXITE). n.d. Web. 26 Mar. 2012, <http://www1.american.edu/TED/bauxite.htm>.
75 Willson, Judith. "The Environmental Impact of Bauxite Mining." *Helium*. 02 July 2010. Web. 27 Mar. 2012, <http://www.helium.com/items/1878788-effect-of-bauxite-mining-on-the-environment>.
76 Jamaica Bauxite Case (BAUXITE). n.d. Web. 26 Mar. 2012, <http://www1.american.edu/TED/bauxite.htm>.
77 Willson, J. The Environmental Impact of Bauxite Mining. *Helium*. 02 July 2010. Web. 27 Mar. 2012, <http://www.helium.com/items/1878788-effect-of-bauxite-mining-on-the-environment>.
78 The Aluminum Association. *The American Aluminum Association*. 2008. Web. 27 Feb 2012. <http://www.aluminum.org/>; EAFA-The Home of Aluminum Foil. *The European Aluminum Foil Association*. nd. Web 27 Feb 2012. <http://www.alufoil.org/home.html>.*Association*. nd. Web 27 Feb 2012. <http://www.alufoil.org/home.html>
79 Garrison, Richard. General Manager Conigliaro Industries. Personal interview. 30 Mar. 2012.
80 Will Campbell. Environmental Scientist. Personal interview. 21 Mar. 2012.
81 Will Campbell. Environmental Scientist. Personal interview. 21 Mar. 2012.

ALUMINUM INCINERATION IMPACTS

Figure 3.7: Aluminum products destined for incineration from the February Waste Audit.

Trace substances in Aluminum

The kilograms of the six substances, dioxin, lead, copper, arsenic, nitrogen, carbon, sulfur, that determine the impacts of incinerating aluminum are described in Table B.4, found in Appendix B.

Transportation Impacts: SEMASS

Aluminum sent to SEMASS for incineration is transported in large, diesel-powered, combination trucks from the US. SEMASS is located 98.16 km away from Wellesley College. The impact factors for transport were calculated using SimaPro7 using the TRACI2 method. The trucking impact values for all aluminum products sent to SEMASS are displayed in Table B.5, found in Appendix B.

Facility Impacts for Aluminum Handling: SEMASS

Aluminum that is discarded in the trash is incinerated at SEMASS. The impacts of incineration of pans, foil, and cans are displayed in Table B.6, found in Appendix B.

Facility Credit for Aluminum Handling: SEMASS

At SEMASS, energy produced from the incineration of most materials is converted into electricity. Some of this electricity is used to run the facility, while the rest is fed to the grid.

Aluminum, however, has a calorific value of zero, meaning it does not produce electricity. In waste-to-energy facilities, like SEMASS, aluminum just melts. SEMASS therefore receives no credit for incinerating aluminum.

Cumulative Impacts: SEMASS

The impacts for aluminum sent to SEMASS per 1 kg are described in Table 3.28. The cumulative impacts of 661.68 kg of aluminum sent to SEMASSare described in Table 3.29.

Table 3.28: Cumulative Impacts per 1 kg for Aluminum Sent to SEMASS.

Impact Category	Transport Impact (per kg)	Facility Impact (per kg)	Facility Credit	Total	Unit
Global Warming	0.0092	4.90E-08	-	0.0092	kg CO2 eq
Acidification	0.003	0.005	-	0.008	H+ moles eq
Eutrophication	2.89E-06	-	-	2.89E-06	kg N eq
Carcinogens	-	2.05	-	2.05	kg benzene eq
Non-Carcinogens	-	5,550.03	-	5,550.03	kg toluene eq
Respiratory Effects	3.47E-06	0.0064	-	0.0064	kg PM2.5 eq

Table 3.29: Cumulative Impacts for 661.68 kg of Aluminum Sent to SEMASS.

Impact Category	Transport Impact	Facility Impact	Facility Credit	Total	Unit
Global Warming	6.09	0.000032	-	6.09	kg CO2 eq
Acidification	2	3.31	-	5.31	H+ moles eq
Eutrophication	0.0019	-	-	0.0019	kg N eq
Carcinogens	-	1,353.44	-	1,353.44	kg benzene eq
Non-Carcinogens	-	3,672,343.85	-	3,672,343.85	kg toluene eq
Respiratory Effects	0.0023	4.23	-	4.23	kg PM2.5 eq

Transportation Kentucky Facility

After aluminum is incinerated at SEMASS, it is recovered post-combustion and sent to Kentucky via rail where it is separated by hand and fashioned into ingots.[82] The trucking impact values for all aluminum products sent to Kentucky is displayed in Table B.7, found in Appendix B.

Facility Impacts for Aluminum Handling: Kentucky

At the Kentucky facility, aluminum is cleaned and recycled in a close loop process. To calculate the impacts for aluminum sent to Kentucky, we estimated the machines used to sort clean and recycle aluminum. These impacts were calculated utilizing data from the SimaPro7 database through the TRACI 2 method. The impacts of recycling of pans, foil, and cans are displayed in Table B.8, found in Appendix B.

Facility Credits for Aluminum Handling: Kentucky

The Kentucky Facility received credit based on the amount of impacts avoided that would have been otherwise created during the extraction and manufacturing process of aluminum. The credit for recycling of pans, foil, and cans are displayed in Table B.9, found in Appendix B.

Overall Impacts: Kentucky

The overall facility impacts for 1 kg and 661.68 kg send to Kentucky are presented in Table 3.30 and 3.31 respectively.

Table 3.30: Overall Impacts per 1 kg for Aluminum Sent to Kentucky.

Impact Category	Transport Impact	Facility Impact	Facility Credit	Total	Unit
Global Warming	0.07	0.43	-3.18	-2.68	kg CO2 eq
Acidification	0.04	1.86	-0.71	1.19	H+ moles eq
Eutrophication	0.00012	0.00022	-0.00027	-0.0024	kg N eq
Carcinogens	0.72	1.48	-.21	1.99	kg benzene eq
Non-Carcinogens	0.00012	0.00074	-241	-241	kg toluene eq
Respiratory Effects	0.00013	0.000041	-0.0028	-0.0026	kg PM2.5 eq

[82] Will Campbell. Environmental Scientist. Personal interview. 21 Mar. 2012.

Table 3.31: Overall Impacts for 661.68 kg of Aluminum Sent to Kentucky.

Impact Category	Transport Impact	Facility Impact	Facility Credit	Total	Unit
Global Warming	46.32	284.52	-2,104.14	-1,773.302	kg CO2 eq
Acidification	26.47	1,230.72	-469.79	787.40	H+ moles eq
Eutrophication	0.08	0.15	-0.18	0.05	kg N eq
Carcinogens	476.41	979.29	-138.95	1,316.74	kg benzene eq
Non-Carcinogens	0.08	0.49	-159,464.90	-159,464.30	kg toluene eq
Respiratory Effects	0.09	0.03	-1.85	-1.74	kg PM2.5 eq

Total Impact of Aluminum in the Trash

The total impacts for 1kg and 661.68 kg of aluminum that is discarded in the trash are represented in Table 3.32 and Table 3.33 respectively.

Table 3.32: Cumulative Impacts per 1 kg for Aluminum Discarded in the Trash.

Impact Category	Transport Impact	Facility Impact	Facility Credit	Total	Unit
Global Warming	0.08	0.43	-3.18	-2.67	kg CO2 eq
Acidification	0.04	1.87	-0.71	1.20	H+ moles eq
Eutrophication	0.00012	0.00022	-0.0003	-0.00004	kg N eq
Carcinogens	0.72	3.53	-0.21	4.04	kg benzene eq
Non Carcinogens	0.00012	5,550.03	-241	5,309.03	kg toluene eq
Respiratory effects	0.00013	0.0064	-0.0028	-0.0037	kg PM2.5 eq

Table 3.33: Overall Impacts for 661.68 kg of Aluminum Discarded in the Trash.

Impact Category	Transport Impact	Facility Impact	Facility Credit	Total Impact	Unit
Global Warming	52.41	284.52	-2,104.14	-1767.21	kg CO2 eq
Acidification	28.47	1,234.03	-469.79	792.71	H+ moles eq
Eutrophication	0.0819	0.15	-0.18	0.05	kg N eq
Carcinogens	476.41	2,332.73	-138.95	2,670.19	kg benzene eq
Non Carcinogens	0.08	3,672,344.34	-159,464.90	3,512,879.52	kg toluene eq
Respiratory effects	0.0923	4.26	-1.85	2.50	kg PM2.5 eq

ALUMINUM RECYCLING IMPACTS

Figure 3.8: Metal shipped for recycling is weighed and shipped in bales.

Transportation Impact: Schnitzer's via Conigliaro

Recycled aluminum from Wellesley College is first sent to Conigliaro in a diesel-powered, single-unit truck, and then to Schnitzer's Steel in a similar vehicle. The total transport distance for recycled plastics to Conigliaro is 10.89 km, and 38.95 km from Conigliaro to Schnitzer's Steel. The impact factors for transport were calculated using SimaPro7 using the

TRACI2 method. The trucking impacts for recycled aluminum products sent to Conigliaro and Schnitzer's Steel are displayed in Table B.10, found in Appendix B.

Facility Impacts for Aluminum Handling: Schnitzer's Steel

Conigliaro sends all of its aluminum waste to Schnitzer's Steel for recycling. At Schnitzer's Steel, the aluminum is sorted, packaged and shipped overseas for recycling. We used the metal-working machine operation from SimaPro7 as our best estimation of the impacts of a mechanical sorter. The impacts for sorting Wellesley's aluminum sent to Schnitzer's Steel are quantified in Table B.11, found in Appendix B.

Facility Credit for Aluminum Handling: Schnistzer's Steel

Schnitzer's Steel does not receive a facility credit; aluminum is sorted at this facility, but no use or end-of-life decisions are made at Schnitzer's Steel.

Overall Impact for Schnitzer's Steel

The impacts for sending 1 kg to Schnitzer's Steel are presented in Table 3.34. The cumulative impacts for sending 806.80 kg of aluminum to Schnitzer's Steel are shown in Table 3.35. In addition to the transportation, facility impact and credit of Schnitzer's Steel, the transportation impacts to Conigliaro are also included in these tables.

Table 3.34: Overall Impacts per 1 kg for Aluminum at Schnitzer's Steel.

Impact Category	Transport Impact	Facility Impact	Facility Credit	Total Impact	Unit
Global Warming	0.0092	0.18	-	0.19	kg CO2 eq
Acidification	0.0027	0.08	-	0.08	H+ moles eq
Eutrophication	2.85E-06	0.000094	-	0.000097	kg N eq
Carcinogens	-	0.79	-	0.79	kg benzene eq
Non-Carcinogens	-	0.00032	-	0.00032	kg toluene eq
Respiratory Effects	2.67E-06	0.000018	-	0.000021	kg PM2.5 eq

Table 3.35: Overall Impacts for 806.80 kg of Aluminum at Schnitzer Steel.

Impact Category	Transport Impact	Facility Impact	Facility Credit	Total Impact	Unit
Global Warming	7.43	145.22	-	152.65	kg CO2 eq
Acidification	2.18	64.54	-	66.72	H+ moles eq
Eutrophication	0.0023	0.08	-	0.08	kg N eq
Carcinogens	-	637.37	-	637.37	kg benzene eq
Non-Carcinogens	-	0.26	-	0.26	kg toluene eq
Respiratory Effects	0.0022	0.01	-	0.02	kg PM2.5 eq

Transportation Impact: Overseas Processing

After sorting at Schnitzer's Steel, aluminum is shipped to processing facilities overseas. As many of these processing facilities are located in Asia, we assume that aluminum is shipped to Shanghai, China. We calculated the distance by sea to be 17,080 km traveled by barge. The impact of this shipment was calculated in SimaPro7 using the TRACI2 method. The impacts for overseas shipment of aluminum waste are displayed in Table B.12 found in Appendix B.

Facility Impacts for Aluminum Handling: Overseas Processing

Aluminum sorted at Schnitzer's Steel is shipped to processing facilities, generally located overseas. In these facilities, aluminum foil, cans, and pans are melted and remolded into aluminum cans. We used the processing and melting of aluminum beverage containers, from SimaPro7 as our best estimation of the impacts of recycling. The combined impacts of these processes are quantified in Table B.13 found in Appendix B.

Facility Credit for Aluminum Handling: Overseas Processing

Overseas recycling received a credit equal to the amount of emissions released from the production of 1kg of aluminum from virgin materials multiplied by the number of kilograms sent to the facility annually. This is because aluminum is not downcycled, and does not deteriorate. Thus, the recycling of this material eliminates the need for new aluminum cans to be produced. The facility credit for aluminum processed overseas is presented in Table B.14 found in Appendix B.

Overall Impact for Overseas Processing

The impacts for sending 1 kg of aluminum overseas are presented in Table 3.36. The cumulative impacts for sending 806.80 kg of aluminum to Schnitzer's Steel are shown in Table 3.37.

Table 3.36: Overall Impacts Per 1 kg of Aluminum Processed Overseas.

Impact Category	Transport Impact	Facility Impact	Facility Credit	Total Impact	Unit
Global Warming	0.79	0.43	-3.18	-1.96	kg CO2 eq
Acidification	0.41	1.86	-0.71	1.56	H+ moles eq
Eutrophication	0.0014	0.00022	-2.66E-04	0.0014	kg N eq
Carcinogens	0.00068	1.48	-.21	1.27	kg benzene eq
Non-Carcinogens	5.46	0.00074	-241	-235.54	kg toluene eq
Respiratory Effects	0.00097	0.000041	-2.83E-03	-0.0018	kg PM2.5 eq

Table 3.37: Overall Impacts of 806.80 kg Aluminum Processed Overseas.

Impact Category	Transport Impact	Facility Impact	Facility Credit	Total Impact	Unit
Global Warming	637.37	346.92	-2,565.62	-1,581.33	kg CO2 eq
Acidification	330.79	1,500.65	-572.83	1,258.61	H+ moles eq
Eutrophication	1.13	0.18	-.22	1.09	kg N eq
Carcinogens	0.55	1,194.06	-169.43	1,025.19	kg benzene eq
Non-Carcinogens	36.88	0.60	-194,438.8	-194,401.32	kg toluene eq
Respiratory Effects	0.78	0.03	-2.28	-1.47	kg PM2.5 eq

Total Impact of Aluminum Recycled

The total impacts for recycling 1 kg and 806.80 kg of aluminum that is recycled are represented in Table 3.38 and Table 3.39 respectively. This table includes transport, facility impact, and facility credit from Schnitzer, Conigliaro and overseas processing.

Table 3.38: Overall Impacts Per 1kg of Recycled Aluminum.

Impact Category	Transport	Facility Impact	Facility Credit	Total Impact	Unit
Global Warming	0.80	0.61	-3.18	-1.77	kg CO2 eq
Acidification	0.41	1.94	-0.71	1.64	H+ moles eq
Eutrophication	0.0014	0.000314	-0.00027	0.0014	kg N eq
Carcinogens	0.00068	2.27	-0.21	2.06	kg benzene eq
Non Carcinogens	5.46	0.0012	-241	-235.54	kg toluene eq
Respiratory effects	0.00097	0.000059	-0.0028	-0.0012	kg PM2.5 eq

Table 3.39: Overall Impacts for 806.80 kg Aluminum Recycled.

Impact Category	Transport	Facility Impact	Facility Credit	Total Impact	Unit
Global Warming	644.8	492.14	-2,565.62	-1,428.68	kg CO2 eq
Acidification	332.97	1565.19	-572.83	1,325.33	H+ moles eq
Eutrophication	1.1323	0.26	-0.22	1.17	kg N eq
Carcinogens	0.55	1831.43	-169.43	1,662.55	kg benzene eq
Non-Carcinogens	36.88	0.86	-194,438.80	-194,401.06	kg toluene eq
Respiratory effects	0.7822	0.04	-2.28	-1.46	kg PM2.5 eq

ALUMINUM DISPOSAL CONCLUSIONS

The impacts of throwing 1kg of aluminum in the trash vs. recycling are compared in Table 3.40 and the overall impacts of Wellesley College's aluminum waste being thrown in the trash vs. recycling are compared in Table 3.41.

Table 3.40: Comparison of Impacts per 1kg of Aluminum in the Trash vs. Recycling.

Impact Category	Impact per 1kg Thrown in Trash	Impact per 1kg Recycled	Unit
Global Warming	-2.67	-1.77	kg CO2 eq
Acidification	1.20	1.64	H+ moles eq
Eutrophication	-0.00004	0.0014	kg N eq
Carcinogens	4.04	2.06	kg benzene eq
Non-Carcinogens	5,309.03	-235.54	kg toluene eq
Respiratory Effects	-0.0037	-0.0012	kg PM2.5 eq

Table 3.41: Comparison of Total Impacts for Aluminum in the Trash vs. Recycling.

Impact Category	Impact for 661.68 kg Thrown in Trash	Impact for 806.8 kg Recycled	Unit
Global Warming	-1,767.21	-1,428.68	kg CO2 eq
Acidification	792.71	1,325.33	H+ moles eq
Eutrophication	0.05	1.17	kg N eq
Carcinogens	2,670.19	1,662.55	kg benzene eq
Non-Carcinogens	3,512,879.52	-194,401.06	kg toluene eq
Respiratory Effects	2.50	-1.46	kg PM2.5 eq

Critical Areas in the Life Cycle of Aluminum

The largest environmental effects of aluminum occur during the disposal process, especially with incineration. Incineration is not only problematic because of the high levels of non-carcinogens released during the process, but also because incineration of aluminum does not receive a facility credit. Incineration of aluminum does not produce any energy, and burning it does not contribute to removing harms from the energy generated as part of the Massachusetts grid.

Assessment of Wellesley College's Handling of Aluminum

The environmental harms of the aluminum recycling process are offset by the gains of not having to produce aluminum from scratch; this offset is why the some of the cumulative impacts are negative, an overall credit. The main reason incineration receives credit, as well as recycling, for global warming, eutrophication, and respiratory effects impacts is because the aluminum is sent to a recycling facility after it is incinerated. Aluminum placed in the recycling bin at Wellesley College is transported a significantly farther distance than aluminum that is throw in the trash, which is why the global warming, acidification, and respiratory effects impacts are slightly lower for incineration. However, aluminum placed in the recycling produces far less non-carcinogens and fewer carcinogens than aluminum sent to SEMASS. Overall, it is better to recycle aluminum because of the impact carcinogens and non-carcinogens have on human health.

STEEL CANS

Figure 3.9: Steel cans discarded in the trash and found in the February Waste Audit.

Steel Cans Background

Steel cans are used as storage containers because of the cans' tight seal. They preserve fruits, vegetables, sauces, soups, pet food, juices, coffee beans, alcoholic beverages, and many other food and drink products.[83] Although mostly known for their role in food storage, steel cans are also used to hold aerosols, paint, shoe polish and motor oils. Most cans are made of tin-plated steel—the can is entirely steel with a "micro-thin" coat of tin on the inside to prevent rusting.[84]

Uses of Steel Cans at Wellesley College

At Wellesley College, steel cans are primarily used for food storage. Wellesley students also purchase deodorant, disinfectants, hairsprays, and shaving cream stored in steel cans.[85] In addition, steel cans hold paint and spray paint, which are used intermittently around campus.

Activities and Behaviors Producing Steel Can Waste at Wellesley College

The primary behavior contributing to steel can waste at Wellesley College is food preparation. Wellesley Fresh primarily purchases food preserved in 102 oz. steel cans.[86] Steel cans protect food content;[87] therefore, steel cans provide Wellesley Fresh with food supplies that will stay fresh for long periods of time, which allows Wellesley Fresh to prepare foods that are not normally available year-round. Aerosols stored in steel cans are mainly personal hygiene products used by students living on campus. The college's maintenance staff also uses paint, primarily for paint touch-ups.

Amount of Steel Cans Produced at Wellesley College

The amount of steel can waste produced annually at Wellesley College is 14,480.98 kg, as indicated in Table 3.42.

Table 3.42: Estimated Annual Steel Can Waste at Wellesley College.

Material	Weight per unit (kg/unit)	#Units (cans) Produced Annually	Total kg produced annually
Food packaging cans	2.72	4,563	12,412.39
Aerosol deodorant	0.21	1,794	376.74
Hairspray	0.21	1,150	241.5
Shaving cream/gel	0.21	638	133.90
Miscellaneous	-	-	1,316.45
Total			**14,480.98**

The various uses of steel cans are shown as a percent of the total weight of steel cans produced annually in Figure 3.10.

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[83] Recycle Steel Cans. *Recycle-steel.org*. The Steel Recycling Institute, n.d. Web. 26 Feb. 2012. <http://www.recycle-steel.org/en/Steel%20Markets/Cans.aspx>.
[84] Waste Management. *Think Green*. n.d. Web. 27 Feb. 2012. <http://www.thinkgreen.com/recycle-what-detail?sec=metals>.
[85] Facts About Aerosol Cans. *Earth911.com*, Earth911. 2012. Web. 1 Mar. 2012. <http://earth911.com/recycling/metal/aerosol-can/facts-about-aerosol-cans/>.
[86] *Wellesley Fresh Purchasing Log*. Rep. Wellesley Fresh, 2010.
[87] Recycling: Frequently Asked Questions. *Can Manufacturers Institute.* 2006. Web. 27 Feb. 2012, <http://www.cancentral.com/recFAQ.cfm>.

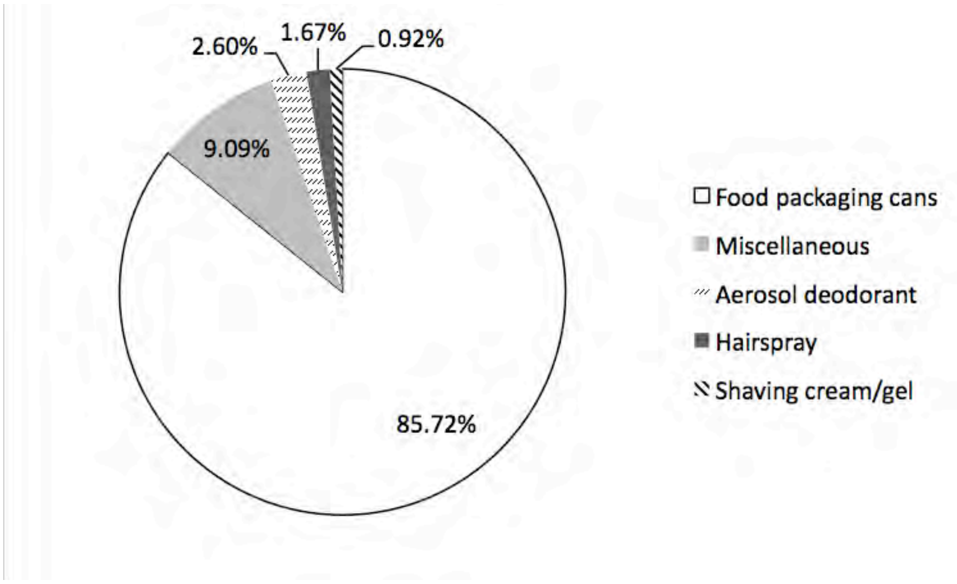

Figure 3.10: Percentage Breakdown of Steel Can Uses on Campus. The Majority of Steel Cans are used by Wellesley Fresh for Food Packaging, 85.72 Percent of the Total.

The amount of food packaging cans produced annually was estimated using Wellesley Fresh's 2010 food purchasing log. In 2010, 1,138 steel food can purchasing orders were completed.[88] The number of 102oz steel cans, 2.72 kg each, ordered was determined for the first 100 orders. If the steel cans were less than 102oz, the smaller cans were added together until the size equaled one 102oz can. The total number of food steel can waste was estimated by multiplying the number of steel cans produced in the first 100 orders to the 1,138 total orders. Overall, 12,412.39 kg of steel food can waste is produced annually by Wellesley Fresh at Wellesley College.

Aerosol deodorant, hairspray, and shaving cream/gel waste was estimated using a similar method, based on student use estimates. In Australia, 39 percent of women use aerosol deodorants (with the rest using other forms of deodorant).[89] Applying the same use percentage to Wellesley students, 1,794 aerosol deodorant cans are produced as waste each year, assuming students use two cans per year. We estimated that 50 percent of Wellesley students own a bottle of hairspray, producing 1,150 hairspray cans as waste annually. Shaving cream/gel can waste was estimated by surveying 101 toiletry kits in New Dorm Complex bathrooms. Seven out of 101 toiletry kits possessed shaving cream/gel. Extrapolating to the entire student body, 638 cans of shaving cream/gel waste are produced annually, assuming students use four cans of shaving cream/gel per year. The can weight for the three personal care products was estimated as .21 kg, weight of an 8oz steel can. Thus, 393.12 kg of aerosol deodorant can waste, 255 kg of hairspray can waste, and 139.73 kg of shaving cream/gel waste is produced annually.

[88] *Wellesley Fresh Purchasing Log*. Rep. Wellesley Fresh, 2010.
[89] Morgan, R. Rexona Deodorant the Choice for Men and Women but Lynx Is Catching up. 16 Mar. 2011. Web. 12 Mar. 2012, <http://www.roymorganonlinestore.com/News/1294---Rexona-deodorant-the-choice-for-men-and-wom.aspx->.

Handling of Steel Can Waste at Wellesley College

The distribution of how steel cans are handled when disposed of at Wellesley College is shown in Table 3.43

Table 3.43 Estimated Handling of Steel Can Waste at Wellesley College.

Material	% Recycled	% Thrown in trash
Food packaging cans	72%	28%
Aerosol deodorant	20%	80%
Hairspray	20%	80%
Shaving cream/gel	20%	80%
TOTAL	**33%**	**67%**

The percent of food packaging cans annually recycled was determined by subtracting the total number of food cans ordered by Wellesley Fresh by the number of steel food cans thrown in the trash. The number of steel cans found in the trash was based on the weight of steel cans sorted during the waste audit, a total of 52.03 kg. The number of steel cans thrown in the trash annually was determined by multiplying 19.13 cans, 52.03 kg, divided by the weight of one steel can, by the number of weeks each of the five dining halls were opened annually. In total, the number of steel cans thrown in the trash annually is 3,443 cans, 28 percent of annual steel can purchases. The estimated recycling rate for aerosol deodorant, hairspray, and shaving cream/gel cans was the same, 20 percent. We estimated a low recycling rate of steel cans for personal care products because steel cans were not found in the recycling audit conducted in the New Dorm Complex. Additionally, most students are probably unaware that steel can recycling exists in the residence halls.

Destination of Steel Can Waste

The weight of steel can waste sent to recycling and MSW handling facilities is estimated in Table 3.44.

Table 3.44: Destination of Steel Can waste by Weight.

	Conigliaro Industries	SEMASS
% of Waste	33%	67%
Weight of Waste (kg)	4,778.72	9,702.26

We calculated that 33 percent, or 4,778.72 kg, of the total steel can waste from Wellesley College is transported to the Conigliaro Industries facility in Framingham, MA annually to be recycled, The remaining 67 percent, or 9,702.26 kg, of total steel can waste is disposed of in the trash, and is sent to SEMASS for incineration.

Abridged Life Cycle of Steel Cans Produced at Wellesley College

At Wellesley College, steel cans are primarily used for food preservation and packaging of foods purchased by Wellesley Fresh. An abridged lifecycle diagram for steel cans used for food packaging from production to disposal is displayed in Figure 3.45.

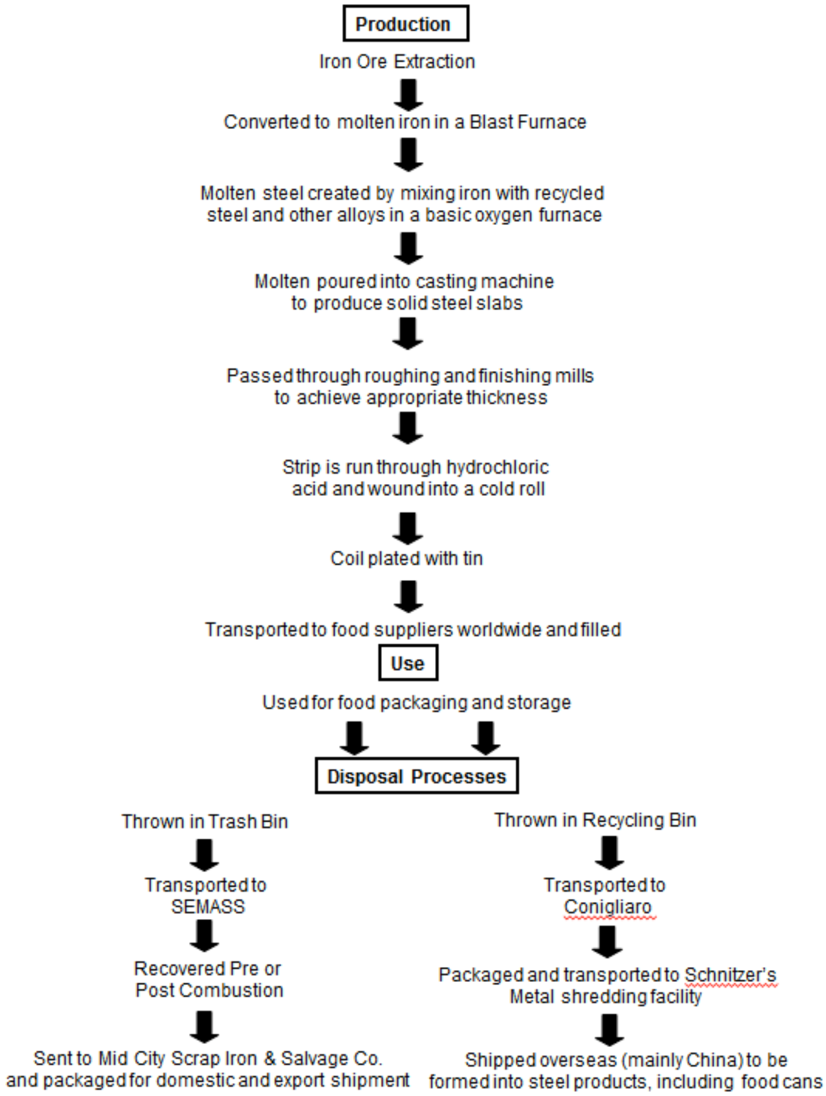

Figure 3.11: Abridged Life Cycle for Steel Cans.

Steel Cans Source Background

Steel cans are made from iron, which is extracted as iron ore.[90] Iron ore is mined by drilling and then blasting iron ore reserves. The iron ore is then transported to a crusher and a grinder where the ore is made into powder.[91] After removing the impurities, the iron ore is shaped into an ingot, a bar or block cast for easy handling, and shipped to steel making facilities.[92] The extraction of iron ore results in intensive land use and disruption from drilling

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[90] Spoerl, J. A Brief History of Iron and Steel Manufacture. *Saint Anselm College*. n.d. Web. 30 Mar. 2012, <http://www.anselm.edu/homepage/dbanach/h-carnegie-steel.htm>.
[91] Bolen, K. Lesson 1: How Do We Mine Iron Ore? *Great Lakes Maritime Transportation Summer Teacher Institute*. 2006. Web. 30 Mar. 2012, <http://wupcenter.mtu.edu/education/great_lakes_maritime/>.
[92] Bolen, K. Lesson 1: How Do We Mine Iron Ore? *Great Lakes Maritime Transportation Summer Teacher Institute*. 2006. Web. 30 Mar. 2012, <http://wupcenter.mtu.edu/education/great_lakes_maritime/>.

and blasting, top soil removal, contamination of local water supplies, air pollution, and depletion of ground water.[93]

Molten iron is created from iron ore using a blast furnace.[94] Blast furnaces use heat to remove oxygen from the iron ore and limestone to remove impurities, carbon, sulfur, phosphorus, and silicon. Coke, derived from coal, is the main source of energy for blast furnaces. The environmental impacts of coal extraction are numerous and include: a large carbon footprint; air pollution from the release of particulate matter and carcinogens; severe land degradation, particularly with surface mining techniques; and surface and groundwater pollution by increasing the acidity, the amount of total dissolved solids, and the concentration of toxic metals in the water supply.[95]

Manufacturing of Steel Cans

We assumed that the ArcelorMittal Dofasco steel company in Hamilton, Ontario manufactures the steel used to package food sources purchased domestically by Wellesley Fresh; this assumption was made because ArcelorMittal, the parent company, is the largest producer of steel in the world and Dofasco is the largest producer of steel used for food packaging in North America.[96] Therefore, we analyzed ArcelorMittal Dofasco's steel making process. Dofasco receives the majority of its iron ore, which is transformed into molten iron on site, from the Quebec Cartier Mining Company and the Scully Iron Ore Mine in Wabush, Newfoundland and Labrador.[97]

In Dofasco's steelmaking facilities, the molten iron is mixed with recycled steel in a basic oxygen steel-making furnace (BOF).[98] Thirty percent of the input into the BOF is recycled steel.[99] The molten steel is refined and poured into a casting machine to make solid steel slabs.[100] The steel slabs are passed through a roughing and finishing mill to achieve the appropriate thickness.[101] The cold rolled steel is then plated with tin and wound into a coil.[102] The coils are

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[93] Shastri, VM. Environmental Impacts of Iron Ore Mining. Lecture. *The Associated Chambers of Commerce and Industry of India.* Assocham India. n.d. Web. 28 Mar. 2012. <http://www.assocham.org/>.
[94] Dofasco. How Steel Is Made. *ArcelorMittal*. n.d. Web. 28 Mar. 2012, <http://www.dofasco.ca/how_steel_is_made/html/index.html>.
[95] Keating, M. Cradle to Grave: The Environmental Impacts From Coal. Rep. Boston: *Clean Air Task Force,* 2001.
[96] Keating, M. Cradle to Grave: The Environmental Impacts From Coal. Rep. Boston: *Clean Air Task Force,* 2001.
[97] "Dofasco Inc." *Company Histories and Profiles*. Funding Universe. Web. 30 Mar. 2012, <http://www.fundinguniverse.com/company-histories/Dofasco-Inc-company-History.html>.
[98] Dofasco. How Steel Is Made. *ArcelorMittal*. n.d. Web. 28 Mar. 2012, <http://www.dofasco.ca/how_steel_is_made/html/index.html>.
[99] Dofasco. How Steel Is Made. *ArcelorMittal*. n.d. Web. 28 Mar. 2012, <http://www.dofasco.ca/how_steel_is_made/html/index.html>.
[100] Dofasco. How Steel Is Made. *ArcelorMittal*. n.d. Web. 28 Mar. 2012, <http://www.dofasco.ca/how_steel_is_made/html/index.html>.
[101] Dofasco. How Steel Is Made. *ArcelorMittal*. n.d. Web. 28 Mar. 2012, <http://www.dofasco.ca/how_steel_is_made/html/index.html>.
[102] Dofasco. How Steel Is Made. *ArcelorMittal*. n.d. Web. 28 Mar. 2012, <http://www.dofasco.ca/how_steel_is_made/html/index.html>.

sold to seven companies across the United States that form the steel into food packaging cans.[103] The companies then sell the tinplated steel cans to food suppliers. Steel making is an energy intensive process; together the iron and steel making industry contribute to more than three percent of anthropogenic greenhouse gas emissions, the largest carbon footprint of any industrial sector.[104] Additionally, steel manufacturing generates toxic effluents, including chromium, cadmium, zinc, fluoride, oil, and grease, which are released into wastewater.[105]

Manufacturing and Use Impact Assessment for Steel Cans

The ecological impact of the manufacture of a steel can for food packaging, per 1 kg of material, is summarized by impact category in Table 3.46. The major contributors to each impact category score are outlined in Table B.3 found in Appendix B.

Table 3.45: Total Impact Values for Steel Cans Material Extraction and Manufacture Per 1 kg and for the Total 14,480.98 kg of Steel Cans Produced at Wellesley College Annually.

Impact category	Total impact per 1kg	Total impact for 14,480.98 kg	Unit
Global warming	0.95	13,756.93	kg CO2 eq
Acidification	0.11	1,592.91	H+ moles eq
Eutrophication	0	0	kg N eq
Carcinogens	5.27E-03	82.83	kg benzene eq
Non-Carcinogens	8.04	116,427.08	kg toluene eq
Respiratory effects	3.13E-04	4.53	kg PM2.5 eq

The additional ecosystem impacts of steel can manufacturing are quantified in Table 3.47.

Table 3.46: Additional Ecosystem Impacts for the Manufacture of Steel Cans.

Erosion	Permanent Land Disruption	Water Use	Resource Use	Biodiversity Disruption	Total Score
.5	1	1	.5	1	**4**

The majority of ecosystem impacts associated with steel can manufacturing are consequences of the extraction process: iron ore and coal mining.[106] Iron ore mining requires millions of liters of water per day, primarily for dust suppression; therefore, steel manufacturing

[103] Aluminum Can Makers. *Can Manufacturers Institute*. 2006. Web. 30 Mar. 2012. <http://www.cancentral.com/members.cfm>.
[104] Fachinger, B. Ten Sources of Greenhouse Gases. *Allianz*. n.d. Web. 31 Mar. 2012, <http://knowledge.allianz.com/climate/agenda/?651/greenhouse-gas-sources>.
[105] Iron and Steel Manufacturing: Pollution Prevention and Abatement Handbook. Report. *World Bank Group*, 1998
[106] Iron and Steel. Sector Programs. *Environmental Protection Agency*, 12 Jan. 2011. Web. 20 Mar. 2012, <http://www.epa.gov/sectors/sectorinfo/sectorprofiles/steel.html>.

earned a high water use score.[107] The drilling and blasting process results in permanent land disruption on mining sites, including removal of vegetation.[108] Aquatic life is similarly reduced around mine sites from the contamination of nearby watersheds; even terrestrial animals bordering mine sites are displaced because of noise pollution from blasting.[109] A high score was given for both permanent land and biodiversity disruption. Although iron ore mining reduces topsoil, steel manufacturing was given a medium impact score for erosion because most iron ore mines now reduce erosion by sloping the land appropriately.[110] A medium impact score was also given for resource use because iron ore is common, even though it is not a renewable resource.

Recycling Overview of Steel Cans

Steel recycling is a closed-loop system. Recycled steel is not down cycled and can be fashioned into new steel products, including food-packaging cans.[111] The recycling process begins with removing the tin from the steel can.[112] The de-tinned steel is placed into a BOF and the process of fashioning cold rolled steel is repeated.[113] Even if Wellesley Fresh employees throw steel cans into the trash, the SEMASS facility recovers 80 percent of the steel cans pre combustion and the steel is recycled.[114] The remaining 20 percent of steel cans is sent through the incinerator and recovered post-combustion. SEMASS sends ferrous metals, including steel cans, to the Mid City Scrap Iron & Salvage Company in Westport, MA.[115] The steel cans that are recycled on campus are packaged at Conigliaro Industries and sent to Schnitzer's Metal Shredding Facility in Worcester, MA.[116]

From both the Mid City Scrap Iron & Salvage Company and Schnitzer's Metal Shredding Facility, the metal is packaged and sent to domestic and international steel manufacturing facilities that produce new steel.[117] Recycling steel reduces the steel industry's carbon footprint; four times as much energy is used making steel from virgin iron ore compared to using recycled

[107] Linkages: Iron Ore Industry and Water. *Institute for Social Sustainability*. Murdoch University, 2007. Web. 25 Mar. 2012, <http://www.istp.murdoch.edu.au/ISTP/casestudies/Pilbara/economic/links/IronOre_Water.html>.

[108] Shastri, VM. Environmental Impacts of Iron Ore Mining. Lecture. *The Associated Chambers of Commerce and Industry of India*. Assocham India. n.d. Web. 28 Mar. 2012, <http://www.assocham.org/>.

[109] Shastri, VM. Environmental Impacts of Iron Ore Mining. Lecture. *The Associated Chambers of Commerce and Industry of India*. Assocham India. n.d. Web. 28 Mar. 2012, <http://www.assocham.org/>.

[110] Major Iron Ore Mines in the World. Iron Ore Articles. *Brazil Brand*. n.d. Web. 30 Mar. 2012, < http://www.brazilbrand.com/world_major_iron_ore_mines.htm>.

[111] How Is Steel Recycled? Find Recycling Centers and Learn How To Recycle. *Earth911.com*, 2012. Web. 28 Mar. 2012, <http://earth911.com/recycling/metal/steel/how-is-steel-recycled/>.

[112] How Is Steel Recycled? Find Recycling Centers and Learn How To Recycle. *Earth911.com*, 2012. Web. 28 Mar. 2012, <http://earth911.com/recycling/metal/steel/how-is-steel-recycled/>.

[113] How Is Steel Recycled? Find Recycling Centers and Learn How To Recycle. *Earth911.com*, 2012. Web. 28 Mar. 2012, <http://earth911.com/recycling/metal/steel/how-is-steel-recycled/>.

[114] Will Campbell. Environmental Scientist. Personal interview. 21 Mar. 2012.

[115] Recycling, Scrap Metal, Roll Off Containers, Steel, Copper, Aluminum, Stainless Steel, Cardboard, Newspaper, Plastics, Circuit Boards, E Waste, E Recycling,Scrap Dealers, Recycling Programs. What We Do. *Mid City Scrap Iron & Salvage Co., Inc*. n.d. Web. 29 Mar. 2012, <http://www.midcityscrap.com/what_we_do.html>.

[116] Garrison, Richard. General Manager Conigliaro Industries. Personal interview. 30 Mar. 2012.

[117] How Is Steel Recycled? Find Recycling Centers and Learn How To Recycle. *Earth911.com*, 2012. Web. 28 Mar. 2012, <http://earth911.com/recycling/metal/steel/how-is-steel-recycled/>.

steel.[118] Additionally, recycling steel reduces water pollution and contamination, air pollution, and land and biodiversity degradation by reducing reliance on iron ore mining.[119]

STEEL INCINERATION IMPACTS

Trace substances in Steel Cans

The kilograms of the six substances, dioxin, lead, copper, arsenic, nitrogen, carbon, sulfur, that determine the impacts of incinerating steel cans are described in Table B.15, found in Appendix B.

Transportation Impact: SEMASS & Mid-City Scrap Iron & Salvage Co Inc.

Annually, 9,702.26 kg of steel can waste is sent to SEMASS from Wellesley. The impacts of transporting steel cans in a combination diesel truck to SEMASS are shown in Table B.16, found in Appendix B.

From SEMASS, all steel cans, sorted pre or post-combustion, are sent to Mid-City Scrap Iron & Salvage Company in Westport, MA.[120] SEMASS is 20.9 miles away from the recycling facility. The impacts of transporting steel cans in a combination diesel truck from SEMASS to Westport, MA are shown in Table B.17 found in Appendix B.

Approximately 75 percent of steel from Mid-City Scrap Iron & Salvage Company is shipped overseas.[121] As many of these processing facilities are located in Asia, we assumed that steel cans are shipped to Shanghai, China. We calculated the distance by sea to be 17,080 km traveled by barge via the Panama Canal. We assumed that the 25 percent transported by rail is sent to either Ghent, Kentucky, or Hamilton, Ontario. Both Ghent and Hamilton are home to the two main Dofasco steelmaking facilities.[122] The impacts for overseas shipment of steel can waste are displayed in Table B.18 ,Appendix B.

The impacts of sending 12.5 percent of Wellesley's steel can waste to Ghent, Kentucky, 930 miles from Boston, and 12.5 percent of steel can waste to Hamilton, Ontario, 529 miles from Boston, are shown in Table B.19, Appendix B.

The impacts of transporting recycled steel cans from Wellesley to its final destinations overseas, Ghent, KY, or Hamilton, Ontario, are consolidated in Table B.20, found in Appendix B.

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[118] Steel Recycling. *Green Networld*. 11 Sept. 1999. Web. 02 Apr. 2012, <http://www.green-networld.com/tips/steel.htm>.

[119] Steel Recycling. *Green Networld*. 11 Sept. 1999. Web. 02 Apr. 2012, <http://www.green-networld.com/tips/steel.htm>.

[120] Recycling, Scrap Metal, Roll Off Containers, Steel, Copper, Aluminum, Stainless Steel, Cardboard, Newspaper, Plastics, Circuit Boards, E Waste, E Recycling,Scrap Dealers, Recycling Programs. What We Do. *Mid City Scrap Iron & Salvage Co., Inc*. n.d. Web. 29 Mar. 2012,

[121] By the Numbers Fiscal 2010. Steel Profile. *Schnitzer Steel Industries, Inc*. 2010. Web. 12 Apr. 2012. <http://www.schnitzersteel.com/metals_recycling_profile.aspx>.

[122] Dofasco's Third-qtr. Earnings Soar on Strong North American Market. (Steel).(Brief Article). *Business Information, News, and Reports*. HighBeam Business. Web. 11 Apr. 2012. <http://business.highbeam.com/436402/article-1G1-93371139/dofasco-thirdqtr-earnings-soar-strong-north-american>.

Facility Impacts for Steel Can Handling: SEMASS & Mid-City Scrap Iron & Salvage Co. Inc.

Although 9,702.26 kg of steel cans are sent to SEMASS annually, 80 percent are recovered and sent to the Mid-City Scrap Iron & Salvage Co., Inc. Therefore, the impacts of incinerating 20 percent of the steel cans sent to SEMASS, 1,940.45 kg, are shown in Table B.21, found in Appendix B.

Facility Impacts for Steel Can Recycling: Mid-City Scrap Iron & Salvage Co. Inc.

As noted previously, all steel cans sorted at SEMASS are transported to Mid-City Scrap Iron & Salvage Co. When determining recycling facility impacts, we assumed that Mid-City Scrap Iron & Salvage Co obtains energy from the Massachusetts energy grid. The recycling process for steel cans begins with scrap steel being placed on an in feed conveyer which passes through double feed rollers to crush the metal.[123] To calculate the impacts of running a double feed roller, we estimated that the double feed roller used the same amount of energy (kJ/kg) as a rock crusher machine. The impacts of operating a rock crusher were calculated using SimaPro7 using the TRACI2 method and are shown in Table B.22, found in Appendix B.

After the steel cans are crushed by the roller, the material is sent through a hammer mill, which cuts through scrap metal, shredding the steel.[124] A hammer mill uses 0.072 kJ/kg to operate.[125] The impacts of operating a hammer mill are described in Table B.23, found in Appendix B.

After shredding, the scrap steel in sent to a steel making facility where the process of producing steel sheets occurs. The sheet manufacturing process includes sending the recycled steel through a basic oxygen steel-making furnace, casting the molten steel into solid steel slabs, and passing the slab through a roughing and finishing mill.[126] The impacts of the manufacturing process are shown in Table B.24, found in Appendix B.

Facility Credit: SEMASS & Mid-City Scrap Iron & Salvage Co.

The energy content of steel is 12,000 KJ per one kilogram.[127] If 1,940.45 kg of steel are incinerated at SEMASS annually, 23,285,400 KJ of energy is released during the incineration process. The energy harnessed from steel's incineration is converted into electricity, some of which is used to run the facility while the rest is fed to the grid. The energy that enters the grid displaces the negative impacts of conventional energy production. SEMASS is able to exploit

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[123] Schnitzer Steel Industries, Inc. "Recycling Process." *Schnitzer Steel: Recycling Process*. 2012. Web. 10 Apr. 2012. <http://www.schnitzersteel.com/metals_recycling_process.aspx>.

[124] Schnitzer Steel Industries, Inc. "Recycling Process." *Schnitzer Steel: Recycling Process*. 2012. Web. 10 Apr. 2012. <http://www.schnitzersteel.com/metals_recycling_process.aspx>.

[125] Bitra, V., Womac, A.R., Chevanan, N., Miu, P.I., Igathinathane C. , Sokhansanj, S. and Smith, D. Direct Mechanical Energy Measures of Hammer Mill Comminution of Switchgrass, Wheat Straw, and Corn Stover and Analysis of Their Particle Size Distributions. *Powder Technology* 193.1 (2009): 32-45.

[126] Dofasco. How Steel Is Made. *ArcelorMittal.* n.d. Web. 28 Mar. 2012, <http://www.dofasco.ca/how_steel_is_made/html/index.html>.

[127] Harvey, L. and Danny, D. Energy and the New Reality 1: Energy Efficiency and the Demand for Energy Services. London: *Earthscan*, 2010.

76.7 percent of the energy produced by incinerating waste. Therefore, the avoided impacts were determined by multiplying SEMASS's percent efficiency by the impacts of producing electricity in Massachusetts, which is typically a mix of fuels, including coal, oil, nuclear, hydroelectric and other sources, using the TRACI2 method on SimaPro7. The avoided impacts are shown in Table B.26, found in Appendix B.

To calculate the recycling credit for steel cans recycled at Mid-City Scrap Iron & Salvage Co., the environmental costs of producing steel cans from virgin materials were subtracted from the impacts of disposing of steel cans. The environmental impact of extracting iron and producing steel from virgin materials is summarized in Table B.27, found in Appendix B. The overall credit for throwing steel cans in the trash is shown in Table B.28, found in Appendix B.

The overall impacts for 1 kg and 9,702.20 kg of steel can waste sent to SEMASS are presented in Table 3.48 and Table 3.49 respectively.

Table 3.47: Total Impacts for 1kg of Steel Cans Sent to SEMASS.

Impact Category	Transport Impact	Facility Impact	Facility Credit	Total Impact	Unit
Global Warming	0.92	1.77	-1.21	1.48	kg CO2 eq
Acidification	0.48	0.17	-0.22	0.43	H+ moles eq
Eutrophication	0.0016	0.000065	-0.000025	0.0016	kg N eq
Carcinogens	0.00085	2.74	-040055	0.98	kg benzene eq
Non-Carcinogens	6.67	27,230.81	-9.16	27,228.32	kg toluene eq
Respiratory Effects	0.0012	0.00035	-0.00077	0.00075	kg PM2.5 eq

Table 3.48: Total Impacts for 9,702.20 kg of Steel Cans Sent to SEMASS.

Impact Category	Transport Impact	Facility Impact	Facility Credit	Total Impact	Unit
Global Warming	184,135.17	10,322.34	-11,160.43	183,297.08	kg CO2 eq
Acidification	106,779.14	1,455.88	-1,912.72	106,322.30	H+ moles eq
Eutrophication	321.03	0.63	-0.19	321.47	kg N eq
Carcinogens	259.05	9,640.02	-52.12	9,846.95	kg benzene eq
Non-Carcinogens	1,754,959.99	52,889,932.93	-86,375.85	54,558,517.07	kg toluene eq
Respiratory Effects	299.76	2.72	-6.41	296.07	kg PM2.5 eq

STEEL RECYCLING IMPACTS

Transportation Impact: Schnitzer's Recycling Facility

All of the 4,778.72 kg steel cans placed in the recycling are transported to Conigliaro Industries. From Conigliaro, all metals are transported to Schnitzer's Metal Shredding facility in Worcester, MA.[128] The impacts of transporting steel cans in a single unit diesel truck from Wellesley, to Conigliaro, and finally to Schnitzer's Metal Shredding facility are shown in Table B.29, found in Appendix B.

Approximately 75 percent of steel from Schnitzer's Metal Shredding Facility is shipped overseas.[129] As many of these processing facilities are located in Asia, we assumed that steel cans are shipped to Shanghai, China. We calculated the distance by sea to be 17,080 km traveled by barge via the Panama Canal. We assumed that the 25 percent transported by rail is sent to either Ghent, Kentucky, or Hamilton, Ontario. Both Ghent and Hamilton are home to the two main Dofasco steelmaking facilities.[130] The impacts for overseas shipment of steel can waste are displayed in Table B.30, found in Appendix B. The impacts of sending 12.5 percent of Wellesley's steel can waste to Ghent, Kentucky, 930 miles from Boston, and 12.5 percent of

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[128] Garrison, Richard. General Manager Conigliaro Industries. Personal interview. 30 Mar. 2012.

[129] By the Numbers Fiscal 2010. Steel Profile. *Schnitzer Steel Industries, Inc*. 2010. Web. 12 Apr. 2012. <http://www.schnitzersteel.com/metals_recycling_profile.aspx>.

[130] Dofasco's Third-qtr. Earnings Soar on Strong North American Market. (Steel).(Brief Article). *Business Information, News, and Reports*. HighBeam Business. Web. 11 Apr. 2012. <http://business.highbeam.com/436402/article-1G1-93371139/dofasco-thirdqtr-earnings-soar-strong-north-american>.

steel can waste to Hamilton, Ontario, 529 miles from Boston, are shown in Table B.31, found in Appendix B.

The impacts of transporting recycled steel cans from Wellesley to its final destinations, overseas, Ghent, KY, or Hamilton, Ontario, are consolidated in Table B.32, found in Appendix B.

Facility Impacts for Steel Can Recycling: Schnitzer's Recycling Facility

When determining recycling facility impacts, we assumed that Mid-City Scrap Iron & Salvage Co or Schnitzer's Recycling Facility followed the same steel recycling process. To calculate the impacts of running a double feed roller, we estimated that the double feed roller used the same amount of energy (kJ/kg) as a rock crusher machine. The impacts of operating a rock crusher were calculated using SimaPro7 using the TRACI2 method and are shown in Table B.33, found in Appendix B.

After the steel cans are crushed by the roller, the material is sent through a hammer mill, which cuts through scrap metal, shredding the steel.[131] A hammer mill uses 0.072 kJ/kg to operate.[132] The impacts of operating a hammer mill are described in Table B.34, found in Appendix B.

After shredding, the scrap steel is sent to a steel making facility where the process of producing steel sheets occurs. The manufacturing process includes sending the recycled steel a basic oxygen steel-making furnace, casting the molten steel into solid steel slabs, and passing the slab through a roughing and finishing mill.[133] The impacts of the manufacturing process are shown in Table B.35, found in Appendix B. The Total Impacts of Steel Sent to Schnitzers is represent in the Table B.36 in Appendix B.

Facility Credit: Recycling

As mentioned previously, recycled steel is not down cycled and can be fashioned into new steel products.[134] To calculate the recycling credit for recycled steel cans, the environmental costs of producing steel cans from virgin materials were subtracted from the impacts of disposing of steel cans. The credit for not extracting iron and producing steel from virgin materials is summarized in Table B.37 in Appendix B.

The overall impacts for 1kg and 4,778.72 kg of steel can waste sent to SEMASS are presented in Table 3.50 and Table 3.51 respectively.

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[131] Schnitzer Steel Industries, Inc. "Recycling Process." *Schnitzer Steel: Recycling Process*. 2012. Web. 10 Apr. 2012. <http://www.schnitzersteel.com/metals_recycling_process.aspx>.

[132] Bitra, V., Womac, A.R., Chevanan, N., Miu, P.I., Igathinathane C. , Sokhansanj, S. and Smith, D. Direct Mechanical Energy Measures of Hammer Mill Comminution of Switchgrass, Wheat Straw, and Corn Stover and Analysis of Their Particle Size Distributions. *Powder Technology* 193.1 (2009): 32-45.

[133] Dofasco. How Steel Is Made. *ArcelorMittal*. n.d. Web. 28 Mar. 2012, <http://www.dofasco.ca/how_steel_is_made/html/index.html>.

[134] How Is Steel Recycled? Find Recycling Centers and Learn How To Recycle. *Earth911.com,* 2012. Web. 28 Mar. 2012, <http://earth911.com/recycling/metal/steel/how-is-steel-recycled/>.

Table 3.49: Total Impacts for 1 kg of Steel Can Waste Sent to Recycling.

Impact Category	Transport Impact	Facility Impact	Facility Credit	Total Impact	Unit
Global Warming	0.92	0.89	-0.95	0.86	kg CO2 eq
Acidification	0.48	0.15	-0.11	0.52	H+ moles eq
Eutrophication	1.60E-03	6.54E-05	0	1.66E-03	kg N eq
Carcinogens	8.43E-04	0.55	-5.27E-03	0.55	kg benzene eq
Non-Carcinogens	6.59	6.43	-8.04	4.98	kg toluene eq
Respiratory Effects	1.16E-03	2.62E-04	-3.13E-04	1.11E-03	kg PM2.5 eq

Table 3.50: Total Impacts for 4,778.78 kg of Steel Can Waste Sent to Recycling.

Impact Category	Transport Impact	Facility Impact	Facility Credit	Total Impact	Unit
Global Warming	90,684.23	4,244	-4,254.29	90,673.94	kg CO2 eq
Acidification	52,588.02	696.41	-492.6	52,791.83	H+ moles eq
Eutrophication	158.11	0.31	0	158.42	kg N eq
Carcinogens	127.57	2,656.62	-23.6	2,760.59	kg benzene eq
Non-Carcinogens	864,019.76	30,730.77	-36,004.73	858,745.80	kg toluene eq
Respiratory Effects	147.63	1.25	-1.4	147.48	kg PM2.5 eq

STEEL DISPOSAL CONCLUSIONS

The impacts of throwing 1kg of steel cans in the trash or the recycling are compared in Table 3.52 and the cumulative impacts of Wellesley College's steel can waste being thrown in the trash or placed in the recycling are compared in Table 3.53.

Table 3.51: Comparison of Impacts for 1kg of Steel Cans in the Trash vs. Recycling.

Impact Category	Impact per 1kg Thrown in Trash	Impact per 1kg Recycled	Unit
Global Warming	1.48	0.86	kg CO2 eq
Acidification	0.43	0.52	H+ moles eq
Eutrophication	1.64E-03	1.66E-03	kg N eq
Carcinogens	0.98	0.55	kg benzene eq
Non-Carcinogens	2,7228.32	4.98	kg toluene eq
Respiratory Effects	7.46E-04	1.11E-03	kg PM2.5 eq

Table 3.52: Comparison of Total Impacts for Placing Steel Cans in the Trash vs. Recycling.

Impact Category	Total Impact for 9,702.26 kg Thrown in Trash	Total Impact for 4,778.72 kg Recycled	Unit
Global Warming	183,297.08	90,673.94	kg CO2 eq
Acidification	106,322.30	52,791.83	H+ moles eq
Eutrophication	321.47	158.42	kg N eq
Carcinogens	9,846.95	2,760.59	kg benzene eq
Non-Carcinogens	54,558,517.07	858,745.80	kg toluene eq
Respiratory Effects	296.07	147.48	kg PM2.5 eq

Critical Areas in the Life Cycle of Steel

The ecosystem impacts for steel cans are spread across the entire lifecycle. Incineration is responsible for the majority of the carcinogens and non-carcinogens released during a steel can's lifecycle. Steel can transport for disposal or recycling results in acidification, eutrophication, and global warming impacts. The combustion of fossil fuels during steel can transport releases sulfur and nitrous oxides, resulting in eutrophication and acidification.[135] The acidification and eutrophication impacts per kilogram of steel are similar between steel thrown in the trash and steel that is recycled because in both circumstances steel cans are transported long distances. The global warming impacts during the extraction, manufacturing, and incineration processes equal the impacts during transport. As noted previously, the extraction and manufacturing of steel cans has the highest carbon footprint of any process in the industrial sector.

Assessment of Wellesley College's Handling of Steel

Overall, the impacts of throwing steel in the trash are greater than placing steel in the recycling. The global warming, carcinogen, and non-carcinogen impacts are all higher when steel is thrown in the trash. Incineration releases carcinogens and a large number of non-carcinogens because steel cans contain lead, which is released when burned.[136] Additionally, dioxins are produced when steel cans are incinerated, increasing the non-carcinogen impact.[137] It is important to note that steel cans sent to SEMASS are recycled post-combustion. Therefore, throwing steel cans in the trash just adds another step in steel can's lifecycle that releases carcinogens and non-carcinogens, compromising human health.

PRIMARY MATERIALS CONCLUSIONS

The impact of recycling all three primary materials is less than throwing the materials in the trash at Wellesley College. For all three materials, recycling is environmentally beneficial because it reduces or even eliminates the impacts of the materials' extraction and manufacturing processes. Although some of the impacts are lower when the materials are thrown in the trash, recycling is the preferred option overall.

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[135] Acids & Alkalis in Freshwater. Effects of Acids and Alkalis on Aquatic Life. *Lenntech.* Web. 20 Apr. 2012. <http://www.lenntech.com/aquatic/acids-alkalis.htm>.

[136] Sources of Lead. *New York State Department of Health*. n.d. Web. 26 Apr. 2012. <http://www.health.ny.gov/environmental/lead/sources.htm>.

[137] Sørum, L. Dioxin Emissions to Air from MSW Combustion – Data from Some IEA Member Countries. Rep. no. TR A5946. Norway: *SINTEF Energy Research*, 2004.

2.4 Paper

At Wellesley College, paper-based materials are mainly used for writing, printing, and packaging. Paper makes up 25% of Wellesley College's waste stream. Paper is made from a variety of natural resources and in this chapter we attempt to understand paper's environmental impacts throughout its manufacturing, use, and disposal processes.

OFFICE PAPER

Office Paper Background

Office paper is primarily made of wood pulp, although other cellulosic fibers can be used.[1] In some cases glue, plastic, and metal components are included to keep the wood pulp together. Office paper is the highest consumed type of paper-based material at Wellesley College, followed by boxboard, cardboard, and mixed paper.

Office paper made from virgin forest sources is created from de-inked or chemical pulp, which can come from wood, rags, sugarcane, and other organic materials. This type of paper is bleached, and then also may be colored. If it is recycled paper, it is made from dissolved fibers mixed with some virgin pulp to maintain the quality of the paper.[2] This material (whether from virgin or recycled pulp) comes in many forms, and is typically classified by its weight, brightness, and smoothness. The office paper Wellesley purchases is made up of least 30% recycled content.[3]

Uses of Office Paper at Wellesley College

There are a variety of uses for office paper on-campus. The majority of office paper is used as computer paper (laser-jet, inkjet, copy, fax), although some may be reused as scrap paper or for miscellaneous uses, like decorations.

Activities and Behaviors Producing Office Paper Waste at Wellesley College

The majority of office paper on campus is used for academic purposes. This includes the paper used for class readings, syllabi, notebooks, pads, folders, sticky notes and any other printed academic material. Besides students and academic departments, administrative departments also use office paper to share memos, agendas, and other printed materials.

A large amount of office paper is used to share information across the Wellesley College campus, in the form of the course catalogue, the Tanner and Ruhlman schedules, the Arts at Wellesley schedule, and other pamphlets and publications. Finally, aside from strictly academic uses or activities related to the College, students organizations also use office paper to share information with the Wellesley College community through paper 'Spam' and student publications.

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[1] Taylor, J.H. Method of manufacturing paper or cardboard products. Patent 4,210,490. 19 December 1978.

[2] Paper recycling information sheet. *Waste Online*, Jan. 2006. Web. 27 Feb. 2012, <http://dl.dropbox.com/u/21130258/resources/InformationSheets/paper.htm>.

[3] Doing Business with Wellesley College. *Purchasing Department Wellesley College.* Wellesley College, n.d. Web. 24 Apr. 2012, <http://www.wellesley.edu/Purchasing/supplier.html>.

Amount of Office Paper Produced at Wellesley College

The amount of office paper waste produced annually at Wellesley College is estimated at 71,970.45 kg, as illustrated in Table 4.1.

Table 4.1: Estimated Annual Office Paper Waste at Wellesley College.

Location	Weight per unit (kg/unit)	# Units per kg (packages)	# Units Produced Annually (packages)	Total kg Discarded Annually
Academic/Administration	22.68	.09	1,807.7	40,998.53
Library	22.68	.09	1,365.6	30,971.81
Total				**71,970.45**

The percentage of annual office paper waste by usage is represented in Figure 4.1.

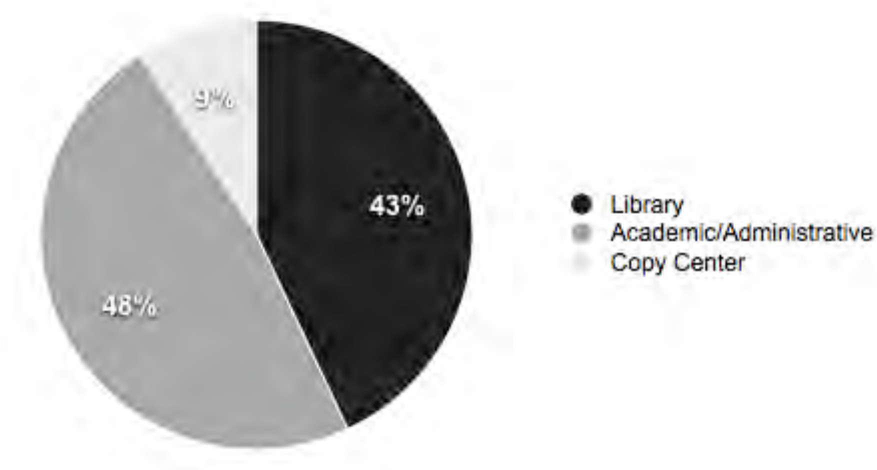

Figure 4.1: Office Paper Waste at Wellesley College by Usage Category.

To estimate the office paper consumption of academic and administrative departments, we used the Conigliaro Industries recycling records of office paper collected over the course of three weeks in late August.[4] We assumed this number was representative of average weekly collection of office paper from academic and administrative departments. According to Conigliaro records, academic and administrative departments recycle 451.78 kg of office paper per week. We assumed that these departments are closed during parts of the summer, the end of December and for a variety of other holidays and breaks (approximately a month's time), resulting in 48 weeks of active waste disposal. During the summer months some administrative functions are curtailed, so by using an average figure we are accounting for instances of

[4] Wellesley College Recycling 2011. *Conigliaro Industries.* 2012. XLS file.

increased office paper use, such as the Tanner Conference, Ruhlman Conference, and Student Orientation.

We calculated that in total, administrative and academic departments recycle 21,685.44 kg of office paper each year. Based on the EPA estimates that the recycling rate for paper is 63%,[5] we determined the total amount of office paper disposed of in the trash annually is 12,735.89 kg. This resulted in a total office paper waste disposal rate of 34,421.33 kg per year from academic and administrative departments at Wellesley College.

The Copy Center is another location on campus that produces large amounts of office paper for administrative and academic departments, as well as student organizations. The Copy Center estimates that they use 1,450,000 sheets of paper a year,[6] approximately 290 packages. Each package of paper the college purchases contains 500 pages, which weighs 0.09 kg. This results in a total of 6,577.20 kg of office paper disposed of from the copy center annually.

Another source of office paper consumption is the library. To estimate the amount of waste produced by libraries on-campus, we consulted the library archives of printed pages for 2011.[7] Using the library's database of total printed pages, we found the total amount of office paper waste generated by all the printing locations at Wellesley (Clapp, Pendleton Hall, Science Center, etc). Since office paper comes in 500-page packages, approximately 1,365.6 packages are purchased annually for the libraries. This creates 30,971.81 kg of disposed office paper each year.

Handling of Office Paper Waste at Wellesley College

Office paper is one of the most recognizable recyclables; therefore, we felt we could rely on the national office paper recycling rate of 63%.[8] However, recycling on-campus is restricted by the inadequate number of recycling containers relative to trash reciprocals at Wellesley College. Due to the difference in amount of recycling bins to and trash bins on campus, it is sometimes easier to dispose of paper rather than recycling it. We assume that a 63% recycling rate is within the median of varying location-specific recycling rates. The distribution of how office paper is handled when disposed of on campus is displayed in Table 4.2.

Table 4.2: Estimated Handling of Office Paper Waste at Wellesley College.

Material	% Recycled	% Thrown in Trash
Residence Hall	63%	37%
Academic/Administration	63%	37%
Library	63%	37%
TOTAL	**63%**	**37%**

[5] Frequent Questions | Paper Recycling. *Environmental Protection Agency*. 29 Nov. 2011. Web. 2 Apr. 2012, <http://www.epa.gov/osw/conserve/materials/paper/faqs.htm#recycle>.
[6] Mutascio, Vicki. Manager of the Wellesley College Copy Center. Personal Interview. 2 Apr. 2012.
[7] Sheriff, Laura. Manager of Public Services. 2011 Archived Printer Page Counts.
[8] Frequent Questions | Paper Recycling. *Environmental Protection Agency*. 29 Nov. 2011. Web. 2 Apr. 2012, <http://www.epa.gov/osw/conserve/materials/paper/faqs.htm>.

Destination of Office Paper Waste

The majority of office paper waste generated on campus is sent to recycling facilities. The portions of office paper waste sent to recycling and MSW handling facilities are estimated in Table 4.3.

Table 4.3: Destination of Office Paper Waste by Percentage.

	Recycling Facilities	**Waste to Energy Facilities**
% of Waste	63%	37%
Weight of Waste (kg)	45,341.38	26,629.07

Office paper handled as recycling on campus is sent to the Conigliaro Industries recycling facility in Framingham, MA. We estimate that 63% of office paper waste from Wellesley College, or about 45,341.38 kg, is sent to Conigliaro annually.

Office paper disposed of as trash is sent to the SEMASS facility in West Wareham, MA, where it is incinerated. We estimate that 37% of office paper, or 26,629.07 kg, is sent to SEMASS annually from Wellesley College.

MIXED PAPER

Mixed Paper Background

Mixed paper is any recovered paper not sorted into categories. It is an all-encompassing term that includes any material that is completely made out of paper. The mixed paper category excludes adhesive envelopes, wax-coated paper, and plastic-coated paper. Examples of mixed paper include: junk mail, magazines, catalogs, paper mail, non-adhesive envelopes, telephone books, coupons, and receipts.[9]

Uses of Mixed Paper at Wellesley College

The majority of mixed paper waste at Wellesley College comes from junk mail for students, which is typically comprised of credit-card propaganda, catalogues, and magazines.[10] Faculty junk mail is similar to students' junk mail because both are usually subscribed to mailing lists from which they receive catalogues, newsletters, and special offers on a regular basis.

Activities and Behaviors Producing Mixed Paper Waste at Wellesley College

Mixed paper waste on campus is typically created due to advertising efforts made through mail. Advertising efforts on and off campus ultimately result in excess mixed paper and junk mail waste.

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[9] The Internet Consumer Recycling Guide: Commonly Recycled Materials. *Evergreen Industries & Obviously Enterprises,* 2006. Web. 26 Feb. 2012, <http://www.obviously.com/recycle/guides/common>

[10] Caulfield, D. Wellesley College Mail Services Staff. Personal Interview. 2 April 2012.

Amount of Mixed Paper at Wellesley College

The amount of mixed paper waste produced annually at Wellesley College is 51,693.98 kg, as shown in Table 4.4. The composition of mixed paper waste on campus is displayed in Figure 4.2.

Table 4.4: The Amount of Mixed Paper Waste Produced at Wellesley College Annually.

Material	Weight per unit (kg/unit)	# Units per kg	# Units Produced Annually	Total Produced Annually (kg)
Residential Mixed Paper/Junk Mail	0.0045	222.22	5,982,313.51	26,920.68
Administrative/Academic/Other Mixed Paper and Junk Mail	0.0045	222.22	5,505,122.73	24,773.30
Total				**51,693.98**

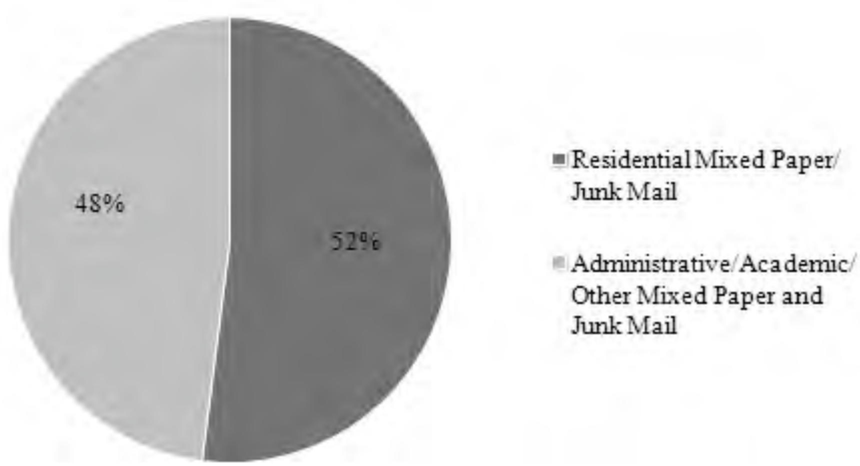

Figure 4.2: Composition of Mixed Paper Waste by Percentage.

To estimate the amount of mixed paper waste on campus, we began our calculations by consulting the Conigliaro recycling inventories.[11] The Conigliaro recycling logs illustrate the total amount of mixed paper recycled at Wellesley College in 2011. However, because "mixed paper" is a very broad term, for the purpose of this analysis we are labeling very specific materials as mixed paper. For this report, recycled mixed paper at Wellesley College includes the typical advertising posters, junk mail, newspaper and brown paper.

From the inventories, we extrapolated that on an annual basis, 32,567.21 kg of mixed paper is recycled at Wellesley College. After estimating the total amount of recycled mixed

[11] Wellesley College Recycling 2011. *Conigliaro Industries.* 2012. XLS file.

paper on campus, we divided that amount by a 63% recycling rate, resulting in the total amount of mixed paper disposed of on-campus. When we divide the total recycled mixed paper by 63%, we calculated that the total annual mixed paper waste at Wellesley College was 51,693.98 kg. Having the total amount of mixed paper and the total amount of recycled mixed paper allowed us to calculate how much mixed paper on campus was discarded in the trash, which was 19,126.77 kg.

To calculate the amount of residential mixed paper and administrative, academic, and miscellaneous mixed paper produced at Wellesley College, we used the results from our waste audit, along with the totals derived from Conigliaro's inventories. The waste audit results show that an average student disposes of 0.11 kg of mixed paper in the trash per week. To calculate how much residential mixed paper is disposed of as trash in one year, we multiplied by the number of students on campus and by the number of weeks per year the students are on campus. The total amount of residential mixed paper disposed of in one year was estimated to be 9,985.73 kg. To calculate the amount of mixed paper thrown in the trash by academic, administrative, and other miscellaneous facilities on campus we subtracted the amount produced residentially from the total mixed paper waste. The total amount of mixed paper waste produced by administrative, academic, and various other miscellaneous facilities on campus was estimated to be 9,141.04 kg annually. It is important to keep in mind what one kg of mixed paper translates into in terms of actual sheets of mixed paper used. As Table 4.3 indicates above, one sheet of paper weighs around 0.0045 kg, and there are 222.22 sheets of paper in 1 kg.

After calculating the amount of mixed paper thrown in the trash at the residential and administrative/academic/ miscellaneous level, we found the relative percentage of each type of mixed paper thrown in the trash. Residential mixed paper represented 52% and administrative/academic/ miscellaneous mixed paper represented 48% of mixed paper discarded in the trash. We then applied the same relative percentages to recycling. The amount of mixed paper recycled at the residential level was 16,934.96 kg and the amount recycled at the administrative/academic/ miscellaneous level was 15,632.26 kg. Our estimates concluded that total amount of residential mixed paper disposed of at Wellesley College annually is about 26,920.68 kg and the total amount of administrative/academic/ miscellaneous mixed paper waste is about 24,773.30 kg annually.

Estimates of mixed paper waste on campus include junk mail produced at the residential and administrative/academic/miscellaneous level. The categorical label of administrative/academic/miscellaneous is meant to be all encompassing, and includes mixed paper waste from administrative buildings such as Green Hall. It also takes into account academic building such as Jewett, Founders and Pendleton Hall, as well as miscellaneous places on campus like the College Club, Facilities, The Stone Center, and Health Services.

Handling of Mixed Paper at Wellesley College

The distribution of how mixed paper/ junk mail is handled when disposed of on campus is displayed in Table 4.5.

Table 4.5: Estimated Handling of Mixed Paper Waste at Wellesley College.

Material	% Recycled	% Thrown in Trash
Residential Mixed Paper	63%	37%
Administrative/Academic/Other Mixed Paper	63%	37%
TOTAL	**63%**	**37%**

Results from the waste audit and Conigliaro's recycling inventories demonstrate that Wellesley College is recycling more mixed paper than it disposes of in the trash. Our estimates show that 37% of residential mixed paper is disposed of in the trash instead of being recycled. Of the total mixed paper produced at Wellesley College, 63% of it is recycled.

Destination of Mixed Paper/ Junk Mail

The portions of mixed paper/ junk mail waste sent to recycling and MSW facilities are estimated in Table 4.6.

Table 4.6: Destination of Mixed Paper Waste by Percentage.

	Conigliaro/Casella/ Paper Mill	SEMASS
% of Waste	63%	37%
Weight of Waste	32,567.21	19,126.77

Mixed paper recycled at Wellesley College is sent to Conigliaro Industries. Of the mixed paper produced on campus, 63%, or 32,567.21 kg, is sent to Conigliaro Industries annually.

The remaining mixed paper produced at Wellesley College disposed of in the trash, is sent to, SEMASS, an incineration facility. The total mixed paper sent to SEMASS is 37% or 19,126.77 kg, of all the mixed paper produced at Wellesley College annually.

CORRUGATED CARDBOARD

Corrugated Cardboard Background

Corrugated cardboard consists of a corrugated medium between liners. The corrugated medium, or fluting, is a wavy sheet of paper adhered to the liner and is responsible for the durability and shock-absorbing features of corrugated cardboard. The liner is the flat sheet of paper that holds the corrugated medium in place.[12] Corrugated cardboard is most often used in packaging materials for transport or shipping. This includes delivery boxes, moving boxes, and pizza boxes.

[12] Corrugated Basics: What is Corrugated? *Corrugated.org*. Corrugated Packaging. n.d. Web. 1 March 2012, <http://www.corrugated.org/Basics/WhatIsCorrugated.aspx>.

Uses of Corrugated Cardboard at Wellesley College

At Wellesley College, students, administrative departments, and academic departments all use corrugated cardboard. Students primarily receive packages from mail services in corrugated cardboard, buy appliances packaged in corrugated cardboard, and receive food deliveries in corrugated cardboard boxes or paper bags with a cardboard support. Administrative departments and academic departments similarly receive office supplies, academic materials, and machinery (i.e. copiers and fax machines) in corrugated cardboard packaging. Dining services and student co-op cafés also create corrugated cardboard waste through the shipment of various bulk food and product orders.

Activities and Behaviors Producing Corrugated Cardboard Waste at Wellesley College

Corrugated cardboard is meant to protect the products within its container. Once used for its purpose, it is discarded. Printing on campus is a major activity that leads to a large portion of corrugated cardboard waste because the bulk supplies of paper and toner are packaged in corrugated cardboard containers.

Another activity that leads to corrugated cardboard waste on campus is the purchasing of food. During events, organizations and departments will order food packaged in corrugated cardboard, thereby creating corrugated cardboard waste at campus events on a regular basis. Similarly during heavy examination periods and when dining halls are closed, an increase in corrugated cardboard waste from students can be expected.

Mail packages also produce corrugated cardboard waste. During the beginning of each semester, many students order books online, which are transported in corrugated cardboard. Similarly, around holidays many students receive packages from loved ones.

Amount of Corrugated Cardboard Waste Produced at Wellesley College

The amount of corrugated cardboard waste produced annually at Wellesley College is estimated at 54,764 kg, as indicated below in Table 4.7. The uses of corrugated cardboard by percentage are displayed in Figure 4.3.

Table 4.7: Estimated Annual Corrugated Cardboard Thrown in the Trash at Wellesley College.

Material	Weight per unit (kg/unit)	# Units per kg	# Units Produced Annually	Total kg Produced Annually
Corrugated Cardboard Box (small)	0.10	10 small boxes	21,910	2,191
Corrugated Cardboard Box (medium)	0.30	3.3 medium boxes	43,371.90	13,143
Corrugated Cardboard Box (large)	0.50	2 large boxes	77,764	38,882
Pizza Box	0.20	5 pizza boxes	2,740	548
Total				**54,764**

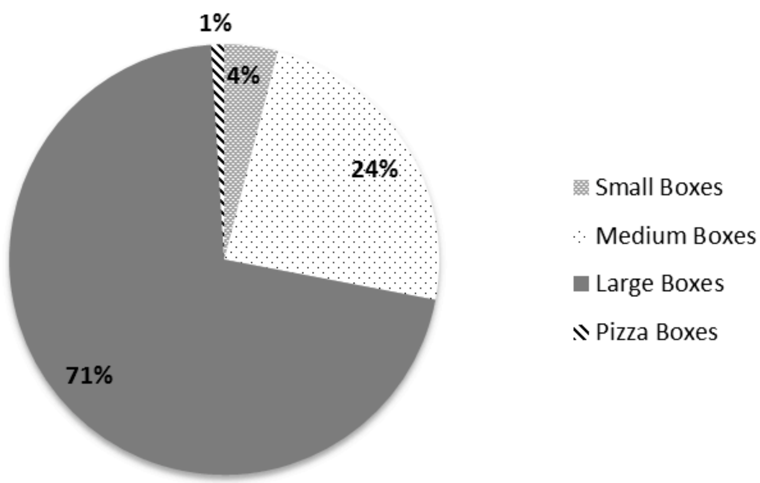

Figure 4.3: Composition of Corrugated Cardboard Waste by Percentage.

The main source of small-corrugated cardboard boxes on campus is mail packaging and individual packaging for food, clothing, and appliances. Most medium and large corrugated boxes come from bulk shipments for academic departments, administrative departments, dining services, and custodial services. All of these items were seen during our February waste audit of the New Dorms' dumpster.

In order to determine how much corrugated cardboard is disposed of in the municipal solid waste stream, we used data from Conigliaro Industries regarding the total amount of corrugated cardboard recycled by Wellesley College, along with our estimated recycling rate for cardboard. The total amount of corrugated cardboard recycled during 2011 was 32,858 kg,[13] and the estimated recycling rate of cardboard is 37.50%. If the amount recycled is 32,858 kg and the recycling rate is 37.50%, we calculated that 54,764 kg of corrugated cardboard waste is discarded in MSW annually, 62.5% of the total amount of cardboard disposed on campus.

The waste audit is representative of a mix of departmental and student waste. Therefore we assumed that the distribution of material categories found in our waste audit represents the average distribution for waste on campus. The data from our waste audit shows that 326.59 kg of cardboard waste was produced from the New Dorms in one week. We estimated that 75% originated from dining services, 20% from indeterminable sources, and 5% from individual packaging. Thus, 244.94 kg is equated to dining services, 65.32 kg to indeterminable sources, and 16.33 kg to individual packaging. We further estimated that 75% of dining services and miscellaneous packaging was in the form of large boxes and 25% medium boxes, equaling 232.7 kg of large boxes and 77.56 kg of medium boxes. In the individual packaging category, 75% was small boxes and 25% was pizza boxes, equaling 12.25 kg of small boxes and 4.08 kg of pizza boxes. The ratios amount to 71% large boxes, 24% medium boxes, 4% small boxes, and 1% pizza boxes, of the total amount calculated for corrugated cardboard discarded annually (Figure 4.3).

Handling of Corrugated Cardboard Waste at Wellesley College

The average recycling rate of corrugated cardboard waste at Wellesley College is 37.50% as shown in Table 4.8. Most small corrugated cardboard boxes are recycled while medium and large corrugated cardboard boxes are recycled significantly less often.

Table 4.8: Estimated Handling of Corrugated Cardboard at Wellesley College.

Material	% Recycled	% Thrown in Trash
Small Corrugated Cardboard Boxes	60%	40%
Medium Corrugated Cardboard Boxes	20%	80%
Large Corrugated Cardboard Boxes	20%	80%
Pizza Boxes	50%	50%
Total	**37.50%**	**62.50%**

Corrugated cardboard is an easily recyclable material. However, corrugated cardboard may not be recycled at Wellesley College due to contamination with food or inconvenience of recycling bin location. For this study, we assumed that 60% of individual small cardboard boxes are recycled, due to the awareness of the student body about recycling and the low number of small cardboard boxes found during our waste audit. Most of the corrugated boxes found during our waste audit were in the form of medium and large boxes from dining services and many were contaminated with food waste. We therefore estimated that 80% of medium and large corrugated cardboard boxes are discarded and 20% of these boxes are recycled. Our calculated recycling

[13] Wellesley College Recycling 2011. *Conigliaro Industries.* 2012. XLS file.

rate of corrugated cardboard is in accordance with the recycling rates of other American universities.[14]

Destination of Corrugated Cardboard Waste

The portions of corrugated cardboard waste sent to recycling and MSW handling facilities are estimated in Table 4.9.

Table 4.9: Destination of Corrugated Cardboard by Percentage.

	Conigliaro	SEMASS
% of Waste	37.50%	62.50%
Weight of Waste (kg)	32,858	54,764

Corrugated cardboard waste that is handled as recycling on campus is sent to the Conigliaro Industries recycling facility in Framingham, MA. Once at Conigliaro, shipments containing only cardboard are bailed separately. Shipments that are mixed with other paper types are bailed together with the mixed paper. Shipments that are too contaminated be separated out are bailed as single stream recycling. We estimate that 37.50% of corrugated cardboard waste from Wellesley College, or 32,858 kg, is sent to Conigliaro Industries annually. Corrugated cardboard waste disposed of in the trash is sent to SEMASS. We estimate that 62.50%, of total cardboard waste, equaling 54,764 kg, is sent to SEMASS annually from Wellesley College.

BOXBOARD AND PAPERBOARD

Boxboard/Paperboard Background

Boxboard, also known as paperboard, is a semi-thick, rigid, and resistant paper-based material used primarily for packaging. In order to make boxboard, paper pulp is compressed to create paper layers.[15] These layers make boxboard sturdier than regular printing paper. Boxboard differs depending on the paper grade used to produce it. It is often coated with polyethylene resin for wet strength food packaging, which is used to store liquid food products, such as milk and juices.[16] Boxboard is gray or tan on the inside, while displaying color and/or print on its outer layer.

Uses of Boxboard/Paperboard at Wellesley College

Boxboard is mainly used at Wellesley College to store packaged goods. Examples of storage containers commonly made out of boxboard include: cereal boxes, cookie boxes, cake mix boxes, tissue paper, beer cases, and shoeboxes.

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[14] Radford University Annual Recycling Report. *Radford University*. 2008. Web. 15 Apr. 2012, <http://www.radford.edu/fac-man/recycling/08-09RUAnnualRecyclingReport.pdf>.
[15] Gardner, S. Frequently Asked Questions about Recycling. *Bridging The Gap: Connecting Environment, Economy & Community*, 2012. Web. 25 Feb. 2012, <http://www.bridgingthegap.org/egap.php?id=250>
[16] Paperboard. *Boelter Industries*, Boelter Industries, Inc., n.d. Web. 8 May 2012, <http://www.boelterindustries.com/carton_basics/paperboard.php>.

Activities and Behaviors Producing Boxboard/Paperboard Waste at Wellesley College

At Wellesley College, most packaged goods consumed by students have boxboard packaging. Thus, the activity of shopping for goods and subsequently discarding their packaging, creates the majority of boxboard waste on campus. Snacking preferences, including foodstuffs contained in boxboard, influence the amount of boxboard waste generated.

Amount of Boxboard/ Paperboard at Wellesley College

The amount of Boxboard waste produced annually at Wellesley College is 56,001.81 kg, as estimated in Table 4.10. The uses of boxboard on campus are displayed in Figure 4.4.

Table 4.10: Amount of Boxboard Produced Annually at Wellesley College.

Material	Weight per unit (kg/unit)	# Units per kg	# Units Produced Annually	Total Produced Annually (kg)
Residential Boxboard	0.05	20 boxes	233,154.20 boxes	11,482.89
Administrative/Academic/Other Boxboard	0.05	20 boxes	886,882 boxes	44,518.92
Total				**56,001.81 kg**

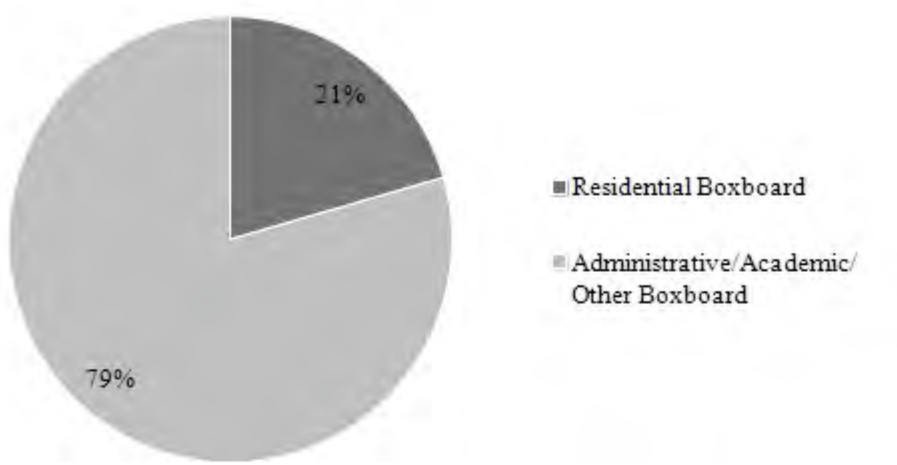

Figure 4.4: Composition of Boxboard Waste by Percentage.

To estimate the amount of boxboard waste on campus, we began our calculations with the Conigliaro Industries recycling inventories. From the Conigliaro recycling inventories we assumed that 52% of mixed paper waste was comprised of boxboard. According to the Paper and

Paperboard Packaging Environmental Council, the current rate of recovery for recycled boxboard is 52%.[17] From the recycling inventories, we extrapolated that on an annual basis the total amount of boxboard recycled at Wellesley College is 35,281.14 kg. After estimating the total amount of recycled boxboard on campus, we then divided it by 63%.[18] We calculated that the amount of total annual boxboard waste at Wellesley College is 56,001.81 kg. The difference between the recycled amount of boxboard and the total amount of boxboard waste on campus is 20,720.67 kg, representing the amount of boxboard disposed of in the trash annually.

To calculate the amount of residential boxboard and administrative/academic/miscellaneous boxboard produced at Wellesley College, we extrapolated from our waste audit data, as well as the totals derived from Conigliaro's recycling logs. The weight of a medium size box made out of boxboard is estimated to be 0.05 kg. Based on the waste audit, each student on average throws 0.05 kg of boxboard in the trash each week. To calculate how much residential boxboard is produced in one year at Wellesley College, we multiplied 0.05 kg by the number of students and by the number of weeks the students are on campus. The total amount of residential boxboard discarded in the trash annually is therefore 4,248.67 kg. By subtracting the total amount of residential boxboard disposed of on campus by the amount thrown in the trash, we determined 7,234.22 kg of residential boxboard is recycled.

The difference between the total amount of boxboard disposed of in the trash and the amount of residential boxboard discarded in the trash represents the remaining amount of boxboard disposed of in the trash by administrative/academic/ miscellaneous places at Wellesley College. We found that 13,486.45 kg of boxboard waste is discarded as trash by administrative/academic/miscellaneous entities on campus. By subtracting the total amount of boxboard waste produced by administrative/academic/miscellaneous entities by 13,486.45 kg we determined that 31,032.47 kg of boxboard waste is recycled by administrative/academic/miscellaneous entities. Our estimates concluded that total amount of residential boxboard disposed of at Wellesley College annually is about 11,482.89 kg and the total administrative/academic/miscellaneous boxboard disposed of is about 44,518.92 kg.

Handling of Boxboard/Paperboard waste at Wellesley College

The distribution of how boxboard is handled when disposed of on campus is displayed in Table 4.11.

Table 4.11: Estimated Handling of Boxboard Waste at Wellesley College.

Material	% Recycled	% Thrown in Trash
Residential Boxboard	63%	37%
Administrative/Academic/Other Boxboard	63%	37%
TOTAL	**63.0%**	**37.0%**

[17] Residential Recovery of Paper Packaging. *The Paper and Paperboard Packaging Environmental Council*, Feb. 2011. Web. 8 May 2012, <http://www.ppec-paper.com/pdfFiles/reports/2_ResidentialRecovery.pdf>.
[18] Frequent Questions | Paper Recycling. *Environmental Protection Agency*, 29 Nov. 2011. Web. 2 Apr. 2012. <http://www.epa.gov/osw/conserve/materials/paper/faqs.htm>.

Results from the waste and recycling audit show that more than half of boxboard waste on campus is being recycled. Our estimations, as shown in Table 4.11, demonstrate that both at the residential and administrative/academic/miscellaneous levels, 63% of boxboard is getting recycled and only 37% of all boxboard waste ends up in the trash.

Destination of Boxboard/ Paperboard

The portions of boxboard waste sent to recycling and MSW handling facilities are estimated in Table 4.12

Table 4.12: Destination of Boxboard Waste by Percentage.

	Conigliaro/ Casella/ Paper	**SEMASS**
% of Waste	63.0%	37.0%
Weight of Waste	35,281.14 kg	20,720.67 kg

Boxboard recycled on campus is sent to Conigliaro Industries. We estimate that 63%, or 35,281.14 kg, of boxboard waste from Wellesley College is sent to Conigliaro Industries annually. Boxboard products disposed of in the trash are incinerated at SEMASS. We estimate that 37% or 20,720.67 kg, of boxboard is sent to SEMASS annually.

BROWN PAPER

Brown Paper Background

The production of brown paper does not require the chemical removal of lignin or bleaching with chlorine, as the process for making white paper does.[19] Brown paper is generally purchased and used by businesses, whereas white paper, often due to its "sanitary appearance" is the preference for home paper goods.[20] Brown paper bags are commonly used for groceries and restaurant takeout. Brown paper is also used for napkins, paper towels, and packing material.

Uses of Brown Paper

On the Wellesley College Campus, the dining hall napkins, paper towels, and paper bags that students receive from dining services, grocery stores, food deliveries, and general shopping, are all made of brown paper. The custodial staff also uses rolls of brown paper towels in their cleaning regime.

Activities and Behaviors Producing Brown Paper Waste at Wellesley College

Brown paper ends up in the trash at Wellesley College through two main paths. The first results from the failure to recycle excess or old newspapers, or clean brown paper products. Although recycling bins are available on campus to dispose of these materials, some of these

[19] Wansbrough, H. The Pulp and Paper Industry. *The New Zealand Institute of Chemistry*. n.d. Web. 28 Feb. 2012, <http://nzic.org.nz/ChemProcesses/forestry/4C.pdf>

[20] Nassasuer, S. Trying on Shades of Brown to Scream Green. *Wall Street Journal*. 5 Jan. 2012. Web. 27 Feb. 2012, <http://online.wsj.com/article/SB10001424052970203718504577180852718515394.html>

clean paper products are still thrown into the general trash. The second way brown paper ends up in the trash occurs when people need to dispose of wet or soiled brown paper products. Paper products that are wet or are contaminated with food are not accepted for recycling.[21] Thus, the paper towels used for hand washing in some bathrooms on campus and the napkins used in the dining halls are thrown away.

Amount of Brown Paper Produced at Wellesley College

The amount of brown paper waste produced annually at Wellesley College is estimated in Table 4.13. The uses of brown paper by percentage is shown in Figure 4.5.

Table 4.13: Estimated Annual Brown Paper Waste at Wellesley College.

Material	**Weight per unit (kg/unit)**	**# Units per kg**	**# Units Produced Annually**	**Total kg Produced Annually**
Take-out bags	0.0048	208.33 bags	12,266	58.88
Packed-lunch bags	0.0045	222.22 bags	12,266	55.20
Paper Towel Roll	22.8	0.05 rolls	167.51	3,350.20
Napkins	0.005	200 napkins	5,152,000	25,760
Miscellaneous				2,922.43
Total				**32,146.71 kg**

[21] What to Recycle. *All-recycling-facts.com*. 2011. Web. 27 Feb. 2012, <http://www.all-recycling-facts.com/what-to-recycle.html>.

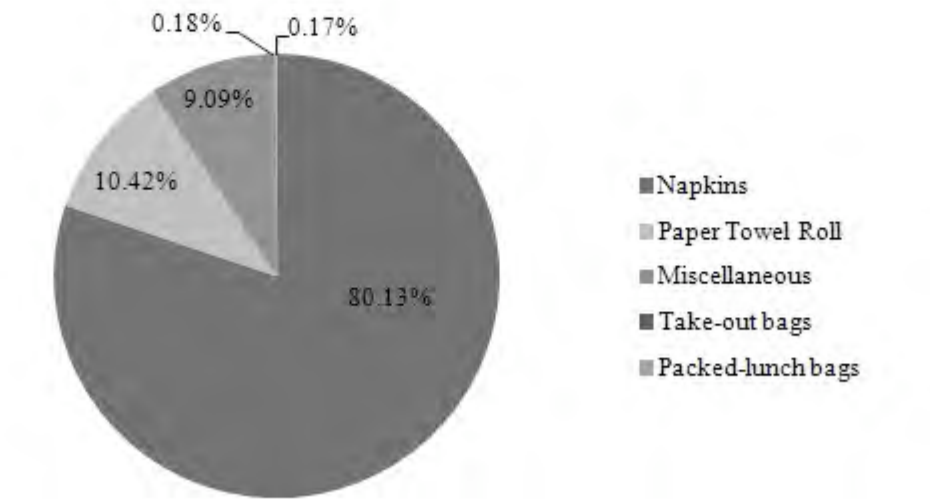

Figure 4.5: Composition of Brown Paper Waste by Percentage.

The amount of brown paper bag waste was estimated by assuming two-thirds of the student body orders take-out involving a brown paper bag once a month. The weight of a take-out bag is estimated to be 0.0048 kg. The total amount of brown paper bags associated with take-out is therefore about 58.88 kg discarded annually. Similarly, we estimated that two-thirds of the student body orders a packed lunch in a brown paper bag once per month. Since there are 222.22 bags in 1 kg, the total weight of brown paper bags disposed of annually is about 55.20 kg.

We estimated the amount of brown paper towel waste generated on campus by assuming that the entire Wellesley College community uses brown paper towels when washing their hands once a day. Additionally, we assumed that approximately 3,000 individuals would be washing their hands daily, which would take faculty, staff and guests into consideration. We assumed a person uses 2 feet of paper towel each time they wash their hands, resulting in the use of 1,471.50 rolls of 1.25' x 1100' annually, where the weight of a roll is 22.80 kg. The total amount of brown paper towel waste disposed of annually at Wellesley College is therefore 3,350.20 kg.

The amount of brown paper napkin waste was estimated by assuming that every student uses about 10 napkins per day. We estimated the weight of a napkin to be 0.005 kg. The total weight of napkins disposed of annually by students is therefore about 25,760 kg. While our calculations tried to account for all significant brown paper uses on campus the miscellaneous category incorporates an additional 10% error to ensure that any uses missed are accounted for in our calculations.

Handling of Brown Paper Waste at Wellesley College

The distribution of how brown paper waste is handled when disposed of at Wellesley College is displayed in Table 4.14.

Table 4.14: Estimated Handling of Brown Paper Waste at Wellesley College.

Material	% Recycled	% Thrown in Trash
Take-out bags	5%	95%
Packed-lunch bags	5%	95%
Paper Towel Roll	0%	100%
Napkins	0%	100%
TOTAL	**2.5%**	**97.5%**

We calculated that approximately 97.5% of brown paper was thrown into the trash. The remaining 2.5% is already accounted for in the top-down mixed paper calculation since the mixed paper sent to Conigliaro Industries from Wellesley College includes newspaper and brown paper. We assumed that, out of all the brown paper discarded on campus, brown paper bags are rarely recycled due to contamination by food. There is no brown paper recycling in bathroom facilities or dining halls on campus. Brown paper items used in dining halls or bathrooms cannot be recycled, due to contamination by food or unhygienic substances. We therefore estimate that 100% of paper towel and napkins waste are disposed of in the trash.

Destination of Brown Paper Waste

The portions of brown paper waste sent to recycling and MSW handling facilities are estimated in Table 4.15.

Table 4.15: Destination of Brown Paper by Percentage.

	Conigliaro	SEMASS
% of Waste	2.5%	97.5%
Weight of Waste	*	31,343.04 kg

*While we estimate that 2.5% of brown paper is recycled annually the amount of brown paper is already accounted for in the top-down calculations for recycled mixed paper.

Brown paper products that are handled as recycling on campus are sent to the Conigliaro Industries recycling facility, where they are processed and sent to Casella Waste and a variety of different paper mills. We estimate that 2.5% of brown paper waste from Wellesley College is recycled annually. Brown paper products disposed of in the trash are sent to SEMASS, where they are incinerated. We estimate that 97.5% of brown paper waste, or 31,343.04 kg, is sent to SEMASS annually.

NEWSPAPER

Newspaper Background

Newsprint is a low quality paper stock that is used in printing newspapers. Newsprint is one of the cheapest forms of paper stock made, so its use by media companies is widespread.

Uses of Newspaper and Behaviors Producing Newspaper Waste at Wellesley College

A student organization prints and distributes copies of the student newspaper, *The Wellesley News*, on a weekly basis.[22] Newspapers are circulated widely on campus and placed around residence hall bell desks. Students and staff generally dispose of the newspapers after they are used. Unclaimed copies are often disposed of by custodial staff. Additionally, spaces such as the Campus Center have copies of a few Boston newspapers (including *The Boston Phoenix* and *The Bay Windows*) delivered via subscription. Some faculty and staff members, as well as the Clapp library, receive subscriptions to newspapers from off-campus. Some of these faculty and staff members also bring newspapers to campus on their daily commutes and dispose of them on campus.

Amount of Newspaper Produced at Wellesley College

The amount of newspaper waste produced annually at Wellesley College is 4,457 kg as estimated in Table 4.16. The types of newspaper disposed of on campus is displayed in Figure 4.6.

Table 4.16: Estimated Annual Newspaper at Wellesley College.

Material	Weight per Unit (kg/unit)	# Units per kg	# Units Produced Annually	Total Produced Annually (kg)
Wellesley News	0.04	25	48,000	1,920
Newspaper Deliveries	0.10	10	2,600	260
Outside Newspapers from Faculty/Staff	0.10	10	18,720	1,872
Miscellaneous				405
TOTAL				**4,457**

[22] About Us. *The Wellesley News*. 2012. Web. 29 Feb. 2012, <http://www.wellesleynewsonline.com/about-us>

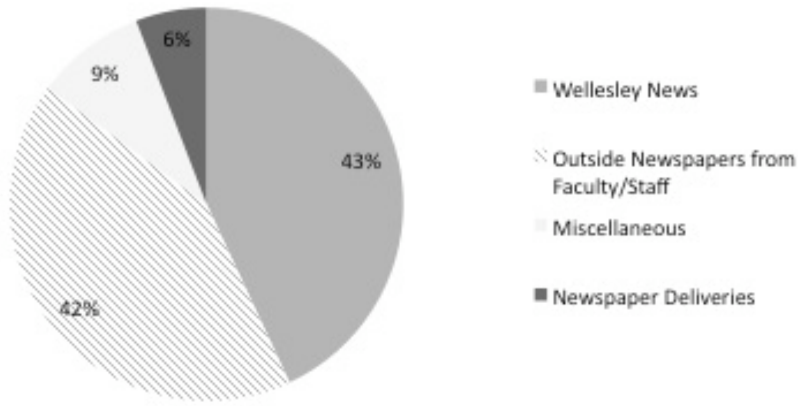

Figure 4.6: Newspaper Waste on Wellesley College by Usage Category.

The *Wellesley News* orders 2,000 copies from Turley Publications each week, and 24 issues a year, which amounts to 48,000 newspapers each year. The weight of an issue of the Wellesley News is 0.04 kg, so the total weight of *Wellesley News* newspapers disposed of annually is about 1,920 kg. The Lulu Chow Wang Campus Center also receives deliveries of the *Boston Phoenix* and *Bay Windows* newspapers on a weekly basis. Based on the average size of their delivery piles, we estimate that 50 newspapers are delivered each week of the year. This amounts to 2,600 newspapers each year. We estimated that larger newspapers weigh about 0.10 g because they have more content.

We believe that some portion of newspaper waste comes from faculty and staff who bring newspapers to campus during their commute. We estimated that 10% faculty and staff bring three newspapers with them to campus on a weekly basis. This percentage is likely low, as many faculty and staff members drive to campus, and newspapers are easily accessible online with the added benefit of carrying less weight. We then assumed that these 120 faculty/staff members brought newspapers with them 5 days a week, accounting for 18,720 newspapers annually. For this bottom-up calculation we added a 10% error to account for items not captured in our estimations.

Handling of Newspaper at Wellesley College

The distribution of how newspaper waste is handled when disposed of at Wellesley College is displayed in Table 4.17.

Table 4.17: Estimated Handling of Newspaper Waste at Wellesley College.

Material	% Recycled	% Thrown in Trash
Wellesley News	70%	30%
Newspaper Deliveries	95%	5%
Outside Newspapers	32%	65%
TOTAL	**65.7%**	**33.3%**

We calculated that approximately 33.3% of newspapers at Wellesley College are thrown into the trash. The remaining 65.7% is sent to recycling. We assumed that the *Wellesley News* and newspapers from deliveries have a high percentage of recyclability due to the awareness of students about recycling paper on campus. In addition to educational signs about recycling from the Office of Sustainability, these newspapers in residence halls and the campus center are placed in close proximity to recycling bins. We assumed that outside newspapers accounted for a lower percentage of recyclability because they do not originate from students, and faculty/staff may encounter trash bins more frequently than recycling bins.

Handling of Newspaper at Wellesley College

The portions of newspaper waste sent to recycling and MSW handling facilities are estimated in Table 4.18.

Table 4.18: Destination of Newspaper by Percentage.

	Conigliaro	SEMASS	Archives
% of Waste	65.7%	33.3%	1%
Weight of Waste	*	1,484 kg	44.57

*While we estimate that 65.7% of newspaper is recycled annually, the amount of newspaper sent to Conigliaro Industries is accounted for in the top-down calculations for recycled mixed paper.

Newspaper waste is either sent to recycling facilities, disposal facilities, or archived. Sixty issues of the *Wellesley News* are archived weekly in Billings and account for only 1% of the newspapers used at Wellesley. The remaining 65.7% of newspapers sent to recycling is accounted for in the top-down mixed paper calculation because the Conigliaro inventories include newspaper under their "mixed paper" category.

ASEPTIC CONTAINERS

Aseptic Containers Background

Aseptic containers are designed to keep contents sterile, and they are usually found in the form of beverage cartons and juice boxes, though they can also store other liquids such as soup. In the context of this report, the term "aseptic container," encompasses two types of containers.

The first, a classic aseptic carton, consists of layers of paperboard, aluminum, and low-density polyethylene (LDPE). The paper allows the container to retain its shape; the aluminum keeps out air, light, and bacteria; and the LDPE separates the aluminum from the container's contents[23] and seals the package's interior and exterior.[24] The second type of aseptic container is a gable-top carton. Gable-top cartons lack an aluminum layer and are made of only paperboard and LDPE.

Uses of Aseptic Containers at Wellesley College

On campus, aseptic containers are used to package milk, rice milk, soymilk, juice and other beverages. They are used in dining halls, cafés, and dormitories.

Activities and Behaviors Producing Aseptic Containers Waste at Wellesley College

Wellesley College's dining halls offer different types of milk to provide more options for students with varying dietary needs. The College uses smaller cartons instead of large milk dispensers because fewer students consume the wide variety of alternatives. Students buy their own cartons of milk, juice, or soup to consume personally as well. All of these activities contribute to aseptic container waste at Wellesley College.

Amount of Aseptic Containers Produced at Wellesley College

We estimated that Wellesley College produces 829.67 kg of aseptic container waste annually, as estimated in Table 4.19.

Table 4.19: Estimated Annual Aseptic Container Waste at Wellesley College.

Material	Weight per unit (kg/unit)	# Units per kg	# Units Produced Annually	Total Produced Annually (kg)
Aseptic cartons	0.03	33.3	11,885	356.55
Gable-top Cartons	0.03	33.3	13,256	397.69
Miscellaneous	0.03	33.3	2,514	75.42
Total				**829.67 kg**

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23 Pasqualino, J. et al., The carbon footprint and energy consumption of beverage packaging selection and disposal. *Journal of Food Engineering*, 103.4 (April 2011): 357-365. Web. 1 Mar. 2012, <http://www.sciencedirect.com/science/article/pii/S026087741000542X>.

24 Aseptic Packaging. *Spartech Plastics.* Spartech Corporation. n.d. Web. 8 May 2012, <http://www.spartech.com/packaging/aseptic.html>.

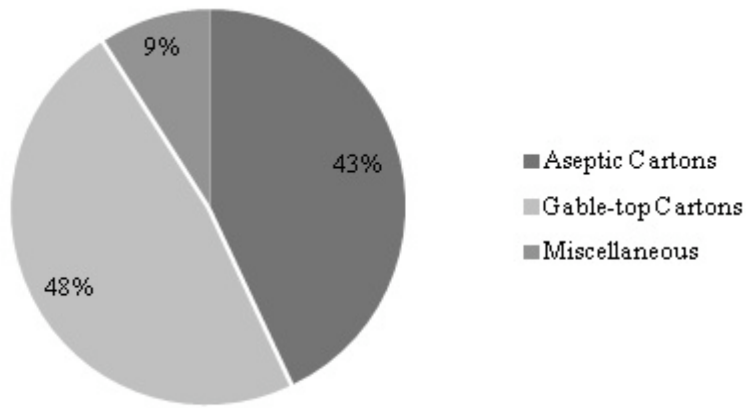

Figure 4.7: Categories of Aseptic Containers, by Percent.

To estimate the number of units produced annually, we performed an informal audit to find the number of units being stored in public places in the New Dorms complex. We counted all the aseptic containers in every common kitchen refrigerator to find how many cartons were being used by individual students. Then we counted all the aseptic containers in the refrigerator of Bates dining hall to find out how many containers were being discarded by the dining halls. We assumed that all the cartons would be finished or expired by the end of one week, and thus would be replaced exactly once a week. Table 4.20 shows the results of our audit.

Table 4.20: Number of Aseptic Cartons Found in the New Dorms Complex.

Location	Number of aseptic cartons	Number of gable-top cartons
Residence Halls	7	12
Dining halls	19	17

In total, we found 19 cartons in the residence halls and 38 in Bates dining hall. Then, we multiplied those numbers by the number of weeks per month, to calculate the number of containers produced per month. Then we divided this number by 400, the number of students living in the New Dorms Complex, to find the average number of cartons one student discards per month for personal use (0.19 containers per student), and for dining hall use (0.36 containers per student).

Using our common assumptions (See Appendix A), we multiplied the number of students living in each residence hall by the number of months that residence hall is open, and we added up the products of all the residence halls to calculate how many containers we might find on campus if each student discarded exactly one container per month. We took that number and multiplied it by the actual average number of cartons discarded per student per month in the residence halls, which we found in the previous step. We repeated the same process for the number of months each dining hall is open and the number of students who ate there. Finally, we added 10% to our total number of units to account for miscellaneous sources, such as the Wellesley College Club, on-campus cafes and events.

Handling of Aseptic Containers at Wellesley College

We estimated how Wellesley College handles aseptic container waste in Table 4.21.

Table 4.21: Estimated Handling of Aseptic Container Waste at Wellesley College.

Material	% Recycled	% Thrown in Trash
Aseptic cartons	0%	100%
Gable-top cartons	0%	100%

The dining halls at Wellesley College do not recycle aseptic containers or separate them from other types of waste. Although aseptic containers can be thrown into commingled recycling bins, it is unlikely that most students recycle them properly because they have food or drink residues that need to be rinsed off before they can be recycled. Moreover, most people aren't aware that they can be recycled at all. We found many aseptic containers during our waste audit, but none in audited recycling bins. Thus, we assumed a 0% recycling rate for aseptic containers—any recycling that does occur on campus would be negligible.

Destination of Aseptic Container Waste

Table 4.22 shows the destinations of aseptic container waste.

Table 4.22: Destination of Aseptic Container Waste by Percentage.

	Conigliaro	SEMASS
% of Waste	0%	100%
Weight of Waste (kg)	0 kg	829.67 kg

Because very little recycling of aseptic containers occurs at Wellesley College, most cartons are sent to the SEMASS facility for incineration. Any recycled cartons sent to Conigliaro Industries would be redirected to a paper mill, where the paper would be extracted and the LDPE and aluminum would typically be discarded.[25]

Abridged Life Cycle of Aseptic Containers Produced at Wellesley College

Aseptic containers are mainly found in the form of milk cartons on the Wellesley College campus. Figure 4.8 shows an abridged life cycle diagram from production to disposal.

[25] Garrison, Richard. Manager at Conigliaro Industries. "Quick question about recycling." Message to Linda Hsu. 14 Mar. 2012. E-mail.

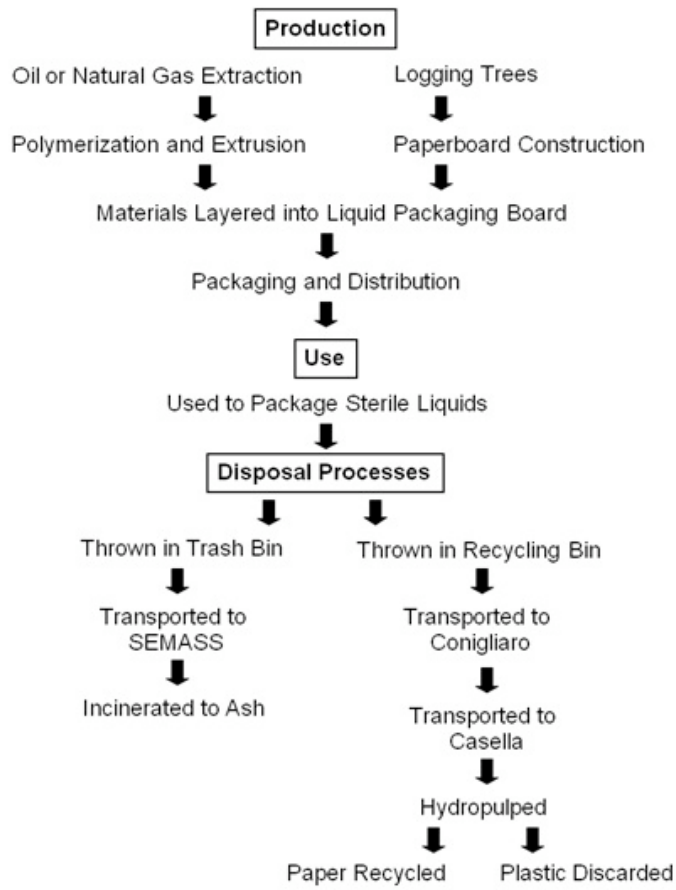

Figure 4.8: Abridged Life Cycle for a Milk Carton.

Aseptic Containers Background

Aseptic containers are composed of liquid packaging board, which can differ depending on its specific contents. An aseptic carton that does not require refrigeration, such as a soup container, is approximately 75% virgin paperboard, 20% LDPE, and 5% aluminum. Alternatively, a gable-top carton that has no aluminum, such as a juice carton, is about 85% paper and 15% LDPE.[26] The liquid packaging board uses only virgin wood fibers instead of recycled paper so that it is stiffer and more hygienic.[27]

Manufacturing of Aseptic Containers

To manufacture an aseptic carton, wood pulp is bleached and washed. The refined pulp is drained of water, sent through rollers and dried,[28] and is combined into layers, becoming

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[26] Brown, L. Milk and Juice Carton Recycling Made Easy. *Earth911*. 10 Apr. 2009. Web. 16 Apr. 2012, <http://earth911.com/news/2009/04/10/milk-and-juice-carton-recycling-made-easy/>.

[27] From Wood Fibre to Paperboard. *The Alliance for Beverage Cartons and the Environment*, ACE. 2012. Web. 30 Mar. 2012, <http://www.beveragecarton.eu/en/beverage-cartons-3/the-beverage-carton/production>.

[28] Pulp & Paper Industry Solutions: Accurate and Reliable Liquid Analysis. *Rosemont Analytical Inc.*. Emerson Process Management, 2012. Web. 8 May 2012, <http://www2.emersonprocess.com/siteadmincenter/PM%20Rosemount%20Analytical%20Documents/Liq_Brochure_91-6028.pdf>.

paperboard.[29] Then, a machine extrudes layers of polyethylene and aluminum onto the paper. Finally, the liquid contents are flash-heated for sterilization and injected into the carton.[30]

Manufacturing and Use Impact Assessment for Aseptic Containers

Table 4.23 explains the ecosystem impacts of 1 kg and 829.67 kg of the manufacture of aseptic containers. The major contributors to each impact category score are outlined in Table C.1 found in Appendix C.

Table 4.23: Impact Categories for the Manufacture of Aseptic Containers.

Impact Category	Impact per 1 kg	Total Impact for 829.67 kg	Unit
Global Warming	1.44	1,194.72	kg CO2 eq
Acidification	0.0043	3.57	H+ moles eq
Eutrophication	0.34	282.09	kg N eq
Carcinogens	0.0048	4.01	kg benzene eq
Non-Carcinogens	54.91	45,557.18	kg toluene eq
Respiratory Effects	0.002	1.63	kg PM2.5 eq

Table 4.24 demonstrates additional impact factors for the manufacture of aseptic containers:

Table 4.24: Additional impact factors for the manufacture of aseptic containers.

Erosion	Permanent Land Disruption	Water Use	Resource Use	Biodiversity Disruption	Total Score
1	1	1	1	1	**5.0**

Because liquid packaging board is only manufactured with virgin wood fiber, the production of aseptic containers involves deforestation, which causes biodiversity disruption and some land erosion; each of these impact factors received a score of 1.0. In terms of resource use, the manufacture of aseptic containers requires petroleum, which is non-renewable; aluminum, which is non-renewable; and wood from trees, which are renewable but may not always be properly replanted. Thus, aseptic containers received a score of 1.0 for resource use. The process of making paper requires large amounts of water, but most of it is re-used repeatedly; when it is finally discarded, it is carefully purified in accordance with strict wastewater controls.[31] As a

[29] From Wood Fibre to Paperboard. *The Alliance for Beverage Cartons and the Environment*, ACE. 2012. Web. 30 Mar. 2012, <http://www.beveragecarton.eu/en/beverage-cartons-3/the-beverage-carton/production>.
[30] Aseptic Packaging System. *Plastics for Environment.* Indian Centre for Plastics in the Environment, n.d. Web. 8 May 2012, <http://icpe.in/icpefoodnpackaging/pdfs/23_aseptic.pdf>.
[31] From Wood Fibre to Paperboard. *The Alliance for Beverage Cartons and the Environment*, ACE. 2012. Web. 30 Mar. 2012, <http://www.beveragecarton.eu/en/beverage-cartons-3/the-beverage-carton/production>.

result, aseptic containers received a score of 1.0 for water use. In total, aseptic cartons received 5 points out of a possible 5, which is the highest impact score.

Recycling Overview of Aseptic Containers

Aseptic containers are recycled at paper mills in a process called hydropulping, which separates paper from the plastic and aluminum.[32] Because hydropulping is intended primarily to process paper, the aluminum and LDPE leave residues that must frequently be cleaned from the pulper.[33] It is possible to use the extracted paper fibers in boxes or stationery,[34] though they are frequently put into tissues and paper towels.[35] The plastic and aluminum components of aseptic containers can be recycled as a composite material, or they can be incinerated for energy.[36] Although aseptic containers can be recycled, they are usually not collected for recycling because it is energetically costly and expensive to recycle them.[37] In this report, we assumed that no aseptic containers were recycled.

Abridged Life Cycle of Paper Produced at Wellesley College

An abridged life cycle diagram for paper from production to disposal is displayed in Figure 4.9.

[32] Brown, L. Milk and Juice Carton Recycling Made Easy. *Earth911*. 10 Apr. 2009. Web. 16 Apr. 2012, <http://earth911.com/news/2009/04/10/milk-and-juice-carton-recycling-made-easy/>.
[33] Abreu, M. Recycling of Tetra Pak Aseptic Cartons. *Tetra Pak Canada Inc*. n.d. Web. 26 Apr. 2012, <http://www.environmental-expert.com/Files/0/articles/2268/tetrapak.pdf>.
[34] Recycling. *The Alliance for Beverage Cartons and the Environment.* ACE. 2012. Web. 30 Mar. 2012, <http://www.beveragecarton.eu/en/beverage-cartons-3/recovery-and-recycling/recycling-process>.
[35] Brown, L. Milk and Juice Carton Recycling Made Easy. *Earth911*. 10 Apr. 2009. Web. 16 Apr. 2012, <http://earth911.com/news/2009/04/10/milk-and-juice-carton-recycling-made-easy/>.
[36] Recycling. *The Alliance for Beverage Cartons and the Environment.* ACE. 2012. Web. 30 Mar. 2012, <http://www.beveragecarton.eu/en/beverage-cartons-3/recovery-and-recycling/recycling-process>.
[37] Commonly Recycled Materials. *Consumer Recycling Guide.* Obviously Enterprises. 2006. Web. 29 April. 2012, <http://www.obviously.com/recycle/guides/common>.

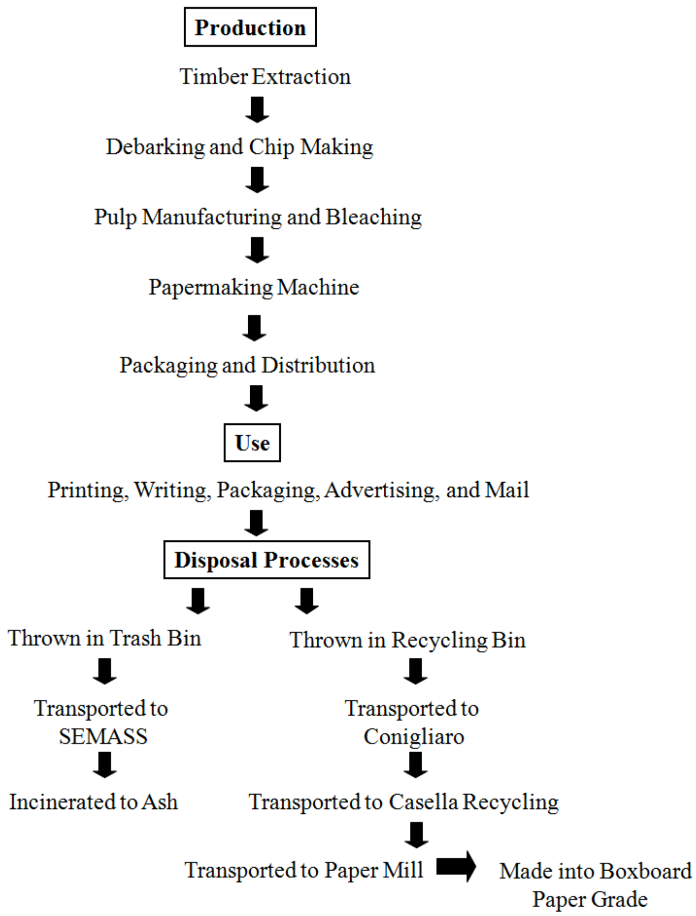

Figure 4.9: Abridged Life Cycle for Office Paper, Mixed Paper, Corrugated Cardboard, and Boxboard.

Paper Source Background

In the cases of office paper, mixed paper, brown paper, newspaper, corrugated cardboard, and boxboard, their backgrounds and manufacturing processes are almost identical. All of the aforementioned paper-based materials are made almost entirely out of paper with wood as the primary raw material. Negative environmental impacts occur throughout the three stages in the life cycle of paper: the harvesting of trees for fiber, the processing of wood fiber into pulp for making paper, and the disposal of paper products at the end of their life.

One of the primary environmental impacts created by the production of paper is deforestation. Today, the papermaking industry primarily depends on virgin wood-fibers to make the pulp that is eventually made into paper. In all parts of the world, a significant portion of the wood currently used comes from old-growth forests and biologically sensitive forests. Out of the world's harvested trees, about 35% of the wood is used to manufacture paper, which equates to roughly 4 billion trees. That figure, however, includes both logging from plantations and forests. Of the wood used to manufacture paper, 16% comes from farms, 71% from second growth forests, and 9% from old growth forests. [38] According to the EPA, trees harvested specifically for wood pulp production account for approximately 53% of the wood delivered to the paper mill.[39]

Deforestation has substantial negative impacts on the environment. Forests are critical protectors of biodiversity and of climate stability. Forests also sustain a variety of habitats by providing carbon dioxide and storing carbon. Therefore, the clear-cutting of forests not only fragments forest ecosystems, but also can destroy them altogether.[40] Clear-cutting practices are additionally responsible for the release of millions of tons of stored carbon. According to the 2006 United Nations report, forests store about 312 billion tons of carbon in their biomass alone.[41] The UN assessment also reports that the destruction of forests adds almost 2.2 billion tons of carbon to the atmosphere each year, which is equivalent to what the U.S emits annually.[42]

Both sodium hydroxide and chlorine are used in the manufacturing process, and must be extracted from salt through an electrolytic process. Salt is obtained through mining since salt is naturally produced as brine or as rock salt.[43] Solution mining is the most common way salt is mined, although there are other alternatives. Solution mining drills an injection well and uses pressurized fresh water on the bedded salt. After introducing the water, the brine is pumped to the surface for treatment. Salt mines are located all over the United States, and the greatest rock salt production in the U.S is obtained from Michigan and Ohio.[44] Sodium sulfate, like salt, also needs to be mined. Typically, the sodium sulfate crystals settle out of the brine and are dissolved and precipitated to get a specific level of purity.[45]

Manufacturing of Paper

First, trees are de-limbed and cut into logs of a manageable lengths. These logs are then de-barked and processed into wood chips. The most common method of turning wood chips into wood pulp is called the "kraft process" (sulfate process).[46] The wood chips are cooked in large vats called digesters. Digesters cook the chips in a chemical solution of sodium hydroxide and

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[38] Martin, S. Paper Chase. *Ecology Global Network*, 10 Sept. 2011. Web. 26 Mar. 2012, <http://www.ecology.com/2011/09/10/paper-chase>.
[39] A Partial Life Cycle Inventory of Process and Transportation Energy for Boxboard and Paper Towels. *Franklin Associated, Ltd*., n.d. Web. 26 Mar. 2012, <http://www.epa.gov/climatechange/wycd/waste/downloads/BackgroundDocumentA_Attachement1.pdf>.
[40] Forest Products. *Environmental Protection Agency*. 2004. Web. 26 Mar. 2012, <http://www.epa.gov/sectors/pdf/2004/forestproducts.pdf>.
[41] Global Forest Resources Assessment of 2005: Progress Toward Sustainable Forest Management. *Food and Agriculture Organization Forestry Paper* 147 (2006). Web. 26 Mar. 2012, <ftp://ftp.fao.org/docrep/fao/008/A0400E/A0400E00.pdf>.
[42] Global Forest Resources Assessment of 2005: Progress Toward Sustainable Forest Management. *Food and Agriculture Organization Forestry Paper* 147 (2006). Web. 26 Mar. 2012, <ftp://ftp.fao.org/docrep/fao/008/A0400E/A0400E00.pdf>.
[43] Rock Salt Mining. *Michigan State University Geography Department*, n.d. Web. 26 Mar. 2012, <http://www.geo.msu.edu/geogmich/saltminingM.html>.
[44] Rock Salt Mining. *Michigan State University Geography Department*, n.d. Web. 26 Mar. 2012, <http://www.geo.msu.edu/geogmich/saltminingM.html>.
[45] A Partial Life Cycle Inventory of Process and Transportation Energy for Boxboard and Paper Towels. *Franklin Associated, Ltd*., n.d. Web. 26 Mar. 2012, <http://www.epa.gov/climatechange/wycd/waste/downloads/BackgroundDocumentA_Attachement1.pdf>.
[46] Chemical Wood Pulping. *Environmental Protection Agency.* n.d. Web. 29 March 2012, <http://www.epa.gov/ttnchie1/ap42/ch10/final/c10s02.pdf>.

sodium sulfide.[47] When the solution boils, the chips dissolve into wood pulp as the alkalinity of the chemicals dissolve the lignin that holds wood fibers together.[48] The pulp is filtered and often bleached; the amount of bleach used during the manufacturing process depends on the desired whiteness of final mixed paper product.

After filtering, wood pulp is ready to be sent to a paper-making plant. At the plant the wood pulp is put through a pounding and squeezing process, which is referred to as beating.[49] During this beating process, various materials may be added to either enhance the opacity or transparency of the mixed paper. Additionally, during beating, sizing is added. Sizing affects the way paper will ultimately interact with different inks. Starch is a common type of sizing used to make paper resistant to water-based inks.

In the case of corrugated cardboard, after the wood pulp is converted into sheets of paper, starch-based adhesives, waxes, and inks are added to make the sheets of paper into a corrugated cardboard box.[50] What differentiates containerboard manufacturing from other paper manufacturing is that the pulp is made into the corrugated cardboard liner and medium. The pulp is cleaned and refined then pumped into a Fourdrinier machine to make paper. Within the machine, the pulp is pressed onto wire meshes and dried.[51]

This pulp is then transported to the converting plant, where the paper liner and medium is corrugated and made into boxes to the specifications of customers. One roll of medium is run through the corrugating rolls and a roll of liner is fed into the corrugator to be joined with the corrugated medium. A second roll of liner is then pressed and glued onto the one-sided corrugated medium. At the end of the corrugator, a slitter-scorer trims the cardboard and cuts it into large sheets called box blanks. The box blanks are then moved to the flexographic machine where the box is assembled. As each box blank passes through the rollers of the machine, it is trimmed, printed on, folded, and glued to form the box. The finished product is then bound and packaged for shipment.[52]

Paper mills and papermaking plants are linked to a variety of environmental harms. Water, air, climate, and ecosystems are all affected by the chemicals discharged from papermaking facilities, as well as the exploitation of these resources by paper mills.[53] For example, the chemical solution used to cook wood chips contains sodium hydroxide and sodium sulfide. The bleaching process in office paper also requires chlorine. Nevertheless, while paper mills still use a number of hazardous chemicals, the use of many toxic substances has become

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[47] Pulp & Paper Industry Solutions: Accurate and Reliable Liquid Analysis. *Rosemont Analytical Inc.*. Emerson Process Management, 2012. Web. 8 May 2012, <http://www2.emersonprocess.com/siteadmincenter/PM%20Rosemount%20Analytical%20Documents/Liq_Brochure_91-6028.pdf>.

[48] Chemical Wood Pulping. *Environmental Protection Agency.* n.d. Web. 29 March 2012, <http://www.epa.gov/ttnchie1/ap42/ch10/final/c10s02.pdf>.

[49] Torraspapel, S. A. Paper Manufacturing. *About Paper*, 2008. Web. 26 Mar. 2012, <http://www.torraspapel.com/Conocimiento%20Tcnico/AboutPaperManufacturing.pdf>.

[50] Life Cycle Assessment of U.S Industry Average Corrugated Product. *Corrugated Packaging Alliance.* 30 December 2009. Web. 8 May 2012, <http://corrugated.theresponsiblepackage.org/Upload/CPA%20LCA%20final%20report%208-25-10.pdf>.

[51] Kline, J.E. Paper And Paperboard: Manufacturing and Converting Fundamentals, 1991. Web. 8 May 2012, <http://books.google.com/books/about/Paper_and_paperboard.html?id=OO1vAAAAIAAJ>.

[52] Kline, J.E. Paper And Paperboard: Manufacturing and Converting Fundamentals, 1991. Web. 8 May 2012, <http://books.google.com/books/about/Paper_and_paperboard.html?id=OO1vAAAAIAAJ>.

[53] Copy Paper: Social & Environmental. *Responsible Purchasing Network*. n.d. Web. 28 Mar. 2012, <http://www.responsiblepurchasing.org/purchasing_guides/copy_paper/social_environ/>.

more regulated and restricted. Even so, chlorine is an unavoidable substance to use when bleaching office paper and the bleaching process may still produce dioxins.[54]

Manufacturing and Use Impact Assessment for Office Paper

We assumed that the most common office paper on-campus is made of 30% recycled content, and 70% virgin material.[55] We used SimaPro7 software to analyze the impacts associated with making one kilogram of office paper. The environmental impacts associated with the manufacture of 1 kg and 71,970.45 kg of office paper as determined by the software are summarized in Table 4.25. For the impacts of the substances attributed to each impact category see Appendix C.

Table 4.25: Total Impact Values for Office Paper Material Extraction and Manufacture per 1kg of Material.

Impact Category	Impact per 1 kg	Total Impact for 71,970.45 kg	Unit
Global Warming	0.82	59,015.77	kg CO2 eq
Acidification	0.46	33,106.41	H+ moles eq
Eutrophication	0.0065	466.37	kg N eq
Carcinogens	0.0051	364.89	kg benzene eq
Non-Carcinogens	97.90	7,045,907.06	kg toluene eq
Respiratory Effects	0.0024	172.73	kg PM2.5 eq

Manufacturing and Use Impact Assessment for Mixed Paper

We used SimaPro7 software to analyze the impacts associated with making 1 kg of mixed paper. The mixed paper category in SimaPro7 includes materials like brown paper and newspaper. The processes input into SimaPro7 were for 100% virgin material of mixed paper. The environmental impacts associated with the manufacture of 1 kg and 51,693.98 kg of mixed paper, as determined by the software, are summarized in Table 4.26 below. For the impacts of the substances attributed to each impact category see Appendix C.

[54] Copy Paper: Social & Environmental. *Responsible Purchasing Network*. n.d. Web. 28 Mar. 2012, <http://www.responsiblepurchasing.org/purchasing_guides/copy_paper/social_environ/>.
[55] Doing Business with Wellesley College. *Purchasing Department*. Wellesley College. n.d. Web. 28 Mar 2012 <http://www.wellesley.edu/Purchasing/supplier.html>.

Table 4.26: Total Impact Values for Mixed Paper Material Extraction and Manufacture per 1 kg and Total Weight of Material.

Impact Category	Impacts per 1 kg	Total Impacts for 51,693.98 kg	Unit
Global Warming	0.06	3,101.64	kg CO2 eq
Acidification	0.02	1,033.88	H+ moles eq
Eutrophication	0.000072	3.72	kg N eq
Carcinogens	0.000052	2.69	kg benzene eq
Non-Carcinogens	0.45	23,262.29	kg toluene eq
Respiratory Effects	0.000075	23,262.29	kg PM2.5 eq

Manufacturing and Use Impact Assessment for Corrugated Cardboard

One kg of cardboard is composed of 0.25 kg of liner and 0.75 kg of corrugated fluting. We estimated this ratio because corrugated fluting is more than half the length of the liner when stretched flat. We used the SimaPro7 software to analyze the impacts associated with making 1 kilogram of corrugated cardboard. The processes input into SimaPro7 were for a liner and fluting made from virgin fibers. The environmental impacts associated with the manufacture of 1 kg and 87,622 kg of cardboard and the total cardboard used (recycled and disposed) at Wellesley College, as determined by the software, are summarized in Table . For the impacts of the substances attributed to each impact category see Appendix C.

Table 4.27: Total Impact Values for Corrugated Cardboard Material Extraction and Manufacture.

Impact Category	Impact per 1 kg	Total Impact for 87,622 kg	Unit
Global Warming	0.75	65,716.50	kg CO2 eq
Acidification	0.23	20,153.06	H+ moles eq
Eutrophication	0.0049	430.22	kg N eq
Carcinogens	0.0028	248.85	kg benzene eq
Non-Carcinogens	31.60	2,768,855.20	kg toluene eq
Respiratory effects	0.0014	122.67	kg PM2.5 eq

Manufacturing and Use Impact Assessment for Boxboard

This impact assessment was for boxboard, unbleached, from virgin fibers. As determined by the SimaPro7, the environmental impacts associated with the manufacture of 1 kg and

56,001.81 kg of boxboard, the total boxboard used (recycled and disposed) at Wellesley College, are summarized in Table 4.28. For the impacts of the substances attributed to each impact category see Appendix C.

Table 4.28: Total Impact Values for Boxboard Material Extraction and Manufacture per 1 kg of Material.

Impact Category	Impact per 1 kg	Total Impact for 56,001.81 kg	Unit
Global Warming	1.30	1,078.57	kg CO2 eq
Acidification	0.36	20,160.65	H+ moles eq
Eutrophication	0.0058	322.01	kg N eq
Carcinogens	0.000052	292.89	kg benzene eq
Non-Carcinogens	80.38	4,501,425.49	kg toluene eq
Respiratory Effects	0.0022	120.96	kg PM2.5 eq

The additional ecosystem impacts associated with the manufacture of the various paper-based materials discussed above are quantified in Table 4.29.

Table 4.29: Additional Ecosystem Impacts for the Manufacture of Paper.

Erosion	Permanent Land Disruption	Water Use	Resource Use	Biodiversity Disruption	Total Score
1	1	1	0.5	1	**4.5**

The harvesting of trees to use for pulp is responsible for 42% of all logged trees.[56] Additionally, deforestation sparked by an increased need for paper may even have an impact on climate change and ecosystems. Forests sequester carbon, stabilize soil and are habitats for diverse flora and fauna,[57] and thus the impact of disruption of these ecosystems through the creation of monocultures and harvesting can be significant. Nevertheless, parts of the logging industry do maintain their forests through sustainable logging techniques, and attempt to keep their resource as intact and healthy as possible.[58] Clear-cutting forests makes soil more vulnerable to erosion because there are no trees serving as barriers. Processing the wood chips and creating wood pulp is very water intensive.[59] Thus, the total ecosystem impact score for

[56] How much of all timber harvested goes into making paper?. *Paper Listing Study*. n.d. Web. 28 Mar. 2012, <http://www.conservatree.org/paperlisteningstudy/Forests/question64.html>.
[57] Benefits of Paper Recycling. *Environmental Protection Agency*, n.d. Web. 28 Mar. 2012, <http://www.epa.gov/osw/conserve/materials/paper/basics/index.htm#benefits>.
[58] Sustainable Forest Management. *Naturally:wood*. Forestry Innovation Investment, Mar 2011. Web. 28 Mar. 2012, <http://www.naturallywood.com/sites/default/files/Sustainable-Forest-Management.pdf>.
[59] Global Forest Resources Assessment of 2005: Progress Toward Sustainable Forest Management. *Food and Agriculture Organization Forestry Paper* 147 (2006). Web. 26 Mar. 2012, <ftp://ftp.fao.org/docrep/fao/008/A0400E/A0400E00.pdf>

paper is 4.5. This is a medium to high impact score, indicating the presence of sustainable forestry practices, as well as the energy necessary to manufacture and recycle paper.

Timber comes from forest farms or naturally occurring forests.[60] Trees are generally slow growing and forests strongly react to disruptions. The forest ecosystem changes sequentially with disturbances known as forest succession.[61] Therefore, deforestation alters biodiversity and lowers the potential to mitigate climate change through carbon sequestration. For these reasons the ecosystem impacts of manufacturing paper are high.

Recycling Overview of Paper

Office paper, mixed paper, boxboard, brown paper and newspaper, can be recycled in the United States into tissue, paperboard, newsprint or even back into a form of office paper (with enough virgin material). Paper can also be significantly downcycled into packaging, compost and kitty litter.[62] Similar to other paper, corrugated cardboard can be recycled into a range of paper-based products, including corrugated cardboard, brown paper, paper towels, again toilet paper, and kitty litter. Recycled pulp is often exported to other countries (like China), where it is cheaper to recycle.[63]

Recycled paper from Wellesley College is sent to Conigliaro Industries, which bales, shreds, and re-sells the paper. Their major buyer is Casella Recycling, with processing factories in Charlestown, MA and Auburn, MA.[64] Casella sorts the paper, and then sells it to pulp mills on the domestic and international market.

In pulp mills paper is broken back down into pulp by adding water and heat. It is screened for adhesives and other contaminants and cleaned before it is de-inked.[65] De-inking chemicals are called surfactants, and they can be toxic to aquatic organisms if they enter the environment.[66] Every time paper fibers are recycled, they unfortunately become shorter and harder to reform into new paper.[67] They can be recycled up to seven times.[68] Unfortunately, all paper sent to Conigliaro is graded down because of the way it combines different paper-based materials. Therefore it is not likely that most of the fibers from recycled office paper will be cycled back into new office paper. It is likely that they will instead be downcycled into some sort of brown paper material.

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[60] Willis, K.G. et al. The Social and Environmental Benefits of Forests in Great Britain. n.d. Web. 22 March 2012, < http://www.forestry.gov.uk/pdf/sebreport0703.pdf/$FILE/sebreport0703.pdf>

[61] Finegan, B. Forest Succession. 8 November 1984. Nature (312): 109-114.

[62] Paper Recycling Markets. *Environmental Protection Agency*, n.d. Web. 28 Mar. 2012, <http://www.epa.gov/osw/conserve/materials/paper/basics/markets.htm>.

[63] 2007 Recovered paper Annual Statistics. *Paperrecycles.org*. American Forest and Paper Association. n.d. Web. 28 Mar. 2012, <http://stats.paperrecycles.org/index.php?graph=pwgo&sub=printing_writing&x=45&y=8>.

[64] Garrison, Richard. Manager of Conigliaro Industries "Quick question about recycling." Message to Linda Hsu. 14 Mar. 2012. E-mail.

[65] How is Paper Recycled? *Paper University*. TAPPI, n.d. Web. 28 Mar. 2012, <http://www.tappi.org/paperu/all_about_paper/earth_answers/earthanswers_recycle.pdf>.

[66] Surfactants; Environmental Assessment of Laundry Detergents. n.d. Web. 28 Mar. 2012, <http://www.eco-forum.dk/detergents/index_files/Page718.htm>.

[67] Garrison, Richard. Manager of Conigliaro Industries. Personal Interview. 9 Mar. 2012.

[68] Surfactants; Environmental Assessment of Laundry Detergents. n.d. Web. 28 Mar. 2012, <http://www.eco-forum.dk/detergents/index_files/Page718.htm>.

PAPER INCINERATION IMPACTS

Figure 4.10: **Corrugated cardboard discarded in the trash and analyzed during February waste audit.**

Transportation Impacts: SEMASS

At Wellesley College, the comprehensive paper category consists of corrugated cardboard, boxboard, mixed paper, office paper, and aseptic containers. The transport calculations are an aggregate of the impacts of transporting all paper-based products disposed of on campus. Once paper is discarded in the trash at Wellesley, it is transported in large, diesel-powered combination trucks to the Covanta SEMASS facility for incineration. Paper waste travels a total of 99.16 km to reach SEMASS, which includes the distance to the Holliston Transfer station in between.

The impact factors for transport were calculated using SimaPro7 and the TRACI2 method. Cumulative transportation impacts of paper sent to SEMASS were calculated by multiplying the total amount of paper discarded in the trash, 154,898.74 kg, by the km traveled. The transportation impact values for 1 kg and all paper sent to SEMASS, Conigliaro, Casella and paper mills are displayed in Table C.6 found in Appendix C.

Facility Impact for Paper Handling: SEMASS

One kilogram of paper contains dioxin,[69] lead,[70] nitrogen,[71] and carbon[72] (see Table C.7 in Appendix C for values). We used SimaPro7 to calculate the environmental impacts associated

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[69] Abad, E., Adrados, M.A., Caixach, J., Fabrellas, B., Rivera, J. Dioxin Mass Balance in Municipal Waste Incinerator. *Chemosphere* 40 (2000): 1143-1147.

[70] Berry, R. M., Corinne E. L., and Voss, R.H. Ubiquitous Nature of Dioxins: A Comparison of the Dioxins Content of Common Everyday Materials with That of Pulps and Papers. *Environmental Science and Technology* 27 (1993): 1164-168. Print.

with incinerating these substances. The facility impacts for incinerating 1 kg and 154,898.74 kg of paper are shown in Table C.8 in Appendix C.

Facility Credit: SEMASS

The energy content of mixed paper is 15,128.3 KJ/kg,[73] and the total mixed paper we sent to the SEMASS facility annually is 154,898.74 kg. Thus, the total energy measure of the mixed paper we send to the facility is 2,343,354,608.34 KJ. This energy measure was then multiplied by the efficiency of the SEMASS facility, 76.7%. The impact credit derived from the energy created from incinerating paper in MA is listed in Table C.9 in Appendix C.

The overall facility impacts for 1 kg and 154,898.74 kg of paper can waste sent to SEMASS is presented in Table 4.30 and Table 4.31 respectively.

Table 4.30: Total Impacts for 1kg of Paper Sent to SEMASS.

Impact Category	Transport Impact	Facility Impact	Facility Credit	Total Impact	Unit
Global Warming	0.0092	1.21	-0.0016	1.22	kg CO2 eq
Acidification	0.003	0.82	-0.00072	0.82	H+ moles eq
Eutrophication	0.0000029	0.82	-0.00000016	0.82	kg N eq
Carcinogens	0.000003	177.40	-0.00000082	177.4	kg benzene eq
Non-Carcinogens	0.063	177.40	-0.0071	177.46	kg toluene eq
Respiratory Effects	0.0000035	0.82	-0.0000028	0.82	kg PM2.5 eq

[71] Dickson, N., T. Richard, and R. Kozlowski. Composting to Reduce the Waste Stream: A Guide to Small Scale Food and Yard Waste Composting. *Ithaca: Northeast Regional Agricultural Engineering Service*,1991.Print.
[72] Bingmemer, H.G. and Crutzen, P.J. The Production of Methane from Solid Wastes. *Journal of Geophysical Research.* 92.D2 (1987): 2181-2187.
[73] Aysen U. Energy recovery from mixed paper waste: Final Report to Sunshares. *Department of Civil and Environmental Engineering, Duke University*, 1990. Web. 8 May 2012, <http://infohouse.p2ric.org/ref/11/10059.pdf>.

Table 4.31: Total Impacts for 154,898.70 kg of Paper Sent to SEMASS.

Impact Category	Transport Impact	Facility Impact	Facility Credit	Total Impact	Unit
Global Warming	1,425.07	187,427.48	-247.84	188,604.71	kg CO2 eq
Acidification	464.70	127,016.97	-111.53	127,370.14	H+ moles eq
Eutrophication	0.45	127,016.97	-0.025	127,017.39	kg N eq
Carcinogens	0.46	27,479,036.54	-0.13	27,479,036.88	kg benzene eq
Non-Carcinogens	9,758.62	27,479,036.54	-1,099.78	27,487,695.38	kg toluene eq
Respiratory Effects	0.54	127,016.97	-0.43	127,017.08	kg PM2.5 eq

PAPER RECYCLING IMPACTS

Figure 4.11: Paper Bailing Machinery at Conigliaro Industries.

Transportation Impacts: Conigliaro, Casella & Paper Mill

Paper recycled on campus is transported 10.78 km to Conigliaro Industries in a single-unit, diesel powered truck to be baled. After Conigliaro, it is sent to Casella Waste Systems, which is 39.91 km from Conigliaro. At Casella, paper is sorted and sold to paper mills that will process it back to wood pulp. Casella has been known to sell its wood pulp to Newark Paperboard Mills,[74] whose facility is 51.66 km away in Fitchburg, MA. The distance to the

[74] Auburn Casella Facility. Personal Interview. Apr. 2 2012.

Newark Paperboard Mill is used to represent transport to other potential paper mills, but the paper recycled at Wellesley goes to a variety of locations.

The transportation impact of recycled paper was calculated by multiplying the total amount of recycled paper at Wellesley College, 146,047.70 kg, by the distance traveled per facility. This product was multiplied by the impact values derived from SimaPro7 for each impact category per 1 kg of paper waste in a single unit diesel truck. The impact for 1 kg and 146,047.70 kg of paper transported from Wellesley to Newark Paper Mill is shown in Table C.10 in Appendix C.

Facility Impacts and Credits for Paper Handling: Conigliaro, Casella and Paper Mills

The power needed to operate the baling and shredding machinery at Conigliaro Industries is generated by solar panels; therefore, there are no facility impacts associated with this machinery.

Casella sorts paper using an optical sorter before selling it to paper mills. Since this is the same facility that receives Conigliaro's plastics, we assumed the impacts associated with plastic preparation would be the same as paper preparation. We used the impacts of a rock crusher from SimaPro7 as our best estimation of the impacts of the mechanical sorter, as no closer estimators were available. These impacts are seen on Table C.11 in Appendix C:

The paperboard mills that receive Wellesley's paper recycling break it down into pulp and recycle the pulp into new paperboard. Since Casella sells all its paper as paperboard grade,[75] the paper mill will likely follow the same processes and use similar technologies to create new paperboard. We used SimaPro7 to identify the impacts of paper pulping, as well as the impacts from the papermaking machine. A paper pulper uses 2,800 kJ/kg for steam production, and 95 kJ/kg for electricity,[76] resulting in a total energy consumption of 2,895 kJ/kg. Since the pulper handles the 146,047.7 kg that are received from Wellesley, it results in a total energy consumption of 422,808,091.5 kJ. The papermaking machine uses 2,735 kJ/kg,[77] which results in a total electrical consumption of 399,440,459.5 kJ to process Wellesley's recyclables. The impacts of running a paper pulper and papermaking machine for 1 kg and 146,047.7 kg is shown in Table C.12 in Appendix C.

Facility Credit: Recycling

The paper mills that receive Wellesley's paper recycling make the inner fluting of corrugated boxes or paper boxes used for packaging.[78] Since recycling paper to create paperboard reduces the impacts of creating paperboard out of virgin materials, we created an facility 'credit' using SimaPro7. The cradle-to-gate impacts of creating virgin paperboard are displayed in Table C.13 in Appendix C. One of Casella's purchasers, the Newark Paperboard

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[75] Auburn Casella Facility. Personal Interview. Apr. 2 2012.

[76] Lindell, K. and Stenström, S. Assessment of Different Paper Drying Processes to Reduce the Total Energy Costs From a Mill Perspective. *Drying 2004 -Proceedingd of the 14th International Drying Symposium*. Aug. 2004. Web. 8 May 2012, <http://www.kytl.com/Upload/tech/20067191521099800.pdf>.

[77] Ek, M., Gellerstedt, G., and Henriksson, G. Pulp and Paper Chemistry and Technology. Berlin: Walter De Gruyter, 2009. Web. 8 May 2012.

[78] Garrison, Richard. Manager of Conigliaro Industries Personal Interview. 2 Apr. 2012.

Mill, claims all their paperboard is 100% recycled,[79] so we are safely assuming Wellesley's paper is recycled into 100% recycled paperboard.

Cumulative Impacts of Paper Disposal

After calculating the transportation and facility impacts, the facility credits were then subtracted from the total impacts for a final total overall impact. The cumulative facility impacts for 1kg and 146047.7 kg of paper waste sent to Conigliaro, Casella and Paper mills is presented in Table 4.32 and Table 4.33 respectively.

Table 4.32: Total Impacts for 1 kg of Paper Waste Sent Placed in the Recycling.

Impact Category	Transport Impact	Facility Impact	Facility Credit	Total Impact	Unit
Global Warming	0.018	0.8	-1.31	-0.49	kg CO2 eq
Acidification	0.0052	0.35	-0.36	-0.0048	H+ moles eq
Eutrophication	0.0000055	0.000076	-0.0054	-0.0053	kg N eq
Carcinogens	0	0.00041	-82.2	-82.2	kg benzene eq
Non-Carcinogens	0	3.44	-0.0023	3.44	kg toluene eq
Respiratory Effects	0.0000052	0.0014	-0.0059	-0.0045	kg PM2.5 eq

Table 4.33: Total Impacts for 146,047.70 kg of Paper Waste Placed in the Recycling.

Impact Category	Transport Impact	Facility Impact	Facility Credit	Total Impact	Unit
Global Warming	2,592.68	116,839.9	-191,322.53	-71,889.95	kg CO2 eq
Acidification	758.1	51,117.08	-52,577.18	-702	H+ moles eq
Eutrophication	0.8	11.11	-788.66	-776.75	kg N eq
Carcinogens	0	59.89	-12,005,123.41	-12,005,063.52	kg benzene eq
Non-Carcinogens	0	502,481.49	-335.91	502,145.58	kg toluene eq
Respiratory Effects	0.75	204.47	-861.68	-656.46	kg PM2.5 eq

[79] Graphic Grades. *The Newark Group*. The Newark Group Inc., n.d. Web. 6 Apr. 2012, <http://www.newarkgroup.com/products/graphic-grades.aspx>.

PAPER DISPOSAL CONCLUSIONS

The impacts of throwing 1kg of paper in the trash or the recycling are compared in Table 4.34 and the overall impacts of Wellesley College's paper waste being thrown in the trash or placed in the recycling is compared in Table 4.35.

Table 4.34: Comparison of Impacts for Placing 1kg of Paper in the Trash or in the Recycling.

Impact Category	Impact per 1kg Thrown in Trash	Impact per 1kg Recycled	Unit
Global Warming	1.22	-0.49	kg CO2 eq
Acidification	0.82	-0.0073	H+ moles eq
Eutrophication	0.82	-0.0048	kg N eq
Carcinogens	177.40	-82.2	kg benzene eq
Non-Carcinogens	177.46	3.44	kg toluene eq
Respiratory Effects	0.82	-0.0045	kg PM2.5 eq

Table 4.35: Comparison of Total Impacts for Placing Paper in the Trash or in the Recycling.

Impact Category	Total Impact for 154,898.74 kg Thrown in Trash	Total Impact for 146,047.7 kg Recycled	Unit
Global Warming	188,604.71	-71,889.95	kg CO2 eq
Acidification	127,370.14	-702	H+ moles eq
Eutrophication	127,017.39	-776.75	kg N eq
Carcinogens	27,479,036.88	-12,005,063.52	kg benzene eq
Non-Carcinogens	27,487,695.38	502,145.58	kg toluene eq
Respiratory Effects	127,017.08	-656.46	kg PM2.5 eq

The impacts of paper disposal differ by facility. Across the board, the impacts from the processes SEMASS were the highest. Overall, the credit for recycling paper creates a 'negative' impact for recycling.

Critical Areas in the Life Cycle of Paper

The most problematic effects encountered in the life cycle of paper-based materials, such as corrugated cardboard, boxboard, mixed paper, and office paper, are found in the extraction of raw materials when analyzed per kg of manufacturing, and the incineration stage of the materials life. Overall it is better to recycle paper, keep it from being incinerated and ultimately decrease the overall demand of virgin wood for paper manufacturing. Paper-based materials are made from trees and therefore the production of paper requires large amounts of wood. The high demand of wood for paper manufacturing ultimately results in a great deal of deforestation. Production of wood and non-wood forest products is the primary function for 34 percent of the world's forests.[80] Deforestation creates various environmental problems, like the destruction of entire ecosystems and the reduction of carbon storage sinks.

When analyzing the problematic effects of paper by the total impacts of annual paper waste at Wellesley College, it is clear that incinerating paper at SEMASS has the most problematic effects.

Assessment of Wellesley College's Handling of Paper

The best available option at Wellesley for the disposal of paper products is recycling. In Table 4.34, we compared the total and per 1 kg impacts of recycling versus incineration to find that recycling is generally the best option. The largest impact per 1 kg is of non-carcinogens produced through incineration, with 177.46 kg of toluene equivalents per kg of paper waste. The total annual impacts from WTE are much higher than the impacts from recycling since the recycling credits were high and the Conigliaro facility did not create any impacts beyond transportation. In comparison, the credits for the generation of energy were relatively low for SEMASS, particularly when compared to the impacts of transportation to SEMASS and the incineration process.

[80] Global Forest Resources Assessment of 2005: Progress Toward Sustainable Forest Management. *Food and Agriculture Organization.* Forestry Paper. 147 (2006). Web. 10 Apr. 2012, <http://www.fao.org/docrep/008/a0400e/a0400e00.htm>.

2.5 Plastics

Plastic is a versatile material that is now quite pervasive in our daily lives. Plastic products, from beverage containers to polystyrene cushioning ('Styrofoam'), comprise a large portion of the waste stream at Wellesley College and present a recycling challenge for our waste handling system. Here, we will discuss plastics by number category, which range from #1 to #6, as well as plastic bags and wraps. We will examine what makes these plastics different from each other and their major uses on campus. Then, we will complete a life cycle analysis to determine the impacts of plastics manufacturing, use and disposal in order to inform recommendations for best practices for plastics use at Wellesley College.

Plastics Manufacture

All plastics are made from petroleum, which is derived from non-renewable fossil fuels such as oil and natural gas. In 2006, about 331 million barrels of petroleum and natural gas were used to make plastic products in the United States.[1] Hydrocarbon chains form various polymers when placed in specific temperature and pressure conditions. These conditions will vary according to the type of plastic being manufactured, and are discussed below.

Oil is a non-renewable resource formed by organic decomposition under high heat and pressure over millions of years. Oil is extracted from the ground by drilling, refined into various fuel products and then used as a fuel source or as a raw material for plastics. The machinery used to extract oil emits methane, a greenhouse gas, and other air pollutants. The oil extraction process requires large quantities of water, contaminates local water supplies by spills and contamination. The oil refinement process produces solid waste containing high levels of heavy metals and toxic compounds.[2]

Natural gas is a non-renewable resource formed from the decomposition of organic matter in high temperature and pressure conditions for thousands of years. Natural gas is extracted from the ground by drilling, treated for impurities and then used as a fuel source or as a raw material for plastics manufacture. The extraction of natural gas causes habitat destruction, erosion, landslides and loss of soil productivity.[3]

Table 5.1 quantifies the ecosystem impacts of the manufacture of all plastics, except for plastic bags and wrap.

Table 5.1: Additional Ecosystem Impacts for the Manufacture of Plastics (excluding plastic bags and wrap).

Erosion	Permanent Land Disruption	Water Use	Resource Use	Biodiversity Disruption	Total Score
1	1	1	1	1	**5**

Since plastics are produced from natural gas or crude oil, the majority of the ecosystem impacts from the manufacture of this material are a result of natural gas and oil extraction. Both

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[1] How Much Oil Is Used to Make Plastic? – FAQ. *U.S. Energy Information Administration.* n.d. Web. 29 Feb. 2012. <http://www.eia.gov/tools/faqs/faq.cfm?id=34&t=6>.

[2] Oil. *U.S. Environmental Protection Agency*. 28 Dec. 2007. Web. 22 Mar. 2012. <http://www.epa.gov/cleanenergy/energy-and-you/affect/oil.html>.

[3] Natural Gas. *U.S. Environmental Protection Agency*. 27 Dec. 2007. Web. 22 Mar. 2012. < http://www.epa.gov/cleanenergy/energy-and-you/affect/natural-gas.html>.

processes require intensive drilling, which causes erosion, permanent land disruption, water use and biodiversity disruption.[4] As both natural gas and oil are non-renewable resources, they earn a high resource use score. Thus, most plastics received a total ecosystem impact score of 5, the highest possible score, which indicates that the manufacture of plastics is very harmful to ecosystems.

Two types of plastic have a slightly different manufacturing process from the rest of the plastics. Plastic #3, or polyvinyl chloride, consumes less petroleum than other plastics because it is partially made of chlorine, which is derived from common rock salt.[5] Also, the polymerization reaction for polyvinyl chloride generates heat and needs to be cooled constantly, using about 30 gallons of water per pound of plastic produced.[6] Despite the minor differences, plastic #3 received a total ecosystem impact score of 5, which is the same as the other plastics.

Plastic bags are also manufactured slightly differently. Although the general oil extraction process has significant potential to pollute ground and standing water nearby,[7] the specific manufacturing process for a plastic bag is quite water-efficient (especially when compared to non-plastic materials). It takes 1,004 gallons of water to make 1,000 paper bags, and 58 gallons to make 1,500 plastic bags.[8] Overall, plastic bags and wraps earn a 4.5 for environmental disruption, mostly for the effects of oil extraction, as shown in Table 5.2.

Table 5.2: Additional Ecosystem Impacts of Plastic Bags and Wraps.

Erosion	Permanent Land Disruption	Water Use (quantity)	Resource Use	Biodiversity Disruption	Total Score
1	1	0.5	1	1	**4.5**

[4] "Natural Gas. *U.S. Environmental Protection Agency*. 27 Dec. 2007. Web. 22 Mar. 2012. < http://www.epa.gov/cleanenergy/energy-and-you/affect/natural-gas.html>.; Oil. *U.S. Environmental Protection Agency*. 28 Dec. 2007. Web. 22 Mar. 2012.

[5] Polyvinyl Chloride PVC. *Plastipedia: The Plastics Encyclopedia*, n.d. Web 18 Apr. 2012. <http://www.bpf.co.uk/plastipedia/polymers/pvc.aspx>.

[6] Malin, N. and Wilson, A. Should We Phase Out PVC? *Environmental Building News Vol. 3,* BuildingGreen. 1 Jan. 1994. Web. 17 Apr. 2012. <http://www.buildinggreen.com/auth/article.cfm/1994/1/1/Should-We-Phase-Out-PVC/>.

[7] Ellis, S. Et. Al. Plastic Grocery Bags: The Ecological Footprint. *Vancouver Island Public Interest Research Group*, 2005. Web. 28 Mar. 2012. <http://www.vipirg.ca/archive/publications/pubs/student_papers/05_ecofootprint_plastic_bags.pdf>.

[8] Review of the Life Cycle Data Relating to Plastic, Compostable, Biodegradable, and Reusable Grocery Bags. *Use Less Stuff Foundation*., Jun. 2007. Web. 28 Mar. 2012. <http://www.use-less-stuff.com/Paper-and-Plastic-Grocery-Bag-LCA-Summary.pdf>.

Plastic #1: Polyethylene Terephthalate (PETE)

Plastic #1 Background

Plastics with the number 1 recycling code are made from polyethylene terephthalate (PET or PETE), a resin of the polyester polymer family. It is a thermoplastic, meaning that it can be molded with sufficiently high heat. PETE is strong, yet lightweight. It is stiff, heat resistant, and clear. Additionally, PETE acts as an effective barrier to gas and moisture, and is therefore widely used in synthetic fibers, beverage bottles (e.g. water, soft drinks), spread jars (e.g. peanut butter), household product containers (e.g. mouthwash), and microwavable film and food trays.[9] PETE is derived from crude oil and natural gas.[10]

Bottle caps and neck rings on PETE bottles are made from polypropylene, or #5 plastic, which is a different type of plastic.[11]

Uses of Plastic #1 at Wellesley College

One major use of PETE on campus is containers for beverages such as water, carbonated drinks, and juices. Beverage products packaged in PETE are sold from vending machines located in various buildings around campus, or are brought from off-campus. A large portion of food containers sold by auxiliary food services (e.g. the Emporium and the Leaky Beaker), such as peanut butter jars and microwavable food trays, are also packaged with PETE. Household and personal care products, such as mouthwash, are also often packaged in PETE containers.

Activities and Behaviors Producing Plastic #1 Waste at Wellesley College

PETE waste on campus is largely a result of the consumption of beverages sold in individual disposable bottles and of non-dining hall meals, such as packaged frozen foods. Additionally, on-campus events provide large quantities of individual products, like water bottles, for attendees to consume, leading to another significant contribution of #1 plastic waste at Wellesley College. The residential nature of the college leads to PETE waste from the discarding of used personal care products.

Amount of Plastic #1 Waste Produced at Wellesley College

The amount of #1 plastic waste produced annually at Wellesley College is 5,588.99 kg, as shown in Table 5.3. The uses of plastics #1 by percentage is displayed in Figure 5.1.

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[9] Best Practices and Industry Standards in PET Plastic Recycling. *National Association for PET Container Resources*, 2012. Web. 25 Feb. 2012. <http://www.napcor.com/pdf/Master.pdf>; Plastic Packaging Resins. *American Chemistry Council*, 2012. Web. 25 Feb. 2012. <http://plastics.americanchemistry.com/Plastic-Resin-Codes-PDF>.

[10] PET Basics. *Resin Association*, 2012. Web. 25 Feb. 2012. <http://petresin.org/faq.asp>.

[11] Why Can't You Recycle Plastic Bottle Caps? *National Public Radio*, 2008. Web. 25 Feb. 2012. <http://www.npr.org/templates/story/story.php?storyId=92510162>.

Table 5.3: Estimated Annual #1 Plastic Waste at Wellesley College.

Material	Weight per unit (g/unit)	# Units per kg	# Units Produced Annually	Total Produced Annually (kg)
Beverage Bottles	12.7	78.70 bottles	248,260 bottles	3,152.90
Spread Jars	30	33.30 jars	27,600 jars	828
Microwavable Food Trays	70	14.29 trays	2,000 trays	140
Household and Personal Product Containers	80	12.50 containers	12,000 containers	960
Miscellaneous	-	-	-	508.09
Total				**5,588.99 kg**

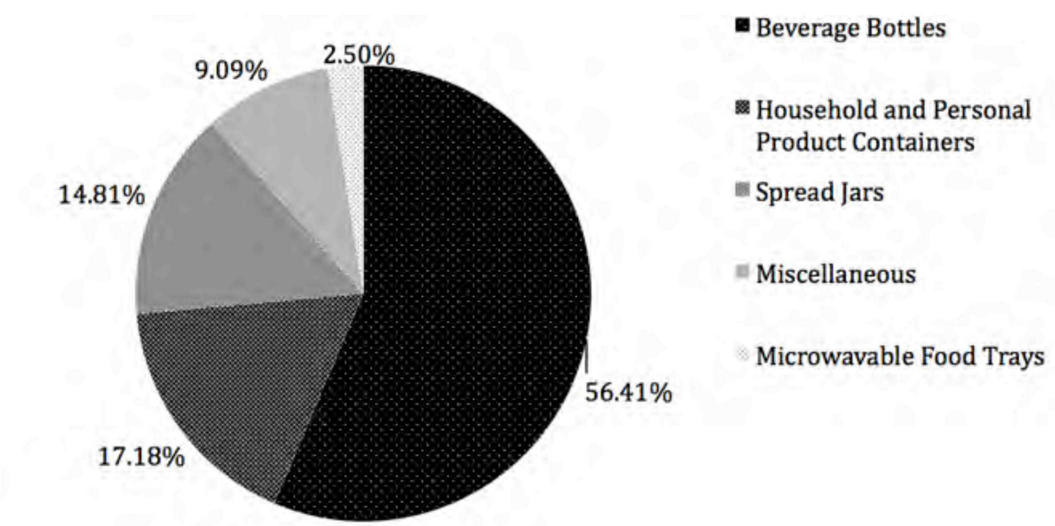

Figure 5.1: **Distribution of the material uses of plastic #1.**

We assumed that Wellesley College community members, including students, faculty and staff, each discard, on average, one PETE beverage bottle per week from personal consumption. This number is small because dining halls provide beverages that are not packaged in PETE bottles, thereby reducing students' need to purchase them. In addition, a sizable portion of Wellesley College students generally carries reusable water bottles to classes and to daily activities on campus. We assumed that the campus holds a population of 3,200 people at any one time during the academic year, including faculty and staff and excluding half the junior class that is abroad. Therefore, during the academic school year, we estimated that 102,400 PETE beverage bottles are discarded. We assumed that only one third of the full population is present during the summer and winter months, taking into account the occurrence of events such as Explo, summer and Wintersession classes that bring people to campus on a daily basis. However, we also assumed that people on campus use and discard more PETE beverage bottles outside the academic year when fewer dining services locations are open. With 1,067 people on campus and assuming that each person discards 5 bottles per week, we estimated that people on campus discard 85,360 bottles during the four non-academic months. The total number of PETE beverage bottles discarded on-campus through personal use is therefore estimated to be 187,760 bottles.

We estimated PETE beverage bottle use from on-campus catered events using the number of events on the campus calendar. Approximately 75 small-scale (20-50 people) and 3 medium-scale (75-125 people) catered events occur per month. Additionally, 5 campus-wide catered events occur per semester. We estimated that all students (2,000, which excludes juniors studying abroad) and 100 additional faculty and staff members attend campus-wide events. Assuming that each person attending an event uses one beverage bottle on average, the total number of bottles discarded from these events during each academic year is approximately 54,000. Bottled water is also included in Wellesley Fresh bag lunches. We estimated that 50 lunches are requested each day during a semester, and therefore 6,500 bottles are discarded in an academic year. The weight of an average PETE beverage bottle is 12.70 g.[12] In total, around 248,260 PETE beverages bottles are discarded annually, which totals 3,152.90 kg of PETE waste discarded.

PETE jars for spreads such as peanut butter and chocolate are discarded by non-dining hall entities (students and auxiliary food services such as El Table and Café Hoop), as peanut butter purchased by Wellesley Fresh does not come in PETE containers. Since a vast majority of students eat at the dining halls and therefore have a lesser need to purchase their own jars of spread, the number of student food jars discarded is estimated to be, on average, one per month per student during the academic year. This may be an overestimation as not every student engages in this behavior, and many spreads are packaged in glass. This estimation can, however, also take into account the higher volume of PETE spread jars used over the winter and summer months. We estimated that students use 27,600 PETE jars in a year, and that each jar weighs around 30 g. The total weight of discarded PETE food jars is about 828 kg annually.

We also estimated that each student discards one microwavable PETE food tray per month per person on average. This number may be an overestimate for the time period during which Wellesley Fresh is open, but it accounts for the more frequent consumption of packaged meals over the summer and winter months. Each food tray weighs around 70 g. With 2,000 students on campus during the academic school year, the campus discards around 161 kg of PETE microwavable food trays annually.

To estimate the number of PETE household and personal product containers used at Wellesley College, we assumed that each student uses 2 PETE-packaged products (e.g. shampoo and mouthwash), and discards the empty containers once every two months. During the academic year, this use amounts to 8,000 containers discarded annually, assuming that 2,000 students live on campus (which excludes juniors studying abroad). During the winter and summer months, around 1,000 students are present on campus. Students during the winter and summer therefore discard around 4,000 containers. We estimated that an average container weighs 80 g. In total, around 960 kg of PETE household and personal product containers are

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[12] Earth Day 2010 Finds Weight of Plastic Water Bottles Reduced by 32%, while Maintaining a Very Small Environmental Footprint. *International Bottled Water Association.* 15 Apr. 2010. Web. 13 Mar. 2012. <http://www.bottledwater.org/news/earth-day-2010-finds-weight-plastic-water-bottles-reduced-32-while-maintaining-very-small-envir>.

discarded annually. The total amount of PETE plastic waste produced annually on campus is about 5,588.99 kg.

Handling and Destination of Plastic #1 Waste at Wellesley College

From our waste audit, we found that 13.88 kg of PETE plastics were discarded in the trash in one week. As the New Dorms house 400 people, we calculated that one student discards around 0.0347 kg of PETE plastics per week. From this we calculated that the entire campus, with roughly 2,000 students (which excludes juniors studying abroad) and 1,200 faculty and staff, discards 2,075 kg of PETE plastics in the trash each academic year. This equates to 54% of the total amount of PETE plastic waste produced on campus. From our PETE trash and total waste percentages, we then extrapolated a 46% recycling rate. The portions of PETE plastic waste sent to recycling and MSW-handling facilities are estimated in Table 5.4.

Table 5.4: Destination of #1 Plastic Waste by Percentage.

	Conigliaro	**SEMASS**
% of Waste	46%	54%
Weight of Waste (kg)	2,570.94	3,018.05

PETE plastics that are recycled at Wellesley College are sent to the Conigliaro Industries recycling facility. We estimated that 46%, or about 2,570.94 kg, of PETE plastics waste from Wellesley College is sent to Conigliaro Industries annually.

PETE plastics that are disposed of in the trash at Wellesley College are sent to the SEMASS waste-to-energy facility. We estimate that 54% of PETE plastic waste, or 3,018.05 kg, is sent to SEMASS annually.

Abridged Life Cycle of #1 Plastic Used at Wellesley College

At Wellesley College, PETE plastic is primarily used in beverage containers, found in the form of water bottles. An abridged life cycle diagram for water bottles from production to disposal is displayed in Figure 5.2.

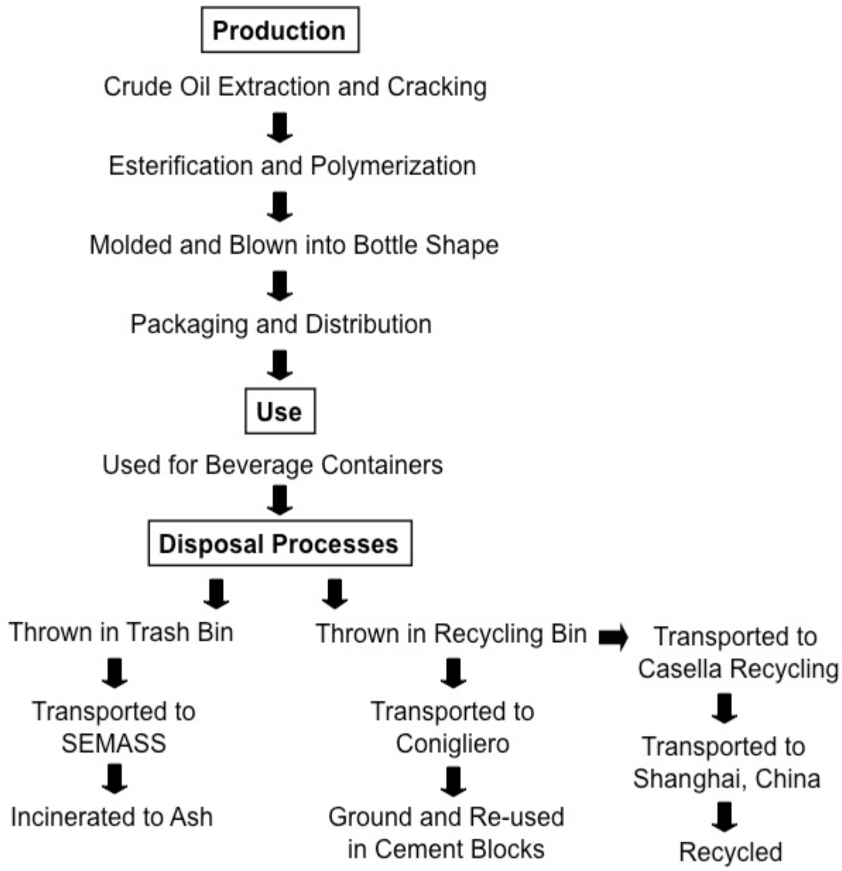

Figure 5.2: **Abridged Life Cycle for PETE Water Bottles.**

#1 Plastic Source Background

Virgin #1 plastic resin is made from polyethylene terephthalate, a type of polyester formed from the esterification of terephthalic acid with ethylene glycol, or the transesterification of dimethyl terephthalate with ethylene glycol.[13] These reactants are derived from the catalytic cracking of crude oil (naphtha) into gasoline.[14]

Manufacturing of #1 Plastic

The most prevalent source of PETE waste on campus is in the form of water bottles, which are manufactured from PETE resin. As mentioned earlier, virgin PETE is produced from the polymerization of the monomer ethylene terephthalate after the esterification or

[13] Polyesters. *Ullmann's Encyclopedia of Industrial Chemistry*. 15 Jun. 2000. Web. 29 Mar. 2012. <DOI: 10.1002/14356007.a21_227>; "Polyethylene Terephthalate (PET)."; *U.S. LCI Database Project: Data Module Report*. PE International, 26 Apr. 2007. Web. 29 Mar. 2012. <http://documentation.gabi-software.com/sample_data/processes/MR_PolyethyleneTerephthalate(PET)-UnitProcess.pdf>.
[14] Origin of Commonly Used Plastics. *General References*. Export911, n.d. Web. 29 Mar. 2012. <http://www.export911.com/ref/oriPlast.htm>.

transesterification process.[15] Resin pellets are dried, compressed and melted, and then placed into an injection molding machine, which molds the PETE into a test-tube shaped preform. The PETE preform is heated, stretched, and blown into a mold to form a PETE bottle.[16] This process uses energy inputs to fuel the plastic forming machinery.

Manufacturing and Use Impact Assessment for #1 Plastic

The impacts of manufacturing virgin PETE, including impacts from the extraction of oil, are displayed in Table 5.5.

Table 5.5: Total impact values for #1 plastic container material extraction and manufacture per 1 kg of material.

Impact Category	Impact per 1 kg	Total Annual Impact For 5,588.99 kg	Unit
Global Warming	4.65	25,988.80	kg CO2 eq
Acidification	1.21	6,762.68	H+ moles eq
Eutrophication	0.000596	3.33	kg N eq
Carcinogens	0.000274	0.83	kg benzene eq
Non-Carcinogens	0.69	3,856.40	kg toluene eq
Respiratory effects	0.0042	23.47	kg PM2.5 eq

PLASTIC #2: HIGH DENSITY POLYETHYLENE (HDPE)

Plastic #2 Background

Plastic #2, or high-density polyethylene (HDPE), is a thermoplastic. HDPE is formed by a process known as cracking, which puts petroleum under extreme heat to produce ethylene gas. The gas molecules then link together, forming polymers, and these chains form into polyethylene.[17] HDPE is composed of linear polyethylene molecules, which are much stronger than branched low-density polyethylene (plastic #4).[18]

Plastic #2 is much sturdier than most other plastics and is less susceptible to breaking down and leaching toxins. Because plastic #2 is a strong non-toxic material, it is often used to contain food and beverages.

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[15] Polyesters. *Ullmann's Encyclopedia of Industrial Chemistry*. 15 Jun. 2000. Web. 29 Mar. 2012. <DOI: 10.1002/14356007.a21_227>.

[16] PET Preform/Bottle Project. *KenPlas Plastics Projects*. KenPlas Industry Ltd., 2012. Web. 29 Mar. 2012. <http://www.kenplas.com/project/pet/>.

[17] Welcome to Bottle 2 Bottle. n.d. Web. 29 Feb. 2012. < http://www.bottle2bottle.com/making-hdpe.asp>.

[18] Polyethylene. *University of Southern Mississippi*, 2005. Web. 29 Feb. 2012. < http://pslc.ws/macrog/pe.htm>.

Uses of Plastic #2 at Wellesley College

On campus, plastic #2 is commonly found in drink and food containers such as milk, yogurt, and margarine containers.[19] Laundry detergent bottles, shampoo bottles, and cleaning supply containers are also often packaged in plastic #2. Plastic #2 food and beverage containers are primarily used in the dining halls, but students also purchase products with plastic #2 packaging, on a smaller scale. Dining hall food packaging comprises the bulk of plastic #2 waste on campus.

Activities and Behaviors Producing Plastic #2 Waste at Wellesley College

On campus, students use many hygiene products, such as shampoo, conditioner, and body wash, that are often packaged in plastic #2 bottles, and most of which are not recycled. The disposal of #2 plastic food and beverage containers used in the dining halls results in a large portion of #2 plastic waste on campus. Often, dining halls do not recycle all of their plastic waste.

Amount of Plastic #2 Waste Produced at Wellesley College

The total weight of #2 plastic waste discarded annually on campus is about 4,507.08 kg. Table 5.6 shows the materials composed of #2 plastic, the amount of units, and the total weight produced annually.

Table 5.6: Estimated Annual #2 Plastic Waste at Wellesley College.

Material	Weight per unit (kg/unit)	# Units per kg	# Units Produced Annually	Total kg Produced Annually (accounting for 10% error)
Laundry Detergent Bottles	0.15	6.67	4,600	759
Shampoo and Toiletry Bottles	0.04	25	13,800	607.20
One-Gallon HDPE Containers used by dining services	0.33	3.03	4,021.33	2,286.69
Juice Jugs	0.40	2.50	1,941.33	854.19
Total				**4,507.08**

[19] HDPE Bottles | Content from Waste360. *Waste360*. 24 Feb. 2004 .Web. 29 Feb. 2012. <http://waste360.com/mag/waste_hdpe_bottles_2>.

Figure 5.3 shows the distribution of materials by weight of plastic #2 disposed of at Wellesley College.

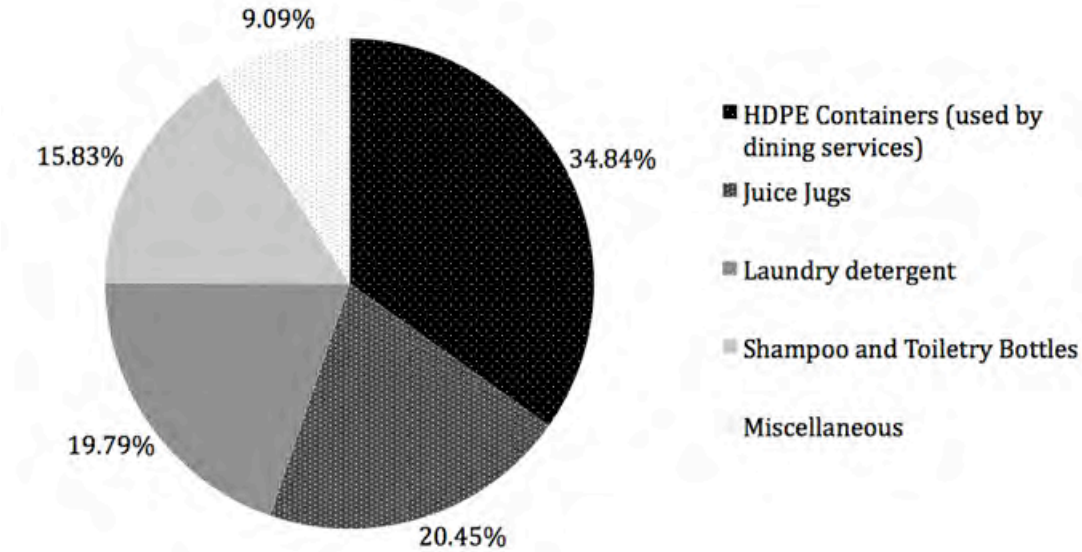

Figure 5.3: **Distribution of #2 Plastic Waste Sources at Wellesley College.**

We estimated the number of laundry detergent bottles disposed of at Wellesley College by assuming that each student does an average of 1 load of laundry every 2 weeks. This assumption is based upon the notion that some students do laundry more, and others less often than every two weeks, making our estimation an approximate average. An average bottle of laundry detergent (50 oz) contains enough detergent for about 32 loads.[20] One bottle of laundry detergent, then, would last a student 4 months, or about one semester. The weight of a laundry detergent bottle is estimated to be 0.15 kg and 7 bottles weigh 1 kg.[21] We multiplied the total weight of this material by the number of units, 4600 (determined by each of the 2300 students on campus disposing of 2 bottles annually), by the weight of 1 unit (0.15 kg). Since this estimation is a bottom-up calculation, we added 10% of the total to the final total; therefore, the total weight of HDPE laundry detergent bottles disposed of annually at Wellesley College is about 759 kg.

We estimated the number of shampoo, conditioner, and body/face wash bottles disposed of at Wellesley College by assuming that each student goes through about 6 total bottles within this category per year. This assumption is based on students using 3 bottles (1 shampoo, 1 body wash, and 1 conditioner) per semester. This is most likely an over-estimation; however, it is meant to account for other hygiene products contained in HDPE bottles used by students. On average, an empty bottle weighs approximately 0.04 kg,[22] so 25 bottles equal 1 kg. We therefore calculated that the total weight of HDPE shampoo and other toiletry bottles disposed of annually at Wellesley College is about 607.2 kg by multiplying the number of units (13,800 bottles) by the weight and adding an additional 10% to the total weight.

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[20] Tide Original Liquid Laundry Detergent. *Tide*. n.d. Web. 5 Apr. 2012. <http://www.tide.com/en-US/product/tide-original.jspx#info>.
[21] United States. Environmental Protection Agency. *Standard Volume-to-Weight Conversion Factors*. 2006. Print.
[22] United States. EPA. *Standard Volume-to-Weight Conversion Factors*. 2006. Print.

We estimated the number of HDPE containers (i.e. dressing, cooking oil, cleaning supplies and syrup) disposed of by dining services by extrapolating the amount that Bates dining hall goes through each week. According to the Bates dining hall manager, Kevin Kesterson, in one week, Bates dining hall goes through about 6 one-gallon dressing tubs, 4 one-gallon syrup bottles, 1 one-gallon vinegar bottle, 7 one-gallon cooking oil bottles, 1 one-gallon cooking wine bottle, 5 one-gallon bottles of cleaning supplies, and 5 one-gallon Thai chili sauce bottles per week, for a total of 29 one-gallon containers per week.[23] A one-gallon jug weighs 0.33 kg,[24] and 3 tubs weigh 1 kg. Bates, Tower and the Campus Center put out about the same amount of food per week, while Pomeroy and Stone-Davis put out about 1/3 less than the other dining halls.[25] We used 2/3 of the Bates number to calculate the amount of containers that Stone-Davis and Pomeroy use. By multiplying the number of units Bates goes through per week by the three dining halls for an 8-month year, we calculated that the larger dining halls (Bates, Tower, and the campus center) go through 2784 units per year, and the smaller dining halls (Pomeroy and Stone-Davis) go through 1,237.33 units per year. In total, Wellesley Fresh goes through 4,021.33 units of HDPE food containers per year. We estimated that the total amount of HDPE food tubs disposed of annually is about 2,286.69 kg by multiplying the number of units the dining hall disposed of annually by the weight of 1 unit and adding 10% of the total weight to account for miscellaneous sources.

We estimated the number of juice containers by the same method used to find the number of food containers. Bates goes through about 14 three-liter juice inserts per week.[26] Thus, Wellesley Fresh goes through 1,941.33 total juice jugs per year (1,344 from the larger dining halls and 597.33 from the smaller dining halls). A three-liter jug weighs 0.4 kg and there are about three jugs in 1 kg. The total amount of HDPE juice jugs disposed of annually is about 854.19 kg.

Handling of Plastic #2 Waste at Wellesley College

The portions of #2 plastic waste that are recycled and thrown in trash are estimated in Table 5.7.

Table 5.7: Estimated Handling of #2 Plastic Waste at Wellesley College.

Material	% Recycled	% Thrown in Trash
Laundry Detergent Bottles	20%	80%
Shampoo and Toiletry Bottles	17%	83%
Cleaning Supply Containers	90%	10%
Food Containers	70%	30%
Milk and Juice Jugs	70%	30%
Total	**53.4%**	**46.6%**

Even though we did not find any laundry detergent bottles during our New Dorms recycling audit, we assumed that a small percentage of these containers are recycled since recycling bins are easily accessible in dorms. We estimated that each student throws away a

[23] Kesterson, Kevin. Manager of Bates Dining Hall. Interview. 4 Apr. 2012.
[24] United States. EPA. *Standard Volume-to-Weight Conversion Factors*. 2006. Print.
[25] Kesterson, Kevin. Manager of Bates Dining Hall. Interview. 4 Apr. 2012.
[26] Kesterson, Kevin. Manager of Bates Dining Hall. Interview. 4 Apr. 2012.

laundry detergent container about once a semester, so one week of recycling would not give an accurate perspective of its disposal.

We estimated that about 80% of laundry detergent bottles are thrown in the trash and about 20% are recycled. We believe that this is a fair assumption because no laundry detergent bottles were found in the recycling bin during our audit, but it is likely that at least a small percentage is recycled.

During our recycling audit of the New Dorm Complex, about 15 shampoo and toiletry bottles were found. Based on this result, we calculated that 2,400 bottles are recycled per year from all the residence halls on campus. Based upon the fact that 2,400 out of 14,000 shampoo bottles are assumed to be recycled annually, we estimated that about 83% of shampoo/toiletry bottles are disposed of as trash, and 17% are disposed of as recycling.

Based on an interview with custodial supervisor Jane Simmons, cleaning supply containers are recycled at a rate of about 90%,[27] leaving 10% of cleaning supplies to be disposed of in the trash. We assumed that although recycling of cleaning supply containers is expected, not all are recycled. We believe that this is a fair assumption because during out waste audit, we found pre-sorted recyclables that never made it to the recycling bin. Due to our findings, it is difficult to assume that everything intended for recycling makes it to the recycling facility.

Based on data collected from our waste audit and an interview with Kevin Kesterson, we assumed that 70% of both food containers and milk and juice jugs used by Wellesley Fresh are recycled. Kesterson stated that all recyclable materials are rinsed and recycled in Bates dining hall and in all the other dining halls.[28] However, during our waste audit, we found enormous quantities of recyclable materials from the Bates dining hall in the trash. Based upon this finding, we cannot assume that Wellesley Fresh recycles all of its recyclable materials.

Destination of Plastic #2 Waste

We estimated that in one year, Wellesley College sends 53.4% of #2 plastic waste (2,406.78 kg) to Conigliaro to be recycled. We also estimated that Wellesley College sends 46.6% of #2 plastic waste (2,100.30 kg) to SEMASS annually for incineration. The portions of #2 plastic waste sent to recycling and MSW-handling facilities are estimated in Table 5.8.

Table 5.8: Destination of #2 Plastic Waste by Percentage.

	Conigliaro	**SEMASS**
% of Waste	53.4%	46.6%
Weight of Waste (kg)	2,647.56	2,100.30

Abridged Life Cycle of Plastic #2 Produced at Wellesley College

At Wellesley College, #2 plastics are primarily found in shampoo and conditioner bottles. An abridged life cycle diagram for shampoo and conditioner bottles from production to disposal is displayed in Figure 5.4.

[27] Simmons, Jane. Custodial Supervisor. Personal interview. 28 Mar. 2012.
[28] Kesterson, Kevin. Manager of Bates Dining Hall. Interview. 4 Apr. 2012.

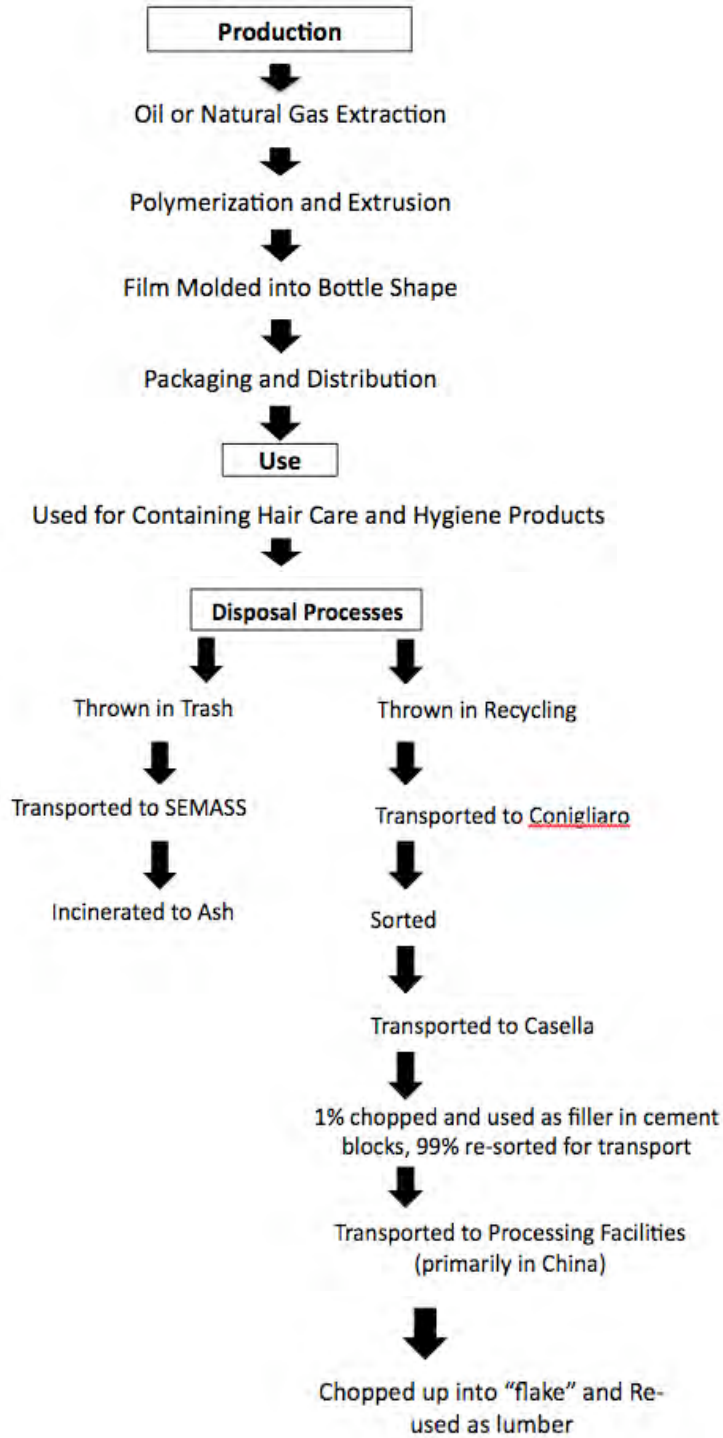

Figure 5.4: **Abridged Life Cycle for HDPE Shampoo Bottles.**

Plastic #2 Source Background

HDPE is made from polyethylene, which is produced by modifying natural gas or 'cracking' crude oil into gasoline.[29] Cracking is the process in which monomers of ethylene are broken up into long polymer chains of ethylene.[30] Both natural gas and crude oil are derived from underground reservoirs through drilling.

Manufacturing of Plastic #2

After refinery, gasoline is sent to a polymerization plant. Ethylene gas is heated under high pressure in a low oxygen environment, and then converted into a solid phase. In addition to the natural gas or oil used to form the polyethylene, raw materials and energy are necessary to run the production machinery.[31] Unlike LDPE, HDPE is composed of very straight chains of ethylene with minimal branching, creating a stiffer and denser plastic. The raw HDPE is made into small pellets, which are then melted and 'blown' into sheets and then molded into products such as shampoo bottles.[32]

Manufacturing and Use Impact Assessment for Plastic #2

The impacts of the manufacture of #2 plastics are quantified in Table 5.9. We calculated the total impact of shampoo bottles by multiplying the impact value by the weight of shampoo bottles disposed of annually at Wellesley College, 4,507.08 kg.

Table 5.9: Total impact values for #2 plastic bottle material extraction and manufacture per 1 kg of material and for total plastic #2 waste.

Impact Category	Impact per 1 kg	Total Annual Impact (4,507.08 kg)	Unit
Global Warming	3.06	13,791.66	kg CO2 eq
Acidification	0.81	3,650.73	H+ moles eq
Eutrophication	0.00037	1.67	kg N eq
Carcinogens	0.023	103.66	kg benzene eq
Non-Carcinogens	21.66	97,623.35	kg toluene eq
Respiratory effects	0.0029	13.07	kg PM2.5 eq

[29] Lepoutre, P. The Manufacture of Polyethylene. *The New Zealand Institute of Chemistry*. 4 Apr. 2012. Web. <nzic.org.nz/ChemProcesses/polymers/10J.pdf>.

[30] Lepoutre, P. The Manufacture of Polyethylene. *The New Zealand Institute of Chemistry*. 4 Apr. 2012. Web. <nzic.org.nz/ChemProcesses/polymers/10J.pdf>.

[31] Aranda, A., Zabalza I., Scarpellini, S., and Valero, A.. Analysis of the Energy Costs and Potential Savings in a Polymer Industry. Case Study and Methodology. *Center of Research for Energy Resources and Consumption*. n.d. Web. 4 Apr. 2012. <teide.cps.unizar.es:8080/pub/publicir.nsf/codigospub/.../cp0280.pdf>.

[32] Lepoutre, P. The Manufacture of Polyethylene. *The New Zealand Institute of Chemistry*. 4 Apr. 2012. Web. <nzic.org.nz/ChemProcesses/polymers/10J.pdf>.

PLASTIC #3: POLYVINYL CHLORIDE

Plastic #3 Background

Plastic #3, or polyvinyl chloride (PVC), is a plastic made of a long string of vinyl chloride monomers that are derived from carbon and salt.[33] PVC is versatile, inert and durable, and therefore it is often used in construction materials, car parts and sports equipment.[34] Depending on the intended use of PVC, plasticizer compounds, such as phthalates, or stabilizer compounds, such as lead and cadmium, are added to achieve desired traits, including flexibility and a higher melting point.[35] After plasticizers are added, PVC can be used to make packaging products, PVC pleather (artificial leather),[36] electric cables, and shrink wrap; stabilized PVC can also be used in construction.[37] PVC is cheap to produce because its main component, chlorine, is easily manufactured from salt, thus making it a material of choice in many applications.[38]

Uses of Plastic #3 at Wellesley College

The use of PVC can be divided into long- and short-term uses. At Wellesley College, in the long term, PVC is used in construction materials such as water and sewage pipes, siding, window frames, and flooring, and it can also be found in the dashboards and seat covers of cars owned by students and faculty. Because of its insulating properties,[39] PVC covers the electric wires in office equipment, including fax machines, printers, and telephones. Additional long-term uses include PVC pleather clothing and accessories and shoes. Short-term uses of PVC include packaging materials, such as bubble wrap used to cushion fragile items in transit; plastic credit cards and phone cards; and shower curtains. Because PVC is an inert substance, and it effectively keeps materials sterile and is cheap to produce, it is often used in medical supplies such as tubing and blood bags.[40] For the same reasons, PVC is used to make single-use custodial and food service gloves, and cling film or shrink-wrap. PVC is also used in the packaging of containers including perfume bottles and body sprays. However, this use seems to be on the decline as a spot check in a small residential hall on Wellesley's campus found only one such PVC container.[41]

Activities and Behaviors Producing Plastic #3 Waste at Wellesley College

Students and faculty produce PVC waste at Wellesley College by disposing of their PVC products, including clothing and accessories, that are old or spoiled; expired credit and phone cards; and PVC containers. PVC bags, such as those that package comforters, also contribute to

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[33] What Is PVC?, *Pvc.org*, n.d. Web. 18 Apr. 2012. <http://www.pvc.org/en/p/what-is-pvc>.

[34] PVC's Physical Properties. *Pvc.org*, n.d. Web. 18 Apr. 2012. <http://www.pvc.org/en/p/pvcs-physical-properties>.

[35] PVC Additives. *Pvc.org*, n.d. Web. 18 Apr. 2012. <http://www.pvc.org/en/p/pvc-additives>.

[36] PVC in Consumer Goods. *Pvc.org*, n.d. Web. 18 Apr. 2012 <http://www.pvc.org/en/p/pvc-in-consumer-goods>.

[37] PVC Additives. *Pvc.org*, n.d. Web. 18 Apr. 2012. <http://www.pvc.org/en/p/pvc-additives>.

[38] Polyvinyl Chloride: PVC. *Plastipedia: The Plastics Encyclopedia*, n.d., Web. 18 Apr. 2012. <http://www.bpf.co.uk/plastipedia/polymers/pvc.aspx>.

[39] PVC Products. *Greenpeace International*, n.d. Web. 10 Apr. 2012. <http://www.greenpeace.org/international/en/campaigns/toxics/polyvinyl-chloride/pvc-products/>.

[40] , PVC Information. *International PVC Network and European Council of Vinyl Manufacturers*. n.d. Web. 10 Apr. 2012. <http://www.pvc.dk/billeder/faktaOmPvc/loesblade.pdf; 'PVC Products'>.

[41] PVC Audit. *Casa Cervantes*, April 15, 2012.

the PVC waste stream. Packaging materials, such as PVC bubble wrap, additionally generate PVC waste. The college may dispose of shower curtains that get torn or worn out, as well as other goods including broken electronics such as lamps, TVs, computers, and printers that contain PVC parts. Wellesley College's Health Services also disposes of medical supplies such as gloves that are made of PVC. Gloves that are used by custodial services in cleaning and gloves used in the dining halls while handling food are also disposed of after a single use. Finally, the PVC shrink wrap used by the dining halls to cover food in order to prevent contamination contributes to PVC waste on Wellesley's campus.

Amount of Plastic #3 Waste Produced at Wellesley College

The total amount of PVC waste produced at Wellesley College is presented in Table 5.10 below with calculations for each category of use following the table. The total amount of PVC waste produced on Wellesley's campus is calculated to be 13,054.70 kg.

Table 5.10: Amount of PVC waste produced at Wellesley College by material use.

Material	Weight per unit (g/unit)	# Units per kg	# Units Produced Annually	Total Produced Annually (kg)
Dining hall gloves	7.53	132.80	527,500	3,972.08
Custodial gloves	7.53	132.80	311,995.01	2,349.36
Shrink wrap (roll)	6,210.00	0.16	474.75	2,948.20
PVC bags & packaging	-	-	-	1,355.04
Containers	-	-	-	1,243.23
Miscellaneous	-	-	-	1,186.79
Total				**13,054.70**

The varied sources of PVC waste are represented in Figure 5.5 below. The largest source of PVC waste is PVC gloves.

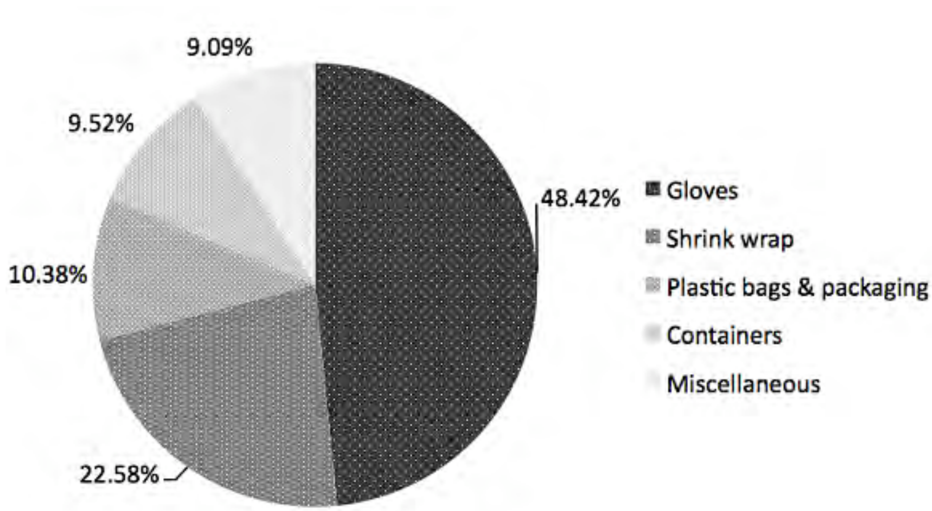

Figure 5.5: PVC waste by use on Wellesley's campus

The two main users of PVC gloves on campus are the dining halls and custodial services. We established that Bates dining hall, which serves about 400 students in the New Dorms Complex, uses about 10 cases of gloves per month, with each case containing 10 boxes of 100 gloves, and each custodian uses about one box of gloves per week.[42] Each case of gloves weighs approximately 7.53 kg.[43] Based on these figures we calculated that the dining halls use and dispose of 3,972.08 kg of gloves every year while custodians use 2,349.36 kg of PVC gloves. The total amount of PVC glove waste generated on Wellesley's campus is therefore 6321.44 kg.

We established that Bates dining hall, in serving the 400 students who live in the New Dorms Complex, uses approximately 9 rolls of PVC shrink-wrap per month. Each shrink wrap roll weighs approximately 6.21 kg.[44] Using these figures, we calculated that the total amount of shrink-wrap waste produced annually on campus is 2,948.20 kg.

Our waste audit found 6.80 kg of PVC waste, which was comprised of PVC bags and bubble wrap packaging. Extrapolating from this figure, we calculated that the annual amount of PVC bags and PVC packaging waste produced on Wellesley's campus is 1,355.04 kg.

We used the amount of PVC waste attributable to containers as reported by McMaster University's waste audit.[45] At McMaster University, a co-ed school where there are 20,300 students and 8,500 members of staff, the total amount of PVC container waste produced in a year was 10,230 kg. Scaling this to Wellesley's case, we estimate that a total of 1,243.23 kg of PVC container waste is generated annually at Wellesley.

In order to account for the PVC waste sources that we might have overlooked, could not measure, or underestimated, we added an extra 10% to our calculations. Our total weight therefore amounted to 1,186.79 kg.

Handling and Destination of Plastic #3 Waste at Wellesley College

All of the PVC waste generated on campus that is disposed of in the trash is presented in Table 5.11 below.

Table 5.11: Handling of PVC waste on Wellesley's campus.

Material	% Thrown in Trash	Amount thrown in trash (kg)
Dining hall gloves	100%	3,972.08
Custodial gloves	100%	2,349.36
Shrink wrap (roll)	100%	2,948.20
PVC bags & packaging	100%	1,355.04
Containers	100%	1,243.23
Miscellaneous	100%	1,186.79
Total	**100%**	**13,054.70**

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[42] Kesterson, Kevin. Manager of Bates Dining Hall. Interview. 16 Apr. 2012.
[43] Exam Powdered Medium Vinyl Glove Description. *Sysco Nashville*. n.d. Web. 16 Apr. 2012. <http://www.robertorrsysco.com/product.php?item_id=5679143&i_desc=glove>.
[44] PVC 2000ft Roll Film Description. *Sysco Nashville*. n.d. Web. 16 Apr. 2012. <http://www.robertorrsysco.com/product.php?item_id=7435332&i_desc=film>.
[45] Waste Audit Report. *McMaster University*. Mar. 2011. Web. 14 Apr. 2012. <http://www.mcmaster.ca/sustainability/documents/Waste%20Audit%202011.pdf>.

Some of the uses of PVC on campus, such as PVC shrink wrap and gloves, result in PVC waste discarded into the trash because they come into contact with food and other contaminants, and would therefore have to be cleaned in order to be recyclable, which does not happen. Regarding the other categories, none were found in the recycling audit done in the New Dorms or as reported by McMaster University.[46] Therefore, the amount of PVC that is disposed of in the trash is 13,054.70 kg. All of the PVC waste generated on campus, 13,054.70 kg, is sent to SEMASS facility for incineration and energy production.

Abridged Life Cycle of Plastics #3 Produced at Wellesley College

At Wellesley College, PVC is primarily found in the form of plastic wrap that is used to cover trays of food in the dining halls. Figure 5.6 shows an abridged life cycle diagram for PVC plastic wrap.

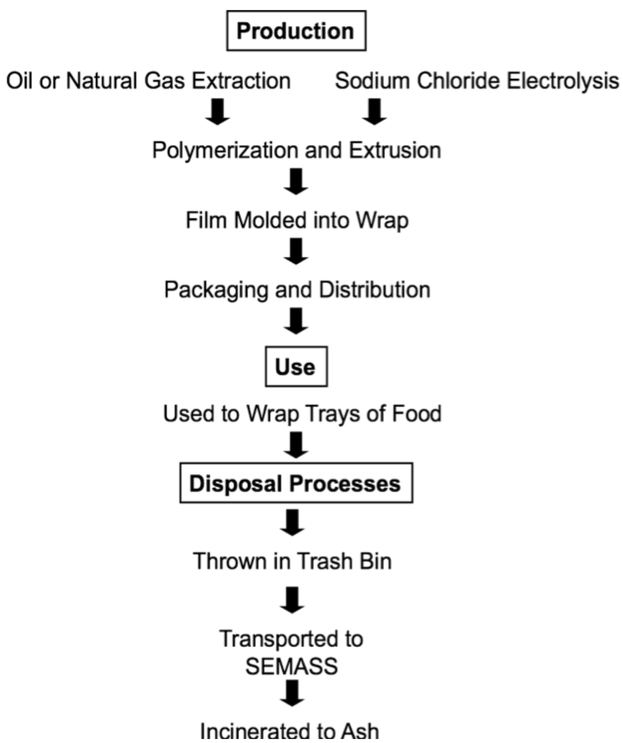

Figure 5.6: Abridged Life Cycle for PVC Wrap.

First, the raw materials in PVC are extracted. Then, the PVC is polymerized and extruded into plastic gloves, which are packaged and distributed. When the plastic gloves arrive at Wellesley College, they are used by dining halls and custodial services. Afterwards, all of the PVC waste is disposed, transported to SEMASS and incinerated into ash.

Plastic #3 Source Background

PVC manufacturing requires two natural resources: petroleum and chlorine. The chlorine is usually made from sodium chloride, or common rock salt, which is a renewable resource. The element is drawn out through electrolysis, which is a process that runs an electric current through

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[46] Waste Audit Report. *McMaster University*. Mar. 2011. Web. 14 Apr. 2012. <http://www.mcmaster.ca/sustainability/documents/Waste%20Audit%202011.pdf>.

the salt solution, separating the sodium and chlorine.[47] By weight, pure PVC is 57% chlorine, with the remaining 43% consisting of carbon and hydrogen;[48] however, after the addition of other chemical compounds, the original PVC resin could comprise only 40-70% of the finished product.[49]

Manufacturing of Plastic #3 Wrap

PVC is a polymer that is produced from vinyl chloride monomers, which are made from mixing either acetylene and hydrochloric acid or, more commonly, ethylene and chlorine.[50] The vinyl chloride is mixed into water, forming a suspension, and then other agents and a chemical initiator are added to the solution,[51] which needs to be stirred constantly and cooled.[52] Then, the plastic is extruded into a film, cut, and rolled onto cardboard tubes for packaging.[53]

Manufacturing and Use Impact Assessment for #3 Plastic

Table 5.12 lists the ecosystem impacts of the manufacture of 1 kg of PVC, as well as the total annual impact at Wellesley College of 13,054.70 kg of PVC.

Table 5.12: Impact Values for Manufacture of PVC Per kg and for Total Annual PVC Waste Produced at Wellesley College.

Impact Category	Impact per 1 kg	Total annual impact (13,054.70 kg)	Unit
Global warming	2.42	31,592.37	kg CO2 eq
Acidification	0.39	5,091.33	H+ moles eq
Carcinogens	0.0046	60.05	kg benzene eq
Non carcinogens	83.05	1,084,193.84	kg toluene eq
Respiratory effects	0.0016	20.89	kg PM2.5 eq
Eutrophication	0.0038	49.61	kg N eq

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[47] Malin, N. and Wilson, A. Should We Phase Out PVC? *Environmental Building News Vol. 3,* BuildingGreen. 1 Jan. 1994. Web. 17 Apr. 2012. <http://www.buildinggreen.com/auth/article.cfm/1994/1/1/Should-We-Phase-Out-PVC/>.
[48] Malin, N. and Wilson, A. Should We Phase Out PVC? *Environmental Building News Vol. 3,* BuildingGreen. 1 Jan. 1994. Web. 17 Apr. 2012. <http://www.buildinggreen.com/auth/article.cfm/1994/1/1/Should-We-Phase-Out-PVC/>.
[49] Malin, N. and Wilson, A. Should We Phase Out PVC? *Environmental Building News Vol. 3,* BuildingGreen. 1 Jan. 1994. Web. 17 Apr. 2012. <http://www.buildinggreen.com/auth/article.cfm/1994/1/1/Should-We-Phase-Out-PVC/>.
[50] Secrest, R. Plastic Wrap; Reference Answers. *The Gale Group, Inc.* n.d. Web. 16 Apr. 2012. <http://www.answers.com/topic/plastic-wrap>.
[51] Secrest, R. Plastic Wrap; Reference Answers. *The Gale Group, Inc.* n.d. Web. 16 Apr. 2012. <http://www.answers.com/topic/plastic-wrap>.
[52] Malin, N. and Wilson, A. Should We Phase Out PVC? *Environmental Building News Vol. 3,* BuildingGreen. 1 Jan. 1994. Web. 17 Apr. 2012. <http://www.buildinggreen.com/auth/article.cfm/1994/1/1/Should-We-Phase-Out-PVC/>.
[53] Secrest, R. Plastic Wrap; Reference Answers. *The Gale Group, Inc.* n.d. Web. 16 Apr. 2012. <http://www.answers.com/topic/plastic-wrap>.

The manufacture of PVC is harmful to ecosystems and human health because the process uses many toxic chemical agents and produces contaminated, hazardous waste that can escape into the environment.[54] For example, the vinyl chloride monomer itself is dangerous to handle, and its creation results in dioxins being released and toxic tar being generated.[55] In addition, the many additives are in PVC, which can include heavy metals and suspected carcinogens,[56] create their own negative externalities when they are produced.[57]

PLASTIC #4: LOW-DENSITY POLYETHYLENE (LDPE)

Plastic #4 Background

Low-density polyethylene (LDPE) is a soft and flexible plastic produced by high-pressure polymerization of ethylene.[58] At room temperatures, LDPE is unreactive, but will slowly be degraded by oxidizing agents and solvents.[59] LDPE is closely related to high-density polyethylene (HDPE, plastic #2) and medium-density polyethylene; of these materials, LDPE is the most flexible.[60] The properties and applications of LDPE are summarized in Table 5.13.

Table 5.13: Properties and Applications of LDPE.[61]

Properties	*Applications*
• Low water permeability • Low temperature toughness • Vapor barrier properties • Not resistant to high temperatures • Easily sealable • Easily processable • Flexible • Transparent • Very resistant to acids, alcohols, bases and esters • Resistant to aldehydes, ketones and vegetable oils	• Plastic wraps • Six-pack rings • Plastic bags • Parts that require flexibility • Food trays • Food storage containers • Corrosion-resistant work surfaces • Tubing • Frozen food packaging • Bread bags

54 The Poison Plastic. *Greenpeace*. 2 Jun. 2003. Web. 17 Apr. 2012. <http://www.greenpeace.org/international/en/campaigns/toxics/polyvinyl-chloride/the-poison-plastic/>.
55 The Poison Plastic. *Greenpeace*. 2 Jun. 2003. Web. 17 Apr. 2012. <http://www.greenpeace.org/international/en/campaigns/toxics/polyvinyl-chloride/the-poison-plastic/>.
56 Malin, N. and Wilson, A. Should We Phase Out PVC? *Environmental Building News Vol. 3,* BuildingGreen. 1 Jan. 1994. Web. 17 Apr. 2012. <http://www.buildinggreen.com/auth/article.cfm/1994/1/1/Should-We-Phase-Out-PVC/>.
57 The Poison Plastic. *Greenpeace*. 2 Jun. 2003. Web. 17 Apr. 2012. <http://www.greenpeace.org/international/en/campaigns/toxics/polyvinyl-chloride/the-poison-plastic/>.
58 Plastic Properties of Low Density Polyethylene (LDPE). *Dynalab Corp*. n.d. Web. 25 Feb. 2012. <http://www.dynalabcorp.com/technical_info_ld_polyethylene.asp>.; Market Study: Polyethelene LDPE (UC-1405*). Ceresana Research*. Apr. 2010. Web. 25 Feb. 2012. <http://www.ceresana.com/en/market-studies/plastics/polyethylene-ldpe/>.
59 Plastic Properties of Low Density Polyethylene (LDPE). *Dynalab Corp*. n.d. Web. 25 Feb. 2012. <http://www.dynalabcorp.com/technical_info_ld_polyethylene.asp>.;
60 What is LDPE? *Container and Packaging Supply.* 7 Oct. 2009. Web. 25 Feb. 2012. <http://www.youtube.com/watch?v=84lhHCcCoug>.
61 Wilcox-Barsalou, M. Recycling Symbol #4- LDPE. *Plastics and the Planet*. 17 Aug. 2010. Web. 25 Jan. 2012. <http://plasticsandtheplanet.com/archives/179>.

Globally, about 67% of LDPE is used in films, bags and sacks.[62] LDPE is also used as a coating for paper milk cartons and in liquid or juice containers, dry foods packaging, snack food packaging, moist food packaging, medical packaging, shipping products, and outdoor lumber.[63] Additionally, LDPE is used in screw caps, lids, coatings, and laboratory dispensing and wash bottles. [64] Because of their different functions, for the purposes of this report, bags and wraps made of LDPE are addressed in a separate "bags and wraps" category and are not included in the analysis of LDPE.

Uses of Plastic #4 at Wellesley College

At Wellesley College, LDPE is found in certain shampoo and cream tubes (Figure 5.7a), though many of these same tubes are made from alternative plastics. Laboratory carboys (Figure 5.7b), wash bottles (Figure 5.7c), and transfer pipettes (Figure 5.7d) are made of LDPE. A small portion of food containers in the dining halls, such as honey dispensers (Figure 5.7e), is made of LDPE. Take-out soup and curry containers (Figure 5.7f) are also made of LDPE.

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[62] Market Study: Polyethelene LDPE (UC-1405*). Ceresana Research.* Apr. 2010. Web. 25 Feb. 2012. <http://www.ceresana.com/en/market-studies/plastics/polyethylene-ldpe/>.

[63] DOW LDPE 5004I: Low Density Polyethylene Resin. *The Dow Chemical Company.* n.d. Web. 25 Feb. 2012. <http://www.ides.com/info/datasheet/E7178/DOW-LDPE-5004I>.; What is LDPE? *Container and Packaging Supply*. 7 Oct. 2009. Web. 25 Feb. 2012, <http://www.youtube.com/watch?v=84lhHCcCoug>.

[64] Market Study: Polyethelene LDPE (UC-1405*). Ceresana Research.* Apr. 2010. Web. 25 Feb. 2012. <http://www.ceresana.com/en/market-studies/plastics/polyethylene-ldpe/>.; Plastic Properties of Low Density Polyethylene (LDPE). *Dynalab Corp*. n.d. Web. 25 Feb. 2012. <http://www.dynalabcorp.com/technical_info_ld_polyethylene.asp>.;

Figure 5.7: Examples of LDPE Uses on Campus. (a) Shampoo and cream containers, (b) laboratory carboys, (c) laboratory wash bottles, (d) transfer pipettes, (e) honey containers, (f) take-out containers.

Activities and Behaviors Producing Plastic #4 Waste at Wellesley College

The primary behaviors and activities associated with the production of LDPE waste at Wellesley College include student use of shampoos and creams, participation in laboratory research, eating in dining halls, and ordering take-out.

Amount of Plastic #4 Produced at Wellesley College

The amount of #4 plastic waste produced annually at Wellesley College is 424.64 kg, as estimated in Table 5.14.

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[65] Cosmetic Tubes, Flexible Tubes, LDPE Tubes, Soft Tubes, Plastic Tubes. *TradeKey.com*. n.d. Web. 10 Mar. 2012. <http://www.tradekey.com/product_view/id/1279915.htm>.

[66] Plastic Carboys & Large Bottles. *Dynalab Corp*. n.d. Web. 10 Mar. 2012. <http://www.dynalabcorp.com/home_carboys.asp>.

[67] Economy Wash Bottle, 500 ml, Label Your Own. *Science First*. n.d. Web. 10 Mar. 2012. <http://www.sciencefirst.com/Economy-Wash-Bottle-500-ml-Label-Your-Own.html>.

[68] Plankton Processing & Counting. *Aquatic Sampling Company*. n.d. Web. 10 Mar. 2012. <http://www.aquasample.com/plankton-samplers-nets-plankton-processing-counting-c-24_98.html?osCsid=1fa5e2b55561ab2dbc4b2e75bbfbe785>.

[69] Plastic Condiment Bottles-LDPE. *Freund Container & Supply*. n.d. Web. 10 Mar. 2012. <http://www.freundcontainer.com/plastic-condiment-bottles-ldpe/p/v3390B01NAT/>.

[70] 32oz Plastic Round DELItainer Deli Soup Container 100PK. *Ebay*. n.d. Web. 10 Mar. 2012. <http://www.ebay.com/itm/32oz-Plastic-Round-DELItainer-Deli-Soup-Container-100PK-/160565081569>.

Table 5.14: Estimated Annual #4 Plastic Waste at Wellesley College.

Material	# Units Produced Annually	# Units per kg	Weight per unit (kg/unit)	Total kg Produced Annually
Take-out Containers	18,400 containers	50 containers	0.02	368
Shampoo and Cream Tubes	575 tubes	50 tubes	0.02	11.50
Transfer Pipettes	5,000 pipettes	1,650 pipettes	0.0006	3
Laboratory Carboys	3 carboys	1.50 carboys	0.68	2.04
Laboratory Wash Bottles	30 wash bottles	20 wash bottles	0.05	1.50
Miscellaneous (additional 10%)	-	-	-	38.60
Total				**424.64**

The distribution of #4 plastic waste by category is shown in Figure 5.8.

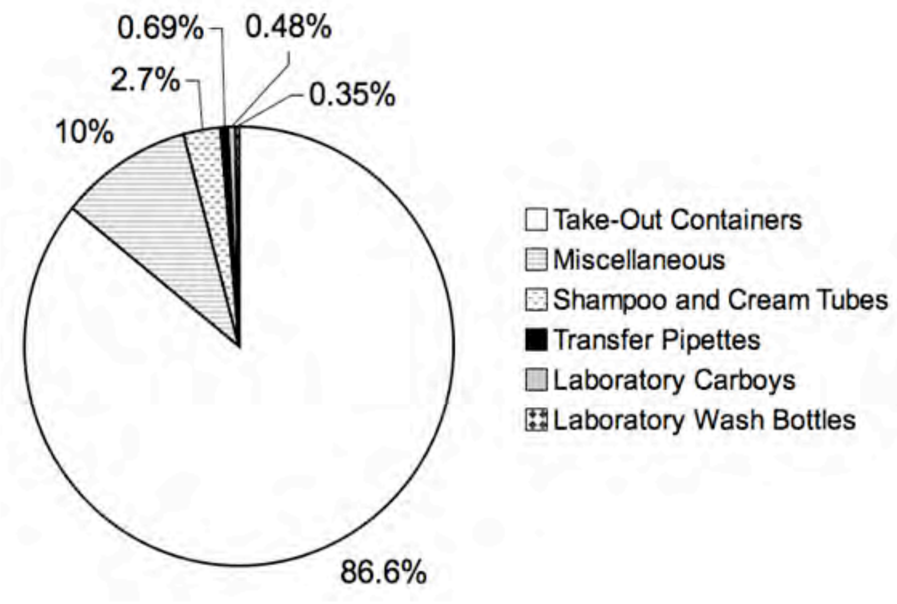

Figure 5.8: Distribution of #4 Plastic Waste at Wellesley College.

The number of take-out containers discarded annually at Wellesley College was estimated by assuming that two-thirds of the student body (1,533 students) orders take-out involving soup or curry once per month over 12 months, producing 18,400 units of take-out container waste annually. The weight of a take-out container is estimated to be 0.02 kg, with 50 containers comprising 1 kg. The total annual disposal of LDPE take-out containers is therefore about 413.64 kg.

Shampoo and cream tubes made of LDPE comprise a small portion of the shampoo and cream tubes found at convenience stores. (This was determined by an informal survey at the CVS in Wellesley.) We estimated that one-fourth of the student body (575 students) disposes of 1 LDPE shampoo or cream tube per year, creating 575 units of LDPE shampoo and cream tube waste. The weight of an empty tube was estimated to be 0.02 kg, with 50 tubes comprising 1 kg. The total amount of LDPE shampoo and cream tubes disposed of annually is about 11.5 kg.

Transfer pipettes are one-time use lab tools. We estimate that the College goes through 10 boxes of transfer pipettes per year, with each box containing 500 pipettes. The weight of one pipette is estimated to be 0.60 g, with 1,650 pipettes comprising 1 kg. The total amount of LDPE pipettes disposed of annually is about 3 kg.

Laboratory carboys, which are large containers used to contain liquids in laboratories, have a long lifespan and are rarely discarded.[71] One carboy weighs 0.68 kg, and there are 1.50 carboys in 1 kg. We estimated that 3 carboys are discarded annually. The total amount of LDPE carboy waste disposed of annually is 2.04 kg.

Laboratory wash bottles are replaced relatively rarely in laboratories on campus,[72] so we estimated that about 30 wash bottles are disposed of annually. An empty wash bottle was weighed at 0.05 kg, with 20 wash bottles comprising 1 kg. The total amount of LDPE wash bottles disposed of annually is about 1.50 kg.

To account for miscellaneous LDPE waste on campus that we have not included in this calculation, 10% was added to our calculation of known LDPE waste sources. The 10% addition is being used as the standard method to account for estimation error for the purposes of this work.

With the addition of 10% to the initial subtotal of 386.05 kg, the combined total of #4 plastics waste discarded annually at Wellesley College is about 424.64 kg. A breakdown of the uses of LDPE on campus is displayed in Figure #. Of the total amount of LDPE waste on campus, take-out containers account for 86.65%, while the other uses collectively account for only 13.35%. Ordering take-out is the primary activity producing LDPE waste on campus.

Handling of Plastic #4 Waste at Wellesley College

The distribution of #4 plastics handling on campus is displayed in Table 5.15.

Table 5.15: Estimated Handling of #4 Plastic Waste at Wellesley College.

Material	% Recycled	% Thrown in Trash	% Special Collection*
Take-out Containers	30%	70%	-
Shampoo and Cream Tubes	5%	95%	-
Transfer Pipettes	-	30%	70%
Laboratory Carboys	-	80%	20%
Laboratory Wash Bottles	10%	40%	50%
Total	**11%**	**63%**	**28%**

**Handled as chemical waste, collected in Science Center.*

Take-out soup and curry containers are often thrown in the trash because they are not rinsed out or contain spoiled food. However, because LDPE take-out containers are a non-composite plastic, most people know that the containers can be recycled. We estimated that about 70% of take-out containers are thrown in the trash and about 30% are recycled.

LDPE shampoo and cream tubes, while usually labeled as recyclable, have lids of different materials that cannot be recycled, and are usually not emptied upon disposal. Because shampoo and cream tubes are made of composite materials and are not easily emptied, it is

[71] Keegan, Raymond. Stockroom Manager. Interview. 8 Mar. 2012.
[72] Keegan, Raymond. Stockroom Manager. Interview. 8 Mar. 2012.

estimated that most LDPE shampoo and cream tubes at Wellesley College are thrown in the trash. We estimated that only 5% of LDPE shampoo and cream tubes are recycled.

Transfer pipettes used during laboratory work are thrown in the regular trash bin if used to transfer water or other non-toxic substances, or are thrown in the special collection bin as part of laboratory safety protocol, which is collected as chemical waste. We estimated that 30% of transfer pipettes are thrown in the trash and 70% are thrown in the special collection bin.

LDPE laboratory carboys are rarely replaced and are mostly used to contain water, though some may contain chemical solutions. We estimated that about 20% contain chemical solutions and are collected as chemical waste, while the other 80% is disposed of in the MSW stream. While many carboys are reused over the years of laboratory use, no carboys are recycled because of their large size.

Laboratory wash bottles contain water and chemical solvents (often ethanol for rinsing glassware). LDPE wash bottles that were used for ethanol (about 50%) are considered chemical waste and are collected by the Phillips Services Corporation (PSC) for regulated chemical waste disposal. Wash bottles that contained only water (50%) are thrown in the trash 40% of the time, and recycled at a rate of 10%, because recycling bins are uncommon in laboratories.

Destination of Plastic #4 Waste

Based on the handling of waste on campus in Table 5.13, the portions of #4 plastic waste sent to recycling, MSW and chemical waste handling facilities are estimated in Table 5.16.

Table 5.6: Destination of #4 Plastic Waste.

	Conigliaro	SEMASS	PSC
% of Waste	11%	63%	28%
Weight of Waste (kg)	46.71	267.52	118.90

LDPE products recycled on campus are sent to the Conigliaro Industries recycling facility. We estimated that 11% of #4 plastics waste from Wellesley College (about 46.71 kg) is sent to Conigliaro annually.

LDPE products disposed of in the trash are sent to SEMASS where they are incinerated. We estimated that 63% (267.52 kg) of LDPE waste is sent to SEMASS annually.

Containers that formerly held chemicals are considered chemical waste and are collected from Wellesley College by PSC each month. We estimated that 28% of LDPE waste produced at Wellesley College (118.90 kg) is collected by PSC annually.

Abridged Life Cycle of Plastic #4 Produced at Wellesley College

At Wellesley College, #4 plastics are primarily found in take-out containers used to deliver liquids like soups and curries. An abridged lifecycle diagram for take-out containers from production to disposal is displayed in Figure 5.9.

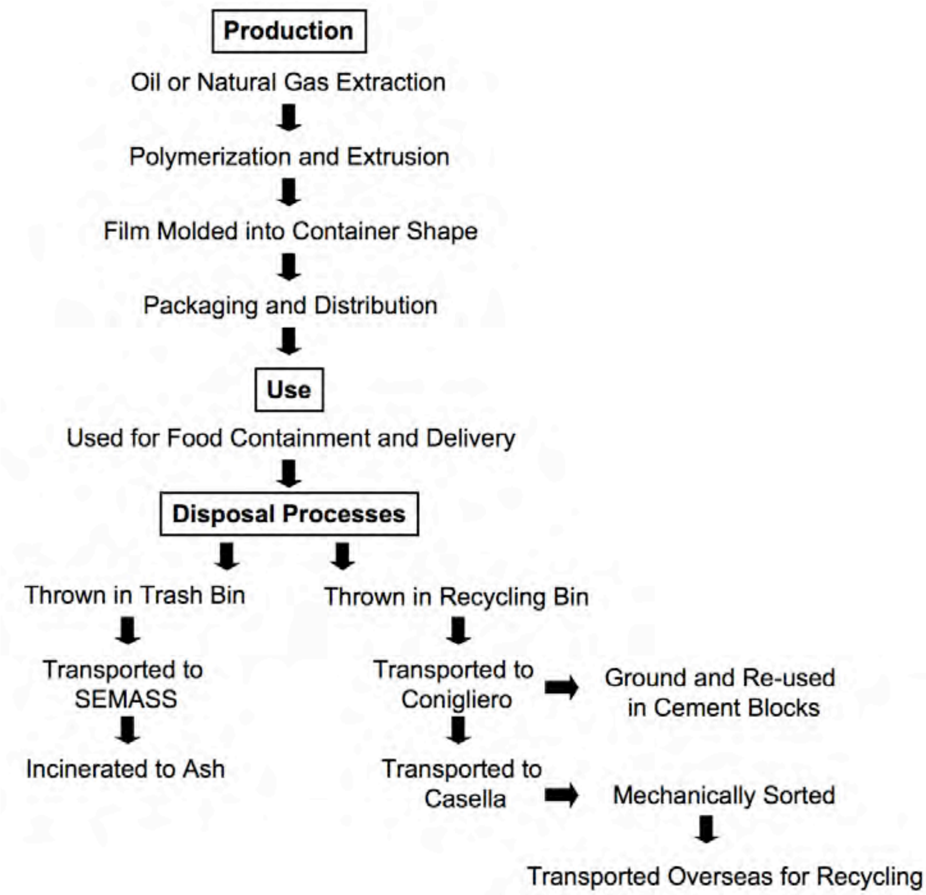

Figure 5.9: Abridged Life Cycle for LDPE Take-out Containers.

Plastic #4 Source Background

LDPE is made from polyethylene, a formulation of ethylene with multiple branches. Polyethylene is formed from modified natural gas, a mixture of methane, ethane and propane, or from the catalytic cracking of crude oil into gasoline.[73] Natural gas and oil used to produce polyethylene are extracted from underground stores by drilling.

Manufacturing of Plastic #4

After purification of natural gas or oil, polyethylene is formed in a polymerization plant where the double bond of the ethylene monomer opens and links to form long chains. When exposed to high-pressure, high-temperature, and low-oxygen conditions, polyethylene forms pellets of low-density polyethylene, or LDPE.[74]

Low-density polyethylene pellets are extruded and blown to produce a film that is then shaped into LDPE products. The extrusion process relies on frictional heat, which causes the pellets to melt. The melted LDPE is then shaped into sheets that can be molded into a range of

[73] Lepoutre, P. The Manufacture of Polyethylene. *The New Zealand Institute of Chemistry*. n.d. Web. 8 May 2012. < http://nzic.org.nz/ChemProcesses/polymers/10J.pdf>.
[74] Lepoutre, P. The Manufacture of Polyethylene. *The New Zealand Institute of Chemistry*. n.d. Web. 8 May 2012. < http://nzic.org.nz/ChemProcesses/polymers/10J.pdf>.

consumer products, including take-out containers.[75] This process uses energy inputs to fuel the machinery used in the formation of plastic products.

Manufacturing and Impact Assessment for Plastic #4

The ecological impacts of the manufacture of a #4 plastic container, per 1 kg of material, are summarized by impact category in Table 5.17. The major contributors to each impact category score are outlined in Table D.4 in Appendix D.

Table 5.17: Total impact values for #4 plastic container material extraction and manufacture.

Impact Category	Impact per 1 kg	Total Annual Impact for 424.64 kg	Unit
Global Warming	3.21	1,363.09	kg CO2 eq
Acidification	0.88	373.68	H+ moles eq
Eutrophication	0.00039	0.17	kg N eq
Carcinogens	0.0000079	0.0034	kg benzene eq
Non-Carcinogens	0.06	25.48	kg toluene eq
Respiratory Effects	0.0031	1.32	kg PM2.5 eq

PLASTIC WRAPS AND BAGS

Plastic Wraps and Bags Background

A plastic film is an extruded piece of plastic usually less than 40 millimeters thick.[76] Once extruded, plastic films can be rolled into sheets for plastic wrap, used as coatings for other materials, or shaped into bags.[77] Most plastic bags and films are made from polyethylene, though some bags can be made from polypropylene, polyvinyl chloride, and ethyl vinyl acetate.[78] Polyethylene plastic bags can, in turn, be made from low-density polyethylene (LDPE), high-density polyethylene (HDPE), or linear low-density polyethylene (LLDPE). All varieties of polyethylene have similar chemical resistances; however, HDPE and LLDPE have fewer branches on their polymer chains, resulting in greater resistance to physical wear.[79] Most plastic bags used in the United States are made from LDPE, but the only way to confirm a bag's material composition is to check for its plastic identification code.[80]

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[75] Lepoutre, P. The Manufacture of Polyethylene. *The New Zealand Institute of Chemistry*. n.d. Web. 8 May 2012. < http://nzic.org.nz/ChemProcesses/polymers/10J.pdf>.

[76] Facts and Information: Thermal Shrinkage of Plastic Film and Sheeting. *Chemical Fabrics and Film Association, Inc.* Oct. 2010. Web. 1 Mar. 2012, <http://www.chemicalfabricsandfilm.com/pdfs_researchSection/techSupport/shrinkage.pdf>.

[77] McWilliam, J.T. The Thick and Thin of Plastic Bags. 2006. Web. Mar. 1, 2012, <http://www.5starwriting.com/wp-content/uploads/2011/06/ThicknThinofPlasticBags.pdf>.

[78] Designing and Manufacturing Plastic Bags. *Thomas Publishing Company*. 1 Mar. 2012. Web. 1 Mar. 2012, <http://www.thomasnet.com/articles/plastics-rubber/designing-plastic-bags>.

[79] Plastic Properties of Low-Density Polyethylene. *Dynalab Corp*. n.d. Web. 23 Feb. 2012, <http://www.dynalabcorp.com/technical_info_ld_polyethylene.asp>.

[80] Designing and Manufacturing Plastic Bags. *Thomas Publishing Company*. 1 Mar. 2012. Web. 1 Mar. 2012, <http://www.thomasnet.com/articles/plastics-rubber/designing-plastic-bags>.

Plastic bags are an important source of plastic in the Municipal Solid Waste Stream (MSW). In some municipalities, plastic bags make up 2.87% of total MSW and are the single largest source of plastic.[81] In America, 88% of these plastic bags wind up in landfills.[82] Plastic bags and films usually do not stay in landfills, though, as their high surface area and low weight allow plastic bags to be easily transported by wind and water, and easily tangled in drains, trees, and wildlife.[83] Plastic bags and films not placed in landfills in America are usually recycled, avoiding incineration and the risk of releasing lead and dioxins from the inks on the bag.[84] It is not necessary to separate out HDPE and LDPE plastic bags from each other for recycling, though it is important to remove PVC plastic bags, since PVC is recycled quite differently.[85] The low density of plastic bags, however, also means that it is not cost-effective to recycle plastic bags; it costs roughly $4,000 to downcycle one ton of plastic bags into polyethylene, worth roughly $32.[86]

Use of Plastic Wraps and Bags at Wellesley College

On campus, LDPE bags and wraps are found frequently in kitchens as plastic wrap, plastic bags, and plastic food-preparation gloves. Plastic bags also package food that students bring to campus or buy at the cafe in the campus center, and plastic bags are handed out with purchases in the campus center bookstore. Finally, plastic bags are used and reused as liners for the recycling and trash bins on campus.

Activities and Behaviors Producing Plastic Wraps and Bag Waste at Wellesley College

The most common behaviors producing plastic wrap and bag waste at Wellesley College take place in the dining hall, where plastic wrap and gloves are essential for the preparation of food. Prepackaged food in plastic bags, both in the dining halls and purchased by the students, is also a contributor. Finally, since all school-maintained (and many student-maintained) waste and recycling bins are lined with LDPE bags, both producing more waste and emptying bins before they are empty adds to plastic bag and wrap waste.

Amount of Plastic Bag Waste Produced at Wellesley College

Annually, Wellesley College produces 1,605.63 kg of plastic bag waste (see Table 5.18).

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[81] Plastic Bag Mandatory Take-Back Recycling Program: Information for Residents. *Municipality of New York*, 2012. Web. 23 Feb. 2012. <http://www.nyc.gov/html/nycwasteless/html/stuff/takeback_plasticbaglaw.shtml>.

[82] Plastic Bag Mandatory Take-Back Recycling Program: Information for Residents. *Municipality of New York*, 2012. Web. 23 Feb. 2012. <http://www.nyc.gov/html/nycwasteless/html/stuff/takeback_plasticbaglaw.shtml>.

[83] Bangladesh: Plastics Proliferate Despite Ban. *IRIN News*, 2 Mar. 2011. Web. 23 Feb. 2012. <http://www.irinnews.org/Report/92072/BANGLADESH-Plastics-proliferate-despite-ban>.; Threats to Sea Turtle Survival. *Sea Turtle Conservancy*. 2011. Web. 23 Feb. 2012. <http://www.conserveturtles.org/seaturtleinformation.php?page=threats>.

[84] Weisel, C., Demak, M., Marcus S., and Goldstein, B.D.. Soft Plastic Bread Packaging: Lead Content and Reuse by Families. *American Journal of Public Health*, Jun. 1991, Vol. 81, No. 6.

[85] Miezkowski, K. Plastic Bags are Killing Us. *Salon: Environment*, Salon. 10 Aug. 2011. Web. 22 Feb. 2012. < http://www.salon.com/2007/08/10/plastic_bags/>.

[86] Bushnell, K. Plastic Bags: What About Recycling Them? *Sierra Club*. Web. 22 Feb. 2012. <http://www.sierraclub.org/sustainable_consumption/articles/bags2.asp>.

Table 5.18: Amount of Plastic Bags Produced at Wellesley College.

Material	Weight Per Unit (g/unit)	Units per kg (bags)	Units produced annually	Total kg produced annually
Large Trash Bags	61.70	16.20	14,081	868.70
Small Trash Bags	7.30	137.00	57,600	420.48
On-Campus Stores	3.60	16.20	13,330	48
Off-Campus Shopping	3.60	273.20	34,030	122.50
Miscellaneous (10%)				145.95
Total				**1,605.63**

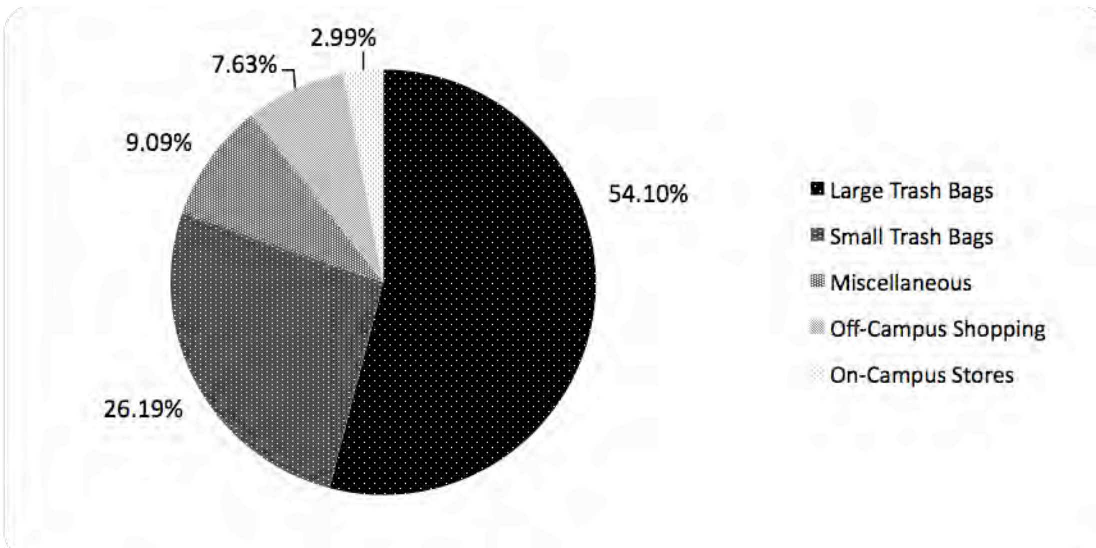

Figure 5.10: Distribution of Plastic Bag Waste Produced at Wellesley College.

The largest use of plastic bags on campus is as liners in trash bins. There is at least one large, public trash bin in nearly every public space on Wellesley's campus larger than a single lecture hall, and there are about fifty trash bins across the entire campus. Assuming that each bag is replaced five times a week during the school year, 10,000 plastic bags are used for mostly non-food waste on campus throughout the school year. For the summer, since fewer people are on campus, we assumed that waste is picked up only once a week, totaling 600 plastic bags.

Food waste is also produced in the dining hall kitchens and sent to the dumpster in plastic bags. Since food waste is generated throughout the day, seven days a week during the academic year, we assumed that there are at least two bags of food waste per day generated for the two largest dining halls on campus when school is in session (Bates and Tower), and at least one bag of food waste generated per day by the smaller dining halls (Pomeroy, Bae Pao Lu Chow, and Stone Davis)[87]. Altogether, we calculated that dining halls discard 1,680 plastic bags containing food per year, and a total of 12,280 large plastic bags used on campus each year, for a total of 757.70 kg of plastic bag waste generated annually.

[87] Sustainable Sustenance: Greening Wellesley's Food System. Wellesley College ES 300. Spring 2011. Web. Mar. 2012. <http://www.wellesley.edu/EnvironmentalStudies/Research/pdf/ES300-2011-SustainableSustenance.pdf>.

Large plastic trash bags are also used to line some of the recycling bins on campus, both in residence halls and public spaces. Since plastic bags are used to line some mixed paper and all mixed plastic and metal recycling bins on campus, we assumed that recycling contained in plastic bags described all of the mixed plastic and metal recycling reported for 2007, and all of the expanded mixed paper and corrugated waste that came from offices and classrooms, 180,008 kg altogether.[88] Assuming each bag is emptied when it contains about 10 kg of waste,[89] we used 1,801 plastic bags to move recycling, weighing a total of 111.1 kg.

Small plastic trash bags, for wastebaskets serving a single public room, are also a significant component of plastic bag and wrap waste at Wellesley College. Last year, the custodial staff ordered and used 57,600 smaller polyethylene bags as trash bags for small, public waste bins,[90] weighing a total of 420.48 kg.

To determine the number of plastic bags handed out to students at the on-campus stores, we assumed that the bookstore handles 8,000-10,000 plastic bags a year,[91] and we estimated that the cafe in the Campus Center gave every student on campus a plastic bag about once every three months. If we assume that 80% of the shopping in the campus bookstore comes from students, and that all of the shopping at the campus café comes from students, then the bookstore provides 6,400-8,000 plastic bags that enter Wellesley's waste stream, and the café provides 6,130 each year. That means on-campus shopping is responsible for between 12,530 and 14,130 plastic bags per year, leading to 45.11-50.87 kg of plastic bags discarded. Since we do not have a good way to distinguish between the two estimates, we averaged the two estimates and assumed that on-campus shopping generates 48 kg of plastic bag waste per year. Some of these bags will end up in the regular waste stream; however, most of them will probably end up lining a trash bag in someone's room.

In order to determine the number of plastic shopping bags from off-campus present in our waste stream, we assumed that all shopping bags discarded on campus were attributable to Wellesley students (not faculty or staff), and that during the school year, a student bought something from off-campus that required a plastic bag approximately every three weeks. Given a 32-week school year and 2,300 students on campus who go shopping, we calculated a total of 24,530 bags. During the summer, however, we assumed that students living on campus shop off-campus more often. For the summer, we estimated that every student present in the New Dorms used two plastic bags for shopping a week for the 10-week summer session, resulting in 8,000 plastic bags. If we also assume that the students in the two-month-long Explo program buy things off-campus requiring a plastic bag once a month--a slightly lower rate than Wellesley College students do during the school year, due to closer supervision and fewer opportunities to leave campus--we add another 1,500 plastic bags. Altogether, a total of 34,030 shopping bags are discarded each year, weighing 122.50 kilograms.

Handling of Plastic Bag Waste at Wellesley College

The handling distribution of plastic bag waste is displayed in Table 5.19.

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[88] Solid Waste (Rubbish). *Wellesley College Sustainability*, 23 Sep. 2009. Web. 13 Mar. 2012. <http://www.wellesley.edu/AdminandPlanning/Sustainability/solidwaste.html>.

[89] Recycling Audit, Wellesley College. 3 Mar. 2012.

[90] Hoey, Tim. Manager of Custodial Services. Personal interview. 16 Mar. 2012

[91] Leva, Joe. Wellesley College Bookstore Manager. Personal interview. 9 Mar. 2012.

Table 5.19: Estimated Handling of Plastic Bags and Wraps at Wellesley College per Year.

Material	% Recycled	% Thrown in Trash
Large Plastic Trash Bags	12.78%	87.22%
Small Plastic Trash Bags	0%	100%
On-Campus Stores	1%	99%
Off-Campus Shopping	1%	99%
Total	**3.70%**	**96.31%**

Wellesley disposes of 1,605.63 kg of plastic bags per year. This figure differs significantly from what we found during our waste audit on February 15th, in which plastic bags made up 56.5 kg, or 1.36% of our total waste stream.[92] If we used this many plastic bags in the west campus over the eight months of the school year, the west campus alone would produce 1,808 kg of waste – more than the campus supposedly produces in a year. This implies that we are underestimating the number of plastic bags disposed of on-campus, even with the addition of 10% from miscellaneous sources. Since plastic bags are used in an incredible number of ways on-campus that might not have a significant impact on their own, such as dry-cleaning and food packaging, our underestimation makes sense.

Destination of Plastic Bag Waste

We assumed that the vast majority of plastic bags discarded at Wellesley College are incinerated at the SEMASS facility rather than recycled. Not only are most of the plastic bags on campus used as trash bags, but also, most municipal recycling programs do not accept plastic bags for recycling, and according to our sustainability website,[93] neither does Wellesley College. Conigliaro Industries, however, does accept and recycle plastic bags,[94] so we assumed that all plastic bags used to contain recycling were recycled, and that less than one percent of the plastic shopping bags from on- and off-campus were recycled. The destination of plastic bag waste is shown in Table 5.20.

Table 5.20: Destination of Plastic Bags and Wraps Waste.

	Conigliaro	SEMASS
% of Waste	7.36%	92.64%
Weight of Waste (kg)	118.13	1,487.50

92 Waste Audit. Feb. 15 2012.

93 Wellesley College Sustainability. *Wellesley College*. n.d. Web. 4 Mar. 2012. <http://www.wellesley.edu/AdminandPlanning/Sustainability/recycling.html>

94 Conigliaro Recycling 2011 Data. *Conigliaro Industries*. <https://docs.google.com/a/wellesley.edu/file/d/0B4xe5GkHK88iT3NoZ2lydU5TOUdrcGxaaW13cVRkUQ/edit>

Abridged Life Cycle of Plastic Bags and Wraps at Wellesley College

At Wellesley College, plastic bags and wraps are most commonly used to line trash and recycling bins. An abridged life-cycle diagram of this material is shown in Figure 5.11 below.

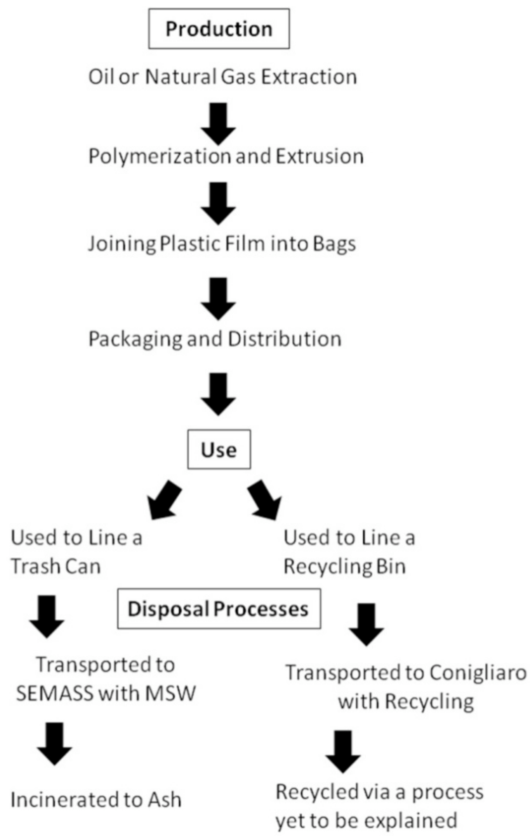

Figure 5.11: Abridged Life-Cycle Diagram of Plastic Bags and Wraps

Plastic Bag and Wrap Source Background

Plastic bags are made from a number of plastic resins, including PVC and polypropylene.[95] The trash bags on Wellesley campus are made with either high-density or low-density polyethylene. All plastics ultimately come from either oil or natural gas, which must be extracted from the earth through drilling.[96]

Plastic Bag and Wrap Manufacturing Background

Once extracted, oil or natural gas is heated to promote chain reactions that cause the formation of long hydrocarbon chains known as polymers. Polymers are distilled by the length of the chain, and the characteristics of the monomers that make up the chain – when heated, the

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[95] Designing and Manufacturing Plastic Bags. *Thomas Publishing Company*, 1 March 2012. Web. 1 March 2012. <http://www.thomasnet.com/articles/plastics-rubber/designing-plastic-bags>.

[96] Ellis, S. Et. Al. Plastic Grocery Bags: The Ecological Footprint. *Vancouver Island Public Interest Research Group*, 2005. Web. 28 Mar. 2012. <http://www.vipirg.ca/archive/publications/pubs/student_papers/05_ecofootprint_plastic_bags.pdf>.

shortest polymers are the first to melt, and the first to volatilize.[97] The polymers are then cooled to form a plastic resin.[98] Depending on the manufacturing technique, the resin is melted and either extruded or blown out to produce sheets of plastic film.[99] To make an individual bag, two sheets are sealed together by heat, and the resulting bag is cut loose from the rest of the roll.

Impact Assessment Inventory per Kilogram for Manufacture and Use of Plastic Bags and Wraps

An impact assessment of polyethylene plastic bags per kilogram is shown below in Table 5.21.

Table 5.21: Impact of Manufacturing per 1 kg of HDPE Plastic Trash Bags

Impact category	Total Impact per 1 kg	Total Impact for 1,605.63 kg	Unit
Global warming	1.81	2,906.19	kg CO2 eq
Acidification	1.68	2,697.46	H+ moles eq
Carcinogens	0.0031	4.98	kg benzene eq
Non carcinogens	45.67	73,329.12	kg toluene eq
Respiratory effects	0.0076	12.20	kg PM2.5 eq
Eutrophication	0.0031	4.98	kg N eq

The most significant impact comes from the toxic non-carcinogens, specifically, the lead associated with inks used on many plastic bags. Lead also makes up a significant portion of the carcinogenic impact of plastic bags.

PLASTIC #5: POLYPROPYLENE

Plastic #5 Background

Polypropylene (PP) is a thermoplastic polymer with the chemical formula C_3H_6. It is rugged and unusually resistant to many chemical solvents, bases and acids. This type of plastic is lightweight, yet durable, and can withstand high temperatures, moisture, and oil, making it ideal for food containers.[100] Its resistance to bacterial growth also makes it suitable for medical

[97] How Plastic is Made. *Plastics Europe.* n.d. Web. 17 Apr. 2012. <http://www.plasticseurope.org/what-is-plastic/how-plastic-is-made.aspx>.

[98] Ellis, S. Et. Al. Plastic Grocery Bags: The Ecological Footprint. *Vancouver Island Public Interest Research Group*, 2005. Web. 28 Mar. 2012. <http://www.vipirg.ca/archive/publications/pubs/student_papers/05_ecofootprint_plastic_bags.pdf>.

[99] Designing and Manufacturing Plastic Bags. *Thomas Publishing Company*, n.d. Web. 1 Mar. 2012. <http://www.thomasnet.com/articles/plastics-rubber/designing-plastic-bags>.

[100] Pots, Pans, and Plastics; a Shopper's Guide to Food Safety. *Environmental Working Group News.* Environmental Working Group. 2009. Web. 27 Feb. 2012. < www.ewg.org/news>.

equipment. Like all plastics, polypropylene is derived from petroleum, or is reconstituted from the recycled petroleum in other products.[101]

Many products contain #5 plastic parts, as food containers of various types (yogurt, cottage cheese, margarine, and sour cream) are extremely visible in the dining halls and auxiliary food services across campus. The caps of PETE beverage bottles are also made from #5 plastic. Products made with #5 plastic are used in the classroom setting, particularly as laboratory equipment such as beakers. Additionally, #5 plastic can be seen in buildings (for example, as loudspeakers), in vehicles (as automotive components) and in living hinges (flexible hinges made from the same material as the rigid pieces it connects) on students' personal items, such as flip-top bottles.

Uses of Plastics#5 at Wellesley College

Many products contain #5 plastic parts, as food containers of various types (yogurt, cottage cheese, margarine and sour cream) are extremely visible in the dining halls and auxiliary food services across campus. The caps of PETE beverage bottles are also made from #5 plastic. Products made with #5 plastic are used in the classroom setting, particularly as laboratory equipment such as beakers. Additionally, #5 plastic can be seen in buildings (for example, as loudspeakers), in vehicles (as automotive components) and in living hinges (flexible hinges made from the same material as the rigid pieces it connects) on students' personal items, such as flip-top bottles.

Activities and Behaviors Producing #5 Plastic Waste at Wellesley College

Dining halls and auxiliary food services use #5 plastic frequently on campus, but they do not have the infrastructure for separate collection or a general understanding of how to properly recycle goods containing #5 plastic. Additionally, it is often easier to dispose of a used yogurt cup in a trashcan, despite the fact that Wellesley College's commingled recycling bins accept #5 plastics.

Even though we generate enough #5 plastic waste on campus to make collection viable, the lack of an economic incentive makes recycling #5 plastics a low priority for recycling plants, producers, and the market.[102] Therefore a rather low emphasis has been placed on #5 plastic in traditional recycling instructions, and individuals are less likely to know what to do with their polypropylene products.

Amount of Plastic #5 Waste Produced at Wellesley College

The amount of #5 plastic waste produced annually at Wellesley College is estimated to be 1,550.65 kg, as shown in Table 5.22. Many categories of polypropylene use involve durable goods that are not discarded frequently. We identified beverage bottle caps and food containers as the polypropylene items most frequently discarded at Wellesley College. The uses of #5 plastics by percentage are displayed in Figure 5.12.

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[101] Polypropylene. *Lenntech Water Treatment Solutions*. 2011. Web. 26 Feb. 2012. <http://www.lenntech.com/polypropylene.htm>.

[102] A Resident's Management Guide For Those Not-So-Common Household Items. *Connecticut Department of Environmental Protection.* Government of Connecticut. 2012. Web. 28 Feb. 2012. <http://www.ct.gov/dep/cwp>.

Table 5.22: Estimated Annual #5 Plastic Waste at Wellesley College.

Material	Weight per unit (g/unit)	# Units per kg	# Units Produced Annually	Total Produced Annually (kg)
Beverage Bottle Caps	2.50	400 caps	248,260 caps	620.65
Food Containers	50	20 tubs	18,600 jars	930
TOTAL				**1,550.65**

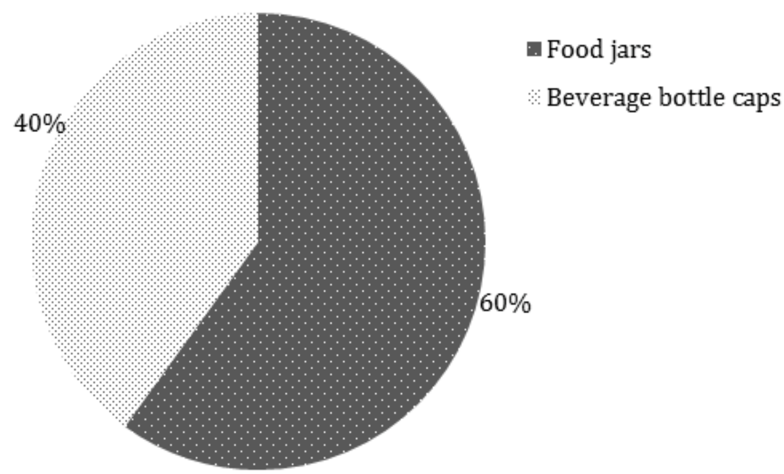

Figure 5.10: Distribution of PP Waste Produced at Wellesley College.

We estimated the number of polypropylene beverage bottles discarded in a year using the previously mentioned estimated number of PETE beverage bottles discarded annually: 248,260. Each cap is estimated to weigh around 2.5 g. We therefore found that around 620.65 kg of polypropylene beverage bottle caps are discarded each year at Wellesley College.

Dining halls and auxiliary food services on campus discard polypropylene food containers that package yogurt, margarine, cottage cheese and sour cream. An informal survey of Pomeroy dining hall revealed that an average of 12 two-pound tubs are discarded each day. We estimated that the other four dining halls discard the same number of polypropylene tubs per day. We also assumed that auxiliary food services, especially El Table, Café Hoop, Collins Café and the College Club, which prepare foods using the ingredients named above, each discard around 2 tubs of the same weight each day. Therefore, the total number of polypropylene food containers discarded in a typical day on campus is around 68.

All dining halls and auxiliary food services are open for the academic school year, which lasts for 8 months. The number of polypropylene food containers discarded during that time period is therefore around 16,320. During the additional one month that the Bates dining hall, Bae Pao dining hall, Collins Café and the College Club are open, 28 tubs are estimated to be discarded per day, amounting to 840 tubs for the one month. In the remaining three months, the Bae Pao dining hall, Collins Café and the College Club discard 16 tubs per day, amounting to

1,440 tubs. Therefore, we estimated the total number of polypropylene food containers discarded on campus by the dining halls and auxiliary food services in a year to be 18,600.

Handling of Plastic #5 Waste at Wellesley College

The distribution of how polypropylene plastics are handled when disposed of on campus is displayed in Table 5.23.

Table 5.23: Estimated Handling of #5 Plastic Waste at Wellesley College.

Material	% Recycled	% Thrown in Trash
Beverage Bottle Caps	49%	51%
Food Jars	20 %	80 %
Total	**34.50%**	**65.50 %**

Destination of Plastic #5 Waste

The portions of polypropylene plastic waste sent to recycling and MSW handling facilities are estimated in Table 5.24.

Table 5.24: Destination of #5 Plastic Waste.

	Conigliaro	SEMASS
% of Waste	34.50%	65.50%
Weight of Waste (kg)	1,318.10	2,504.50

Abridged Life Cycle of Plastic #5 Produced at Wellesley College

At Wellesley College, #5 plastics are primarily found in food containers used to hold things like yogurt. An abridged life cycle diagram for yogurt containers from production to disposal is displayed in Figure 5.13.

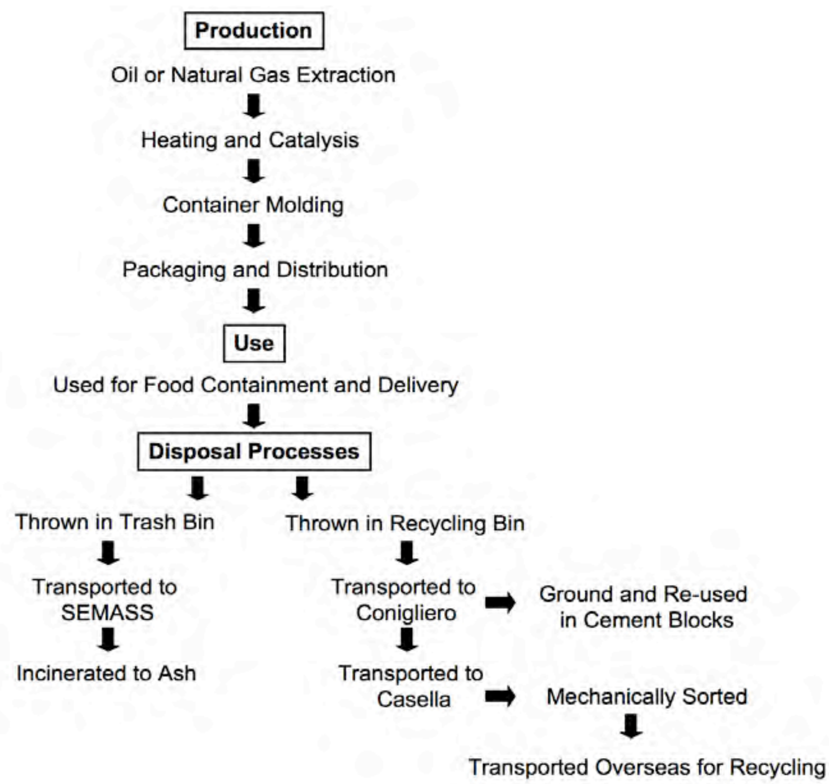

Figure 5.13: **Abridged Life Cycle of #5 Plastic Containers.**

Plastic #5 Source Background

Polypropylene (PP) is a linear hydrocarbon polymer[103] formulated from natural hydrocarbons like oil and natural gas. The natural gas and oil used to produce polypropylene are extracted from underground stores.

Manufacturing of #5 Plastic

Polypropylene production utilizes heat and pressured exposure of a propylene monomer to a catalyst, forming long chains of polypropylene. Variations in the catalytic stage of PP can offer variations in the physical properties of the plastic. PP can be polymerized at low temperatures and pressures to create a translucent product that can be colored.

Manufacturing and Use Impact Assessment for #5 Plastic

The ecosystem impacts of the manufacture of a #5 plastic container, per 1 kg of material, are summarized by impact category in Table 5.25.

[103] Polypropylene PP. *Plasticpedia.co.uk*. n.d. Web. 12 Apr. 2012. <http://www.bpf.co.uk/plastipedia/polymers/pp.aspx>.

Table 5.25: Total Impact Values for #5 Plastic Container Material Extraction and Manufacture per 1 kg of Material.

Impact Category	Impact Per 1 kg PP	Total Annual Impact (1,550.65 kg)	Units
Global Warming	1.19	1,845.27	kg CO2 eq
Acidification	1.47	2,279.46	H+ moles eq
Carcinogens	0.0014	2.17	kg benzene eq
Non-Carcinogens	26.30	40,782.10	kg toluene eq
Respiratory Effects	0.01	15.51	kg PM2.5 eq
Eutrophication	0.00025	0.39	kg N eq

PLASTIC #6: POLYSTYRENE

Plastic #6 Background

Polystyrene, or plastic #6 (commonly referred to by the name of a specific brand of polystyrene, Styrofoam), is a lightweight and sturdy petroleum-derived plastic that is made of long strings of styrene (ethyl-benzene) monomers.[104]

Two main kinds of polystyrene are produced: expanded polystyrene (EPS), which includes construction insulation boards, package cushioning and disposable cups; and extruded polystyrene (EXPS), which includes meat trays, egg trays, foam dishware and insulation.[105] Extruded polystyrene has a smoother finish to it than extruded polystyrene, which has visible foam beads, and the manufacture of EXPS involves the use of HFCs or HCFCs.[106]

Recycled content can be incorporated into plastic #6 packaging materials; for example, packaging peanuts are colored according to the amount of recycled content they contain.[107]

Plastic #6 Uses

Polystyrene is both a poor conductor of heat and easily moldable. For these reasons, it is used for insulation purposes such as around hot water pipes in buildings; in some take-out food containers; and in disposable cups and dishware.[108] Additionally, it is used in meat and egg packaging to reduce the amount of heat reaching the food, which reduces the likelihood of the spoiling.[109] Polystyrene is also used as cushioning for fragile or sensitive items such as electronics because it can be molded into the shape of the item it contains. Cushioning

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[104] Polystyrene. *Polymer Science Learning Center, University of Southern Mississippi*, 2005. Web. 25 Feb. 2012. <http://www.pslc.ws/macrog/styrene.htm>.
[105] Vitruvian Built- FAQ- What Is Polystyrene. *Vitruvian Built*, n.d., Web. 25 Feb. 2012. <http://www.vitruvianbuilt.com/faq.html>.
[106] McBride, M. Energy and Environmental Benefits of Extruded Polystyrene Foam and Fiberglass Insulation Products in U.S. Residential and Commercial Buildings. *Earth Technologies Forum* (April 27, 2004): 7.
[107] Packing, Cushioning and Biodegradable Foam Peanut. *A Better Box Company*, n.d. Web. 25 Feb. 2012. <http://www.abbconet.com/a-earth-friendly-packaging-peanuts.aspx>.
[108] Flynn, H. What Are the Different Uses of Polystyrene? *wiseGEEK,* 20 Jan. 2012. Web. 25 Feb 2012. <http://www.wisegeek.com/what-are-the-different-uses-of-polystyrene.htm>.
[109] Flynn, H. What Are the Different Uses of Polystyrene? *wiseGEEK,* 20 Jan. 2012. Web. 25 Feb 2012. <http://www.wisegeek.com/what-are-the-different-uses-of-polystyrene.htm>.

polystyrene is mainly in the form of shaped-end pieces, packaging peanuts or polystyrene sheets.[110]

Behaviors and Activities Producing Plastic #6 Waste at Wellesley College

On Wellesley's campus, polystyrene waste is generated through the use of polystyrene disposable plates and bowls in the dining halls, such as when the dishwasher breaks down, or to provide students with the option of taking food to their rooms without the risk of loss of dishware. The dining halls also provide polystyrene lid covers for their paper to-go cups. Additionally, some restaurants such as Lemon Thai package their food in polystyrene take-out food containers, and some students buy meat and eggs that are in polystyrene packages, and beverages in disposable polystyrene cups. The polystyrene waste from these uses is invariably disposed of in the garbage because it is contaminated with food. At small- and medium-sized events on campus, disposable plates and cups provided by the organizers are often made of polystyrene.

Wellesley College, and to a lesser extent, Wellesley students, also purchase electronics and other fragile items that come packaged in polystyrene cushioning in the form of blocks, peanuts or sheets (expanded).

Other long term polystyrene uses on the campus are for hot water pipe insulation and in some of the CD and DVD cases in the libraries, Slater International Center and those owned by students.

Amount of #6 Plastic Produced at Wellesley College

The total amount of polystyrene waste produced at Wellesley College is 2,495.49 kg, as presented in Table 5.26, with calculations for each category of use following the table.

Table 5.26: Amount of Polystyrene Waste Produced at Wellesley College by Use of Material.

Material	Weight per unit (g/unit)	# units per kg	# units produced annually	Total produced annually (kg)
Institutional packaging	-	-	-	1,233.78
Events disposable plates	7.26	137.70	37,125	269.53
Events disposable cups	10.05	99.46	37,125	373.29
Dining hall disposable bowls	5.73	174.50	19,000	108.87
Dining hall disposable plates	7.26	137.70	7,000	50.82
Dining hall disposable lids	1.72	581.40	42,000	72.24
Student packaging & take-outs	-	-	-	160.10
Miscellaneous 10%)	-	-	-	226.86
Total				**2,495.49**

[110] Flynn, H. What Are the Different Uses of Polystyrene? *wiseGEEK,* 20 Jan. 2012. Web. 25 Feb 2012. <http://www.wisegeek.com/what-are-the-different-uses-of-polystyrene.htm>.

The varied sources of polystyrene waste are represented in Figure 5.14. The largest source of polystyrene waste at Wellesley College is institutional packaging materials.

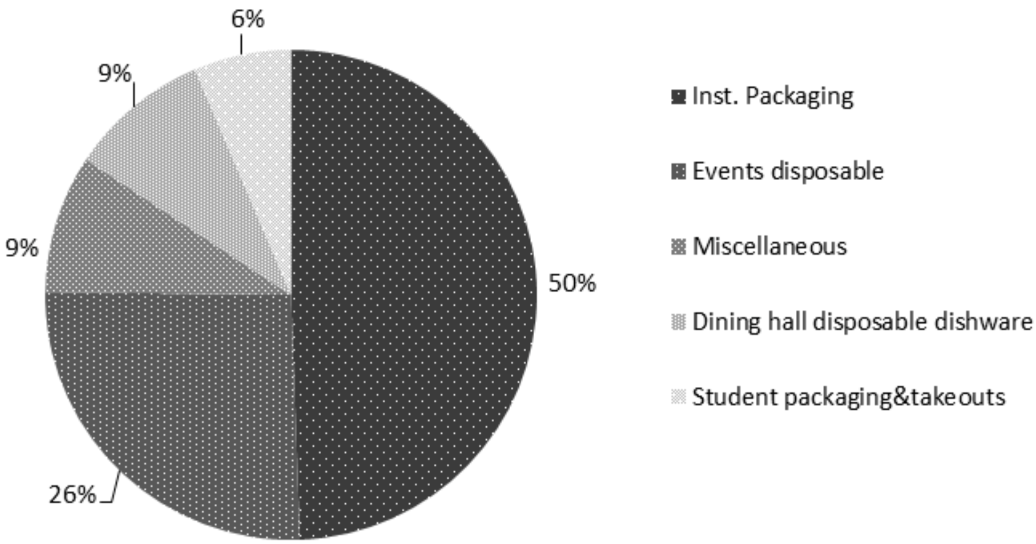

Figure 5.14: Polystyrene Waste by Use on the Wellesley College Campus.

Since expanded polystyrene is molded into the shape of the material it is meant to cushion, it is difficult to make an approximation for the weight of one unit of cushioning block.

The total amount of recycled polystyrene from packaging materials that was picked up from the Science Center and Billings collection centers for the year 2011 was 616.89 kg. Assuming that this represents a 50% recycling rate because it does not account for all the administrative buildings on campus, the total weight of polystyrene waste produced from institutional packaging materials is 1233.78 kg.

Some events sponsored by student organizations or departments at Wellesley College provide food and dishware for the event attendees. Often the dishware, such as plates and cups, is made of polystyrene. We assumed that event organizers buy one plate and cup for each attendee, and used a proxy for the weight of each plate and cup based on those provided in the dining hall.[111] Estimating that there are 75 small-scale catering events, serving up to 50 people, and 3 medium-scale events, serving up to 125 people that happen per month, the total amount of disposable dishware waste from catered events is 642.82 kg.

From January 2011 to December 2011, Wellesley Fresh purchased 19 cases of black foam bowls; 14 cases of foam plates and 42 cases of polystyrene lids. We used the weights of these items from the provider's website[112] to calculate the total weight of polystyrene waste

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[111] Plate Foam UL Wht 9 Product Description. *Sysco Nashville*, 2012. Web. 22 Mar. 2012. <http://www.robertorrsysco.com/product.php?item_id=5274832&cat_id=8>; Cup Paper Cold Poly 12 Oz Sqt Product Description. *Sysco Nashville,* n.d. Web. 22 Mar. 2012. <http://www.robertorrsysco.com/product.php?item_id=5484811&cat_id=8&i_desc=cup>.

[112] Bowl Foam HL Blk 12 Oz Product Description. *Sysco Nashville*, 2012, <http://www.robertorrsysco.com/product.php?item_id=8064729&cat_id=8>; Plate Foam UL Wht 9 Product Description. *Sysco Nashville*, 2012. Web. 22 Mar. 2012. <http://www.robertorrsysco.com/product.php?item_id=5274832&cat_id=8>; ; Lid Plas Tear Tab (for 10 Oz Cup)

produced from dining hall disposable dishware. This weight was calculated to be 108.87 kg of foam bowl waste; 50.82 kg of foam plate waste; and 72.24 kg of polystyrene lid waste per year. We assumed that all of the polystyrene dishware purchased by the dining hall is discarded into the garbage because it is contaminated with food and can therefore not be easily recycled. The total polystyrene waste from disposable dishware provided by the dining hall annually is 231.93 kg.

We calculated the amount of polystyrene waste using purchasing records from 2011, which do not take into account products such as small dessert plates, that the Wellesley food service providers introduced in 2012. The total amount of polystyrene waste from dining hall-provided disposable dishware is therefore likely to be higher than calculated.

Our waste audit found 1.22 kg of polystyrene waste. This comprised of packaging peanuts, packaging sheets, disposable coffee cups and food containers as shown in Figure 5.12 below.

Figure 5.15: Team member sorting through polystyrene waste during waste audit.

We extrapolated from our waste audit to find the annual amount of polystyrene waste produced by all students on campus. The annual polystyrene waste from student packaging materials and take-out containers weighs 160.10 kg.

10% of the calculated weight of polystyrene waste was added to the total amount of waste produced in order to account for miscellaneous sources and uses of polystyrene that might not be captured in our estimation.

Handling of Polystyrene Waste at Wellesley College

23.27% of polystyrene waste generated on Wellesley's campus is recycled, and 75.28% is thrown into the trash, as represented in Table 5.27.

Product Description. *Sysco Nashville,* 2012. Web. 22 Mar. 2012. <http://www.robertorrsysco.com/product.php?item_id=4918645&cat_id=8&i_desc=lid>.

Table 5.27: Handling of polystyrene waste at Wellesley College.

Material	% Recycled	Weight recycled (kg)	% Thrown in Trash	Weight thrown in trash (kg)
Institutional packaging	50%	616.89	50%	616.89
Events disposable dishware	0%	0.00	100%	642.82
Dining hall disposable dishware	0%	0.00	100%	231.93
Student packaging & take-out containers	0%	0.00	100%	160.10
Miscellaneous	0%	0.00	100%	226.86
Total	**24.72%**	**616.89**	**75.28%**	**1,878.60**

The total amount of polystyrene waste from institutional packaging that was recycled in the year 2011 was 616.89 kg. We assume that this represents a 50% recycling rate based on the presence of only 2 polystyrene collection centers on campus. Therefore the total recycled polystyrene weighs 616.89 kg.

All other uses of polystyrene either result in contamination of the polystyrene from food, or occur in areas of campus that are at some distance from the recycling bins, thus reducing the likelihood that these items will be recycled. For example, meat trays and take-away containers, by virtue of their functions, are contaminated with food and are disposed of in the garbage bins. Polystyrene cushioning from student packages is likely to be disposed of in the Wang Campus Center mail services area or in the students' rooms, from which it is inconvenient to walk to the Science Center for disposal in polystyrene recycling bins. The total weight of polystyrene disposed of in the garbage is 1,878.60 kg.

Destination of #6 Plastic Waste

23.27% of polystyrene waste generated on Wellesley's campus is sent to Conigliaro Industries for recycling, and 76.73% is sent to SEMASS for incineration, as represented in Table 5.28.

Table 5.28: **Destination of Wellesley's Polystyrene Waste**.

	Conigliaro	SEMASS
% of Waste	24.72%	75.28%
Weight of Waste (kg)	616.89	1,878.60

We found that polystyrene waste from institutional packaging materials is sent to Conigliaro Industries at a rate of 50%. Polystyrene waste from disposable dining hall dishes, disposable events dishware and student-associated packages and take-out containers, is disposed of in the garbage and ends up in SEMASS. The total weight of polystyrene waste that ends up in the trash and sent SEMASS is 1,878.60 kg.

Abridged Life Cycle of Plastics #6 Produced at Wellesley College

At Wellesley College, polystyrene waste is primarily generated from institutional packaging materials. These packaging materials include blocks, sheets and peanuts used for cushioning fragile items in packages. This form of polystyrene is known as expanded polystyrene (EPS). An abridged life cycle diagram for EPS from production to disposal is displayed in Figure 5.16.

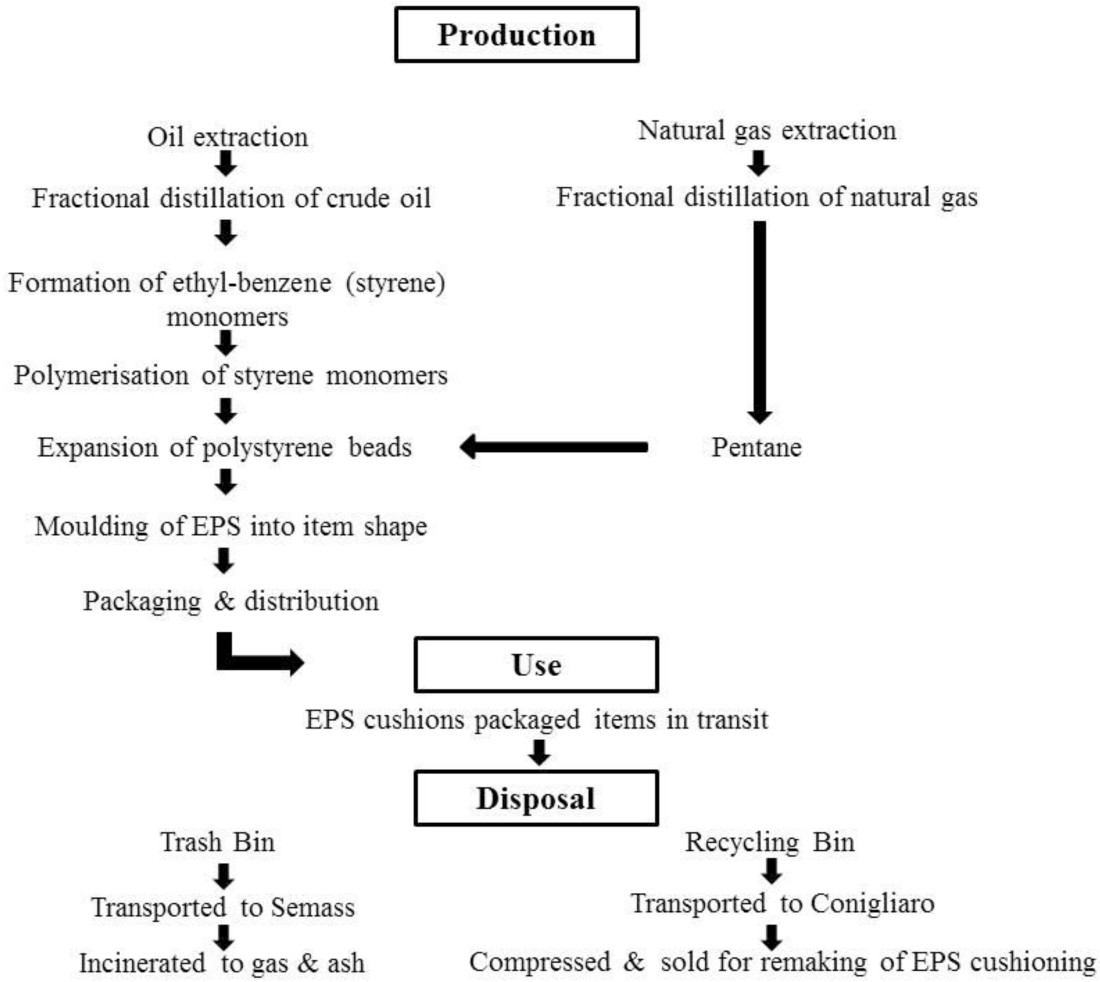

Figure 5.16: **Abridged Life Cycle for Expanded Polystyrene (EPS) in Package Cushioning.**

Polystyrene Source Background

Expanded polystyrene (EPS) is made from styrene monomers that are polymerized. Ethylene and benzene are the building blocks of styrene and are both produced in the fractional distillation of crude oil that is extracted from underground reserves.[113] Once the styrene monomers are polymerized to form small polystyrene beads, the beads are expanded into EPS using pentane, which is distilled from crude oil or natural gas. Pentane is blown through the

[113] How Is Expanded Polystyrene Foam Made? *Answers.com*, 2012. Web. 24 Mar. 2012. <http://www.answers.com/topic/expanded-polystyrene-foam-epf>.

polystyrene beads, which causes the beads to expand into lightweight foam beads.[114] After an aging process, the beads are molded into the required form and shape for use as cushioning.[115]

Manufacturing of Polystyrene

Ethylene and benzene derived from petroleum and natural gas are combined to form ethyl-benzene.[116] Ethyl-benzene is then dehydrogenated to form styrene monomers.[117] The styrene monomers are polymerized either by heat or by an initiator resulting in polystyrene.[118] In order to produce the beads that make up EPS, polystyrene undergoes a suspension process in which the polystyrene is suspended in water and an agent is added to cause the polystyrene to form dense beads.[119] The next stage of the process involves the expansion of these dense beads into lightweight foam beads by blowing pentane through them. The foam beads are then heated and molded into polystyrene blocks. These EPS blocks are allowed to 'age', during which time much of the pentane in the beads is released into the air.[120] After this stage, the polystyrene can be molded into the required shapes for package cushioning including end-blocks and packing 'peanuts'. This manufacturing process uses energy inputs to fuel the machinery used in the formation of EPS products.

Manufacturing and Use Impact Assessment for Polystyrene

The environmental impacts from the manufacture Per 1 kg and total polystyrene cushioning disposed of at Wellesley are displayed in Table 5.29 below.

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[114] European Union Risk Assessment Report on n-Pentane. *European Commission Joint Research Center,* (Norway, 2003), 19. <http://esis.jrc.ec.europa.eu/doc/existing-chemicals/risk_assessment/REPORT/n-pentanereport043.pdf>.
[115] European Union Risk Assessment Report on n-Pentane. *European Commission Joint Research Center,* (Norway, 2003), 19. <http://esis.jrc.ec.europa.eu/doc/existing-chemicals/risk_assessment/REPORT/n-pentanereport043.pdf>.
[116] European Union Risk Assessment Report on n-Pentane. *European Commission Joint Research Center,* (Norway, 2003), 19. <http://esis.jrc.ec.europa.eu/doc/existing-chemicals/risk_assessment/REPORT/n-pentanereport043.pdf>.
[117] European Union Risk Assessment Report on n-Pentane. *European Commission Joint Research Center,* (Norway, 2003), 19. <http://esis.jrc.ec.europa.eu/doc/existing-chemicals/risk_assessment/REPORT/n-pentanereport043.pdf>.
[118] European Union Risk Assessment Report on n-Pentane. *European Commission Joint Research Center,* (Norway, 2003), 19. <http://esis.jrc.ec.europa.eu/doc/existing-chemicals/risk_assessment/REPORT/n-pentanereport043.pdf>.
[119] European Union Risk Assessment Report on n-Pentane. *European Commission Joint Research Center,* (Norway, 2003), 19. <http://esis.jrc.ec.europa.eu/doc/existing-chemicals/risk_assessment/REPORT/n-pentanereport043.pdf>.
[120] European Union Risk Assessment Report on n-Pentane. *European Commission Joint Research Center,* (Norway, 2003), 19. <http://esis.jrc.ec.europa.eu/doc/existing-chemicals/risk_assessment/REPORT/n-pentanereport043.pdf>.

Table 5.29: Total impact values for the extraction and manufacture of polystyrene cushioning

Impact category	Impact Per 1 kg	Total Impact for 1,233.78 kg	Unit
Global warming	3.32	4,096.15	kg CO2 eq
Acidification	0.57	703.25	H+ moles eq
Eutrophication	0.00033	0.41	kg N eq
Carcinogens	0.00033	0.41	kg benzene eq
Non-carcinogens	1.17	1,443.52	kg toluene eq
Respiratory effects	0.002	2.47	kg PM2.5 eq

Recycling Overview of Plastics

Most of Wellesley College's recycled plastic, including plastics #1, #2, #4, #5 and plastic bags and wrap, is sent to Conigliaro Industries in a single stream. There, about 1% of the commingled plastics are ground into small pieces to be used as an additive to cement in the manufacture of cement-retaining wall blocks sold by the company.[121] In this way, a very small portion of Wellesley's plastic recycling is not actually recycled, but reused. The other 99% of plastics, which are sent from Conigliaro to Casella Recycling, are sorted and shipped to processing facilities. They are ground into flakes, washed to remove labels and contaminants, and dried so that they can be reformulated into recycled plastic pellets.[122] These pellets can then be used as a feedstock in the manufacture of new plastic products.

Two types of plastics are exceptions that are not handled in the same stream as the other plastics. Plastic #3, or PVC, is very difficult to recycle because raw PVC is mostly composed of chlorine, and it also has many additives mixed in.[123] At Wellesley College, PVC is not recycled. Plastic #6, or polystyrene, is sent to Conigliaro Industries separately from the other plastics and processed on site. The polystyrene is compressed into big bales to reduce its volume, and then it is sold to customers. Recycled expanded polystyrene is melted and remolded to form new EPS blocks that can be made into any EPS product.[124]

Recycled plastics can be used as inputs in a variety of new products. Post-consumer recycled PETE (PCR PETE) from beverage bottles can be made into new beverage bottles after

[121] Richard Garrison. Manager of Conigliaro Industries. Interview. 20 Mar. 2012.
[122] Casella Auburn Facility. Phone Interview. 2 Apr. 2012.
[123] PVC Waste and Recycling. *Greenpeace*. n.d. Web. 17 Apr. 2012. <http://archive.greenpeace.org/toxics/html/content/pvc3.html>.
[124] Recycling Styrofoam. n.d., Web. 22 Mar 2012. http://www.all-recycling-facts.com/recycling-styrofoam.html.

undergoing a process that approves the products as contaminant-free and close enough to the original in quality. PCR PETE is also recycled into bottles for non-food products, such as cleaning liquids, synthetic fibers for clothing (such as fleece) and carpet, and fiberfill for pillows.[125] It is recommended that no more than 20% of PETE resin used in manufacturing be sourced from recycled PETE because of the effects on the viscosity, color and odor of the melt.[126] HDPE can be recycled into many products, from piping and plastic lumber to ropes and toys.[127] LDPE can be recycled into a range of LDPE and mixed-plastic products, including compost and garbage cans, plastic film, furniture, garbage can liners, paneling, plastic lumber and shipping envelopes.[128] Expanded polystyrene can be recycled into other EPS products such as cushioning blocks, packing peanuts and construction insulation blocks.[129]

Plastic bags and wraps can be recycled into more of the same plastic (PVC, LDPE or HDPE) if the bags or wraps are clean, though it is usually not cost-effective to do so since use degrades and dirties plastic bags.[130] As a result, 43% of plastic recovered from bags and wraps is recycled into composite lumber, a building material made out of wood fibers embedded in a polyethylene matrix.[131] Composite lumber does not require as high a plastic quality as other applications, such as recycling into polyethylene resin. Once polyethylene is used in the manufacture of this wood substitute, the plastic cannot be recovered and is permanently removed from the waste stream.

Plastics Incineration Impacts

Transportation Impacts for Plastics Handling: SEMASS

Plastics thrown into the trash at Wellesley College are sent to SEMASS for incineration. Plastic waste is transported in large, diesel-powered combination trucks, to the SEMASS facility located 212.45 km away from Wellesley College. The impact factors for transport were calculated using SimaPro7 using the TRACI2 method shown in Table D.8 in Appendix D.

Facility Impacts for Plastics Handling: SEMASS

Depending on the composition of the plastic product, the incineration of these plastics carries unique impacts. The toxic material content of plastics was used to estimate the

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125 PET Preform/Bottle Project. *KenPlas Plastics Projects*. KenPlas Industry Ltd., 2012. Web. 29 Mar. 2012. <http://www.kenplas.com/project/pet/>.

126 PET Preform/Bottle Project. *KenPlas Plastics Projects*. KenPlas Industry Ltd., 2012. Web. 29 Mar. 2012. <http://www.kenplas.com/project/pet/>.

127 HDPE Recycling. *Wastecare*. n.d. Web. 28 Feb. 2012. <http://www.wastecare.com/Articles/HPDE_Recycling.htm>.

128 Belsey Priebe, M. How to Recycle LDPE (Plastic #4). *Eco Life*. n.d. Web. 24 Mar. 2012. <http://www.ecolife.com/recycling/plastic/how-to-recycle-ldpe-plastic-4.html>.

129 Polystyrene Recycling Process. *Polystyrene Packaging Council*. n.d., Web. 22 Mar 2012. http://www.polystyrenepackaging.co.za/files/polystyrene_bob.jpg.

130 Bushnell, K. Plastic Bags: What About Recycling Them? *Sierra Club*. n.d. Web. 22 Feb. 2012. <http://www.sierraclub.org/sustainable_consumption/articles/bags2.asp>.

131 2010 National Postconsumer Plastic Bag and Film Recycling Report. *Moore Recycling*, As Presented to the American Chemistry Council. Jan. 2012. Web. 8 May 2012. <http://www.plasticbagrecycling.org/08.0/2010FilmReport.pdf>.

environmental impacts of burning plastics displayed in Table D.9 in Appendix D. The impacts for all the plastic waste sent to SEMASS can be found in Table D.10 Appendix D.

Facility Credit for Plastics Handling: SEMASS

At SEMASS, energy produced from the incineration of plastics is converted into electricity, some of which is used to run the facility while the rest is fed to the grid. Plastics, which are hydrocarbons derived from oil and natural gas, have a high heating value and thereby release a large amount of energy when burned. The heating value in kJ for each plastic type can be found in Table D.11 found in Appendix D.

The portion of electricity that goes to the grid displaces part of the negative impacts from conventional electricity production. We estimated the impacts avoided by calculating the impacts of producing electricity in Massachusetts, which is from a mix of fuels (coal, oil, nuclear, hydroelectric and other sources), using the TRACI2 method on SimaPro7. These avoided impacts can be found in Table D.12 found in Appendix D. The ecosystem impacts per 1 kg of plastic waste sent to SEMASS are displayed in Table 5.30. The overall impacts for SEMASS are presented in Table 5.31.

Table 5.30: Impacts per 1 kg of Plastic Waste Sent to SEMASS.

Impact Category	Transport Impact	Facility Impact	Facility Credit	Total Impact	Unit
Global Warming	0.0091	1.10	-4.37	-3.26	kg CO2 eq
Acidification	0.0032	0.09	-2.06	-1.96	H+ moles eq
Eutrophication	0.0000028	0.000095	-2.24	-2.23	kg N eq
Carcinogens	0.0000029	0.01	-0.0024	0.0075	kg benzene eq
Non-Carcinogens	0.06	19.34	-20.41	-1.01	kg toluene eq
Respiratory Effects	0.0000034	0.00034	-0.0082	-0.0078	kg PM2.5 eq

Table 5.31: Total Ecosystem Impacts for All Plastics Sent to SEMASS.

Impact Category	Transport Impact	Facility Impact	Facility Credit	Total Impact	Unit
Global Warming	73.40	6,947.59	-28,294.01	-21,807.08	kg CO2 eq
Acidification	24.27	555.27	-12,310.05	-11,730.51	H+ moles eq
Eutrophication	0.02	0.87	-2.70	-1.81	kg N eq
Carcinogens	0.02	366.40	-14.42	352.00	kg benzene eq
Non-Carcinogens	504.17	368,204.58	-121,864.78	246,913.97	kg toluene eq
Respiratory Effects	0.02	2.26	-49.08	-46.80	kg PM2.5 eq

PLASTICS RECYCLING IMPACTS

Figure 5.17: Plastic Bales at Conigliaro Industries.

Transportation Impacts for Plastics Handling: Conigliaro

Plastics handled as recycling from Wellesley College are first sent to Conigliaro Industries in a single-unit, diesel powered truck. Polystyrene is sorted and compacted on site at Conigliaro. For all other plastic types, 1% is removed for on-site use. The total transport distance of recycled plastics from Wellesley College to Conigliaro is 10.89 km. The impact factors for transport to Conigliaro were calculated using SimaPro7 using the TRACI2 method. The trucking impacts for all recycled plastic products sent from Wellesley College to Conigliaro are displayed in Table D.13 in Appendix D. PVC plastic wrap is not recycled and is not included in this calculation.

Facility Impacts for Plastics Handling: Conigliaro

At Conigliaro Industries, about 1% of commingled plastics are mechanically ground into small pieces, which are used as a fill component in cement blocks produced on site. Conigliaro's solar panels provide enough energy to power the plastics shredders throughout the year.[132] Using the TRACI2 analysis method in SimaPro7, we found that solar panels' energy production carries no impact for our selected impact factors. We therefore concluded that there is no measurable impact for the shredding of 1% of Wellesley's recycled plastics at Conigliaro.

Facility Credit for Plastics Handling: Conigliaro

Conigliaro receives no credit for plastics handling, as the 1% of plastics retained on site are ground for permanent enclosure in cement blocks and are not recycled. The per 1 kg impacts and overall facility impacts for Conigliaro are presented in Table 5.32 and Table 5.33.

Table 5.32: Impacts Per 1 kg of Plastic Waste Sent to Conigliaro Industries.

Impact Category	Transport Impact per 1 kg	Facility Impact per 1 kg	Facility Credit per 1 kg	Total Impact per 1 kg	Unit
Global Warming	0.0018	-	-	0.0018	kg CO2 eq
Acidification	0.00054	-	-	0.00054	H+ moles eq
Eutrophication	0.00000058	-	-	0.00000058	kg N eq
Carcinogens	-	-	-	-	kg benzene eq
Non-Carcinogens	-	-	-	-	kg toluene eq
Respiratory Effects	0.00000054	-	-	0.00000054	kg PM2.5 eq

[132] Garrison, Richard. Manager of Conigliaro Industries. Personal Interview. 9 Apr. 2012.

Table 5.33: Overall Impacts for All Plastics Handling at Conigliaro Industries.

Impact Category	Transport Impact	Facility Impact	Facility Credit	Total	Unit
Global Warming	5.40	-	-	5.40	kg CO2 eq
Acidification	1.57	-	-	1.57	H+ moles eq
Eutrophication	0.0016	-	-	0.0016	kg N eq
Carcinogens	-	-	-	-	kg benzene eq
Non-Carcinogens	-	-	-	-	kg toluene eq
Respiratory Effects	0.0015	-	-	0.0015	kg PM2.5 eq

Transportation Impacts for Plastics Handling: Casella

From Conigliaro Industries, 99% of the plastics, excluding #3 and #6 plastics and plastic bags and wrap, are sent to Casella in a single-unit, diesel powered truck. The distance from Conigliaro to Casella is 39.91 km. The impact factors for transport were calculated using SimaPro7 with the TRACI2 method. The trucking impacts for transporting 99% of the plastics to Casella are displayed in Table D.14 found in Appendix D.

Facility Impacts for Plastics Handling: Casella

Conigliaro sends 99% of our plastics, with the exception of polystyrene, which is sent to a reprocessing facility, to Casella for recycling. At Casella, the plastics are sorted, repackaged and shipped out for recycling into new plastic materials. The largest impact of this stage is the mechanical sorting of plastics. We used the impacts of a rock crusher from SimaPro7 as our best estimation of the impacts of the mechanical sorter, as no closer estimators were available. The approximate impacts for sorting 99% of Wellesley's commingled plastics (excluding plastic bags and polystyrene) sent to Casella are quantified in Table D.15 found in Appendix D.

Facility Impacts for Plastics Handling: Casella

Casella gets no credit for plastics handling, as all plastics received by the facility are sorted and then transported to domestic and overseas processors. None of the plastics are actually recycled on site. The impacts per 1kg of plastic waste and the cumulative facility impacts for Casella are presented in Table 5.34 and 5.35 respectively.

Table 5.34: Impacts Per 1 kg of Plastic Waste Handling at Casella.

Impact Category	Transport Impact per 1 kg	Facility Impact per 1 kg	Facility Credit per 1 kg	Total Impact per 1 kg	Unit
Global Warming	0.0069	0.000011	-	0.0069	kg CO2 eq
Acidification	0.0020	0.0000026	-	0.0020	H+ moles eq
Eutrophication	0.0000021	0.000000055	-	0.0000022	kg N eq
Carcinogens	-	0.000000075	-	0.000000075	kg benzene eq
Non-Carcinogens	-	0.00053	-	0.00053	kg toluene eq
Respiratory Effects	0.0000020	0.000000037	-	0.0000020	kg PM2.5 eq

Table 5.35: Cumulative Impacts for handling of Plastics Waste at Casella.

Impact Category	Transport Impact	Facility Impact	Facility Credit	Total Impact	Unit
Global Warming	14.61	0.03	-	14.64	kg CO2 eq
Acidification	4.27	0.0071	-	4.27	H+ moles eq
Eutrophication	0.0045	0.00014	-	0.0046	kg N eq
Carcinogens	-	0.00020	-	0.00020	kg benzene eq
Non-Carcinogens	-	1.44	-	1.44	kg toluene eq
Respiratory Effects	0.0043	0.00010	-	0.0024	kg PM2.5 eq

Transportation Impacts for Plastics Handling: Overseas Processing

After sorting at Casella, plastics are shipped to processing facilities. Although Casella sends plastics to both domestic and overseas processors, we assumed that the majority of plastics are shipped overseas. As many of these processing facilities are located in Asia, we assumed that plastics are shipped to Shanghai, China. We calculated the distance by sea to be 17,080 km traveled by barge via the Panama Canal. We calculated the impact of this shipment in SimaPro7 using the TRACI2 method. The impacts for overseas shipment of 99% of our plastics waste can be found in Table D.16 found in Appendix D.

Facility Impacts for Plastics Handling: Overseas Processing

As mentioned earlier, plastics sorted at Casella (99% of the total recycled plastics from Wellesley College) are shipped to processing facilities, generally located overseas. In these facilities, #1-5 plastics are melted down and extruded into pellets or films, which can then be manufactured into new plastic products. The combined impacts of these processes are quantified in Table D.17 found in Appendix D.

Facility Credit for Plastics Handling: Overseas Processing

In Shanghai, the processed, recycled plastics are sent to manufacturers for the production of new products. Below are the primary materials made from each type of recycled plastic and the percentage of recycled content that can be incorporated into the final product.

- #1 plastics are primarily recycled into synthetic fiber (polyester). Polyester can contain up to 100% recycled content.[133]
- #2 plastics are primarily recycled into plastic lumber. Plastic lumber can contain up to 95% recycled content.[134]
- #4 plastics are primarily recycled into plastic film. Up to 100% of plastic film can be recycled content.
- #6 plastics are primarily recycled into foam packaging. Up to 60% of recycled foam packaging can be recycled content.[135]
- Plastic bags are primarily recycled into plastic lumber. However, because plastic bags are harder to sort than most plastics, the resultant recycled plastic stock is of lower quality. Only about half of manufactured plastic composite lumber has a post-consumer recycled plastic wrap content of 50% or more.[136]

To calculate the recycling credit for recycled plastics, the environmental costs of producing the ultimate recycled product from virgin materials were subtracted from the gross life cycle cost of the plastic. For products that would not exist without the recycling industry, such as plastic-composite lumber, a similar product, such as wood lumber, was substituted. These credits are summarized in Table D.18 found in Appendix B. Plastic #6 is recycled within the U.S., and the calculated recycling credit applies to the recycling facility within the country rather than to an overseas facility.

The impacts for 1kg of plastic processed overseas and the cumulative impacts for total plastics processed overseas are presented in Table 5.36 and Table 5.37 respectively.

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[133] Eco-fi. *Foss Manufacturing Company*, LLC, 2010. Web. 9 Apr. 2012. <http://www.eco-fi.com/>; Fabrics: eco-fabrics. *Brentano, Inc*., 2012. Web. 9 Apr. 2012. <http://www.brentanofabrics.com/green/Default.aspx?fiber=Recycled>; *Repreve*. UNIFI, Inc., 2011. Web. 9 Apr. 2012. <http://www.repreve.com/>.

[134] Recycled Plastic Lumber. *California Department of Resources Recycling and Recovery* (CalRecycle), 1 Apr. 1999. Web. 5 Apr. 2012. <http://www.calrecycle.ca.gov/Plastics/recycled/lumber/>.

[135] ACH Foam Technologies Rolls Out EcoSix: First 60% Recycled Content EPS Packaging. *WineBusiness*. Wine Communications Group, 5 May 2010. Web. 9 Apr. 2012. <http://www.winebusiness.com/suppliernews/?go=getSupplierNewsArticle&dataId=73842>.

[136] The Healthy Building Network's Guide to Plastic Lumber. *Healthy Building Network*, October 2005. Web. 6 Apr. 2012. <http://www.healthybuilding.net/pdf/gtpl/guide_to_plastic_lumber.pdf>.

Table 5.36: Impacts per 1 kg of Plastic Waste Sent Overseas for Processing.

Impact Category	Transport Impact	Facility Impact	Facility Credit	Total Impact	Unit
Global Warming	0.79	1.15	-1.76	0.18	kg CO2 eq
Acidification	0.41	0.26	-0.34	0.33	H+ moles eq
Eutrophication	0.0013	0.0064	-0.00017	0.0064	kg N eq
Carcinogens	0.00067	0.0036	-0.024	-0.02	kg benzene eq
Non-Carcinogens	5.47	38.92	-5.91	38.48	kg toluene eq
Respiratory Effects	0.00096	0.0015	-0.0012	0.00044	kg PM2.5 eq

Table 5.37: Overall Impacts for Overseas Processing of All Plastics Excluding Plastic Bags.

Impact Category	Transport Impact	Facility Impact	Recycling Credit	Total impact	Unit
Global Warming	2,150.64	3,152.30	-8,847.42	-3,544.48	kg CO2 eq
Acidification	1,116.15	724.27	-1,759.88	80.54	H+ moles eq
Eutrophication	3.78	17.64	-5.67	15.75	kg N eq
Carcinogens	1.84	9.92	-7.32	4.44	kg benzene eq
Non-Carcinogens	14,891.19	106,197.58	-23,454.49	97,634.28	kg toluene eq
Respiratory Effects	2.63	4.28	-6.55	0.36	kg PM2.5 eq

Cumulative Impacts of Plastics Disposal

Accounting for all of the transportation, sorting and processing credits and impacts for plastics recycling, the impact per 1 kg and the cumulative impacts for plastics recycling at each handling stage are presented in Tables 5.38 and Table 5.39 respectively.

Table 5.38: Impacts per 1 kg for Recycling of All Plastics Excluding Plastic Bags.

Impact Category	Transport Impact	Facility Impact	Recycling Credit	Total Impact	Unit
Global Warming	0.79	1.15	-1.76	0.18	kg CO2 eq
Acidification	0.41	0.26	-0.34	0.33	H+ moles eq
Eutrophication	0.0013	0.0064	-0.00017	0.0075	kg N eq
Carcinogens	0.00067	0.0036	-0.024	-0.02	kg benzene eq
Non-Carcinogens	5.47	38.92	-5.91	38.40	kg toluene eq
Respiratory Effects	0.00096	0.0015	-0.0012	0.00013	kg PM2.5 eq

Table 5.39: Cumulative Impacts Recycling of All Plastics Excluding Plastic Bags.

Impact Category	Transport Impact	Facility Impact	Recycling Credit	Total Impact	Unit
Global Warming	2,170.65	3,152.33	-8,847.42	-3,524.44	kg CO2 eq
Acidification	1,121.99	724.27	-1,759.88	86.38	H+ moles eq
Eutrophication	3.78	17.64	-5.67	15.75	kg N eq
Carcinogens	1.84	9.92	-7.32	4.44	kg benzene eq
Non-Carcinogens	14,891.19	106,1989.02	-23,454.49	97,634.28	kg toluene eq
Respiratory Effects	2.63	4.28	-6.55	0.36	kg PM2.5 eq

PLASTICS DISPOSAL CONCLUSIONS

The impact values per 1 kg of material sent to either incineration at SEMASS or recycling are displayed in Table 5.40. The cumulative impacts for throwing plastics in the trash or in the recycling bin for total annual waste are shown in Table 5.41.

Table 5.40: Trash vs. Recycling Impacts Per 1 kg of Plastics Sent from Wellesley College. The Trash Total is SEMASS Impacts and the Recycling Total is the Sum of Conigliaro, Casella and Overseas recycling impacts.

Impact Category	Trash Total	Recycling Total	Unit
Global Warming	-3.26	0.18	kg CO2 eq
Acidification	-1.96	0.33	H+ moles eq
Eutrophication	-2.23	0.0064	kg N eq
Carcinogens	0.0075	-0.02	kg benzene eq
Non-Carcinogens	-1.01	5,533.49	kg toluene eq
Respiratory Effects	-0.0078	0.00044	kg PM2.5 eq

Table 5.41: Trash and recycling impacts for all plastics waste produced in Wellesley College by destination. The trash total is SEMASS impacts and the recycling total is the sum of Conigliaro, Casella and overseas recycling impacts.

Impact Category	Trash Total	Recycling Total	Unit
Global Warming	-21,807.08	-3,524.44	kg CO2 eq
Acidification	-11,730.51	86.38	H+ moles eq
Eutrophication	-1.81	15.75	kg N eq
Carcinogens	352.00	4.44	kg benzene eq
Non-Carcinogens	246,913.97	97,635.72	kg toluene eq
Respiratory Effects	-46.80	0.36	kg PM2.5 eq

LCA Findings and Implications

In comparing the impacts of throwing plastics in the trash versus recycling, for both 1 kg and total weight measures, incineration appears to be the environmentally favorable option. For most measures, incineration has negative impacts because of the high waste-to-energy efficiency rate of SEMASS' incineration facility. Most recycling impacts, on the other hand, result from plastics transportation and processing. Based on the LCA analysis of impacts, credits and transportation costs of waste handling from Wellesley College, incineration has fewer impacts than recycling.

However, this analysis does not account for a number of auxiliary factors that should be considered in deciding which bin to toss your used water bottle into. Firstly, the additional ecosystem impacts associated with plastics manufacture are not incorporated in this analysis. For example, the recycling of plastics into other plastic products alleviates many of the impacts associated with oil and natural gas extraction and virgin plastics production. Furthermore, the virgin hydrocarbon sources necessary for making plastics are a non-renewable resource, so it would be unsustainable to eliminate recycling. Additionally, the MA Waste Ban explicitly bans the disposal of recyclable materials like plastics into the MSW stream. Therefore, it would be illegal for Wellesley to eliminate its recycling program on the basis of these LCA findings.

Therefore, we still recommend that plastics from Wellesley College be recycled. To minimize the impacts of recycling under our current system, Wellesley College could investigate more local recycling providers to eliminate the transport costs associated with plastics manufacture.

Of course, any plastics waste production results in environmental impacts, whether from the waste handling process or material manufacture. Therefore, a general emphasis on primary reduction and reuse of plastics is the best course of action. We have several suggestions for how to reduce plastic use in the following section.

Recommended Plastics Reduction Strategies

Reusable water bottles could be used in place of one-use PETE bottles. This could especially be done on campus where there is already a culture of reusable water bottles that only needs to be encouraged further. For example, Wellesley College might provide or subsidize reusable aluminum or steel water bottles instead of the plastic PETE bottles provided at events or to incoming students. Another alternative to providing PETE water bottles would be to have refillable drinking water dispensers and cups at events on campus. PETE beverage bottles could be replaced with products made from materials that are more easily or likely to be recycled, such as glass or aluminum. PETE containers could also be designed to decrease the amount of PETE in each bottle without compromising the volume of the container.

To reduce the use of HDPE plastic material, bioplastics could be used in its place. Bioplastics can be made from fermented corn syrup, which is easily biodegradable if disposed of in a commercial composter.[137] Corn is an annually renewable crop, and harvesting it does not have the severe environmental impacts associated with oil extraction. Also, bioplastics have a longer recycling life than petroleum-derived plastics.[138] Biopackaging could also be used as a substitute for foam packaging polystyrene. Currently biopackaging is either made from plant products,[139] or is fungi-produced;[140] it has fewer impacts on soil erosion, water use, land disruption and biodiversity effects while providing the same quality of material afforded by petroleum-based products.

To reduce the amount of LDPE take-out containers used on campus, we would have to decrease the amount of take-out ordering by students and staff. Unfortunately, because of the popularity of local take-out restaurants, which provide convenient late-night and weekend deliveries of foods generally not found in the dining halls, it is unlikely that take-out ordering behaviors can be realistically changed. Extreme measures, such as drastically improving the

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[137] Dell, K. The Promise And Pitfalls of Bioplastic. *Time*, 3 May 2010. Web. 20 Apr. 2012. <http://www.time.com/time/magazine/article/0,9171,1983894,00.html>.
[138] Greener Paths for Plastics. *Green American*, Feb. 2006, Web. 20 Apr. 2012. <http://www.greenamerica.org/livinggreen/plastics.cfm>.
[139] Biodegradable Packaging. *Nviroplast*, n.d.,Web. 08 Apr. 2012. <http://www.nviroplast.com/biopackaging.asp>.
[140] Bayer, E. Are Mushrooms the New Plastic?, *Tedtalks*, n.d. Web. 8 Apr. 2012. <http://www.ted.com/talks/eben_bayer_are_mushrooms_the_new_plastic.html>.

quality of dining hall food to discourage interest in take-out or mandating local business to increase delivery fees for orders sent to Wellesley College, would be options for decreasing the use of #4 plastic take-out containers on campus. However, neither of these options is financially realistic. This is similar to the regulation of plastic bags from off-campus use. Beyond asking retailers to change their policies, there is not much that the college can do to reduce the use of plastic shopping bags from off-campus.

Substituting for plastic bags largely depends on how you are using the plastic bags. Reusable cloth tote bags, for instance, are becoming increasingly popular as a way to avoid using disposable plastic shopping bags. Although paper shopping bags are also touted as a substitute for plastic bags, LCA assessments have mostly come to the conclusion that plastic bags are less environmentally damaging if you reuse them even once (for example using a bag as a shopping bag, and then using it as a small trash can liner). Finding a good substitute for plastic trash bags, which make up most of Wellesley's waste stream, is more complex, since we need to be able to throw the trash bag liners away, in order to avoid coming into contact with trash and to help transport trash without dropping things. Although waxed-paper liners (like what we use in the bathroom stalls for sanitary disposal) might substitute for small bags well, the same is not true for larger bags. Larger bags could be made from compostable corn. A simple way to affect use of plastic shopping bags on campus is to either start giving customers at the campus stores a discount for bringing a reusable bag, or to start charging customers a "plastic bag tax" when a plastic bag is required to carry their purchases. Of the two, a plastic bag use fee has been shown to be more effective at reducing plastic bag use overall, but also most likely to alienate customers when support for plastic bag reduction is low. It is also possible to institute a wholesale ban on giving away plastic shopping bags with purchases, but that has proven problematic when municipalities have tried it.

To reduce the use of polystyrene covers for disposable beverage cups, Wellesley Fresh could start a Bring Your Own Mug campaign, which is already in use on other campuses such as in Harvard dining halls.[141] In this model, students could use their own mugs instead of taking out the dining hall's mugs or using disposable ones (which are the two options currently available). Not only does this option reduce the use of disposable beverage cups and polystyrene lids, but it also overrides laziness or lack of time to wash mugs, which might be a barrier to the use of non-disposable mugs for some students.

The Wellesley College administration could reduce polystyrene waste generated from package cushioning by either buying goods from manufacturers who use alternative forms of packaging, such as bio-packaging, or requesting that their goods be packaged in materials other than polystyrene during purchasing. These practices can be implemented through a change in policy in the purchasing department.

Encouraging the campus to use reusable items is an easy way to reduce our plastics waste. An effective tactic could be to target plastic products that are not only used and discarded widely and frequently, but that also have substitutions that are accessible to the campus community. If Wellesley College does not need to purchase or use so many plastics, we can cut impacts from the entire life cycle of each type of plastic, from manufacture to disposal. The primary reduction in use is especially important because at Wellesley College, recycling may be

[141] You Can Bring Your Mug or Thermos to the Dining Hall, and They'll Wash it and Return it to the Mug Tree Where you Can Retrieve It. *Harvard College Freshman Dean's Office § Yard Amenities*, n.d., Web. 4 May 2012. <http://fdo.fas.harvard.edu/icb/icb.do?keyword=k3806&pageid=icb.page433196&pageContentId=icb.pagecontent913102&view=view.do&viewParam_name=YardAmenities_GreenLiving.html>.

even less beneficial than incineration, leaving us with no particularly good ways of disposing of plastics once we acquire them.

2.6 Organics

Organic material in the Wellesley waste stream includes yard waste, food waste, and compostable dishware and cutlery. Organics comprise the largest portion of Wellesley College's waste. They represent a necessary by-product of college maintenance, food service, and efforts to avoid use of certain types of disposable dishware that may have more problematic environmental impacts. The materials discussed in this section are all made up of biodegradable, organic materials and can potentially be composted.

YARD WASTE

Yard Waste Background

Yard waste refers to organic waste material created through landscape maintenance. It comprises of organic vegetation that is removed for aesthetic, recreational, or safety reasons. Yard waste encompasses lawn trimmings, leaves, lake vegetation, brush, and removed trees or plants. Yard waste is an unavoidable byproduct of landscaping, but how much yard waste is removed and where it goes can vary tremendously.

Yard Waste at Wellesley College

Wellesley's image as a beautiful campus is important to the College. The College relies on its campus' beauty to attract new students and to please alumnae who come back on visits or for reunions. Wellesley College is renowned for its beautiful campus.[1] The Wellesley College Botanic Gardens, including the Margaret C. Ferguson greenhouses and the H. H. Hunnewell Arboretum, house an impressive collection of plants and trees. These facilities are open for students to enjoy, as well as to numerous outside visitors. The manicured greens of the Neohoiden Golf Course are open to faculty and staff, residents of the town of Wellesley, and alumnae.

Activities and Behaviors Producing Yard Waste at Wellesley College

The Wellesley College campus grounds, Botanic Gardens, Lake Waban, and Neohoiden Golf Course cumulatively produce every subcategory of yard waste. In each of these areas, staff members trim and remove vegetation for aesthetic purposes. Staff members also remove yard waste in order to avoid safety hazards. Loose branches, unstable trees, and overgrown vegetation present dangers of falling debris, tripping, or roadblocks. The mowing of grass in high traffic areas reduces the risk of students and visitors picking up ticks.

Lake Waban and the Neohoiden Golf Course require the regular removal of yard waste for recreation to occur. In order to golf, the greens must be cleared and cut short. Lake Waban contains Eurasian Milfoil, an invasive species of water plant that must be removed for boats to be able to move freely.[2]

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[1] The World's Most Beautiful College Campuses. *Forbes*, 31 Aug. 2010. Web. 8 May 2012. <http://www.forbes.com/2010/08/31/beautiful-campuses-lifestyle-education-colleges-10-university-architecture_slide_14.html>.

[2] Landscape. *Wellesley College Sustainability*. Wellesley College, 2009. Web. 8 May 2012. <http://www.wellesley.edu/AdminandPlanning/Sustainability/landscape.html>.

Amount of Yard Waste Produced at Wellesley College

The amount of yard waste produced annually at Wellesley College is estimated as 112517.33 kg, as indicated in Table 6.1.

Table 6.1: Estimated Annual Yard Waste at Wellesley College

Material	# Cubic Yards	Total Produced Annually (kg)
Brush, Branches, and Tree trunks	2,333.33	58,333.33
Vegetation (Grass, Leaves, Plants)	1,500	54,000
Student Yard Waste (Flowers, Leaves)	-	184
Total		**112,517.33**

The percentage of annual yard waste by usage is represented in Figure 6.1.

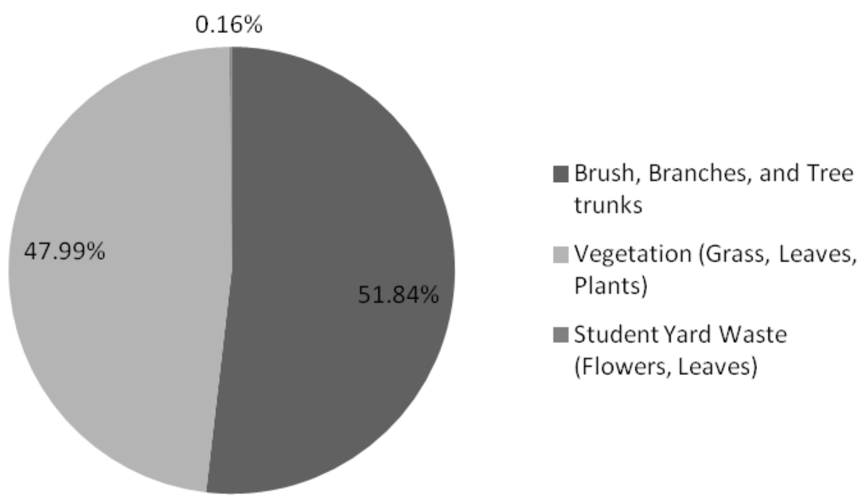

Figure 6.1: Percent Composition by Source of Annual Yard Waste at Wellesley College.

Yard waste is measured in cubic yards after it has been converted to its new form as waste. Thus, all of the measurements refer to the weight of its final form rather than the raw material. A cubic yard of Wellesley's compost weighs roughly 36 kg.[3] As mulch is lighter than compost, we estimate that a cubic yard of Wellesley's mulch weighs roughly 25 kg a cubic yard.

The Director of Sustainability, Patrick Willoughby, estimated that Wellesley College annually collects yard waste representing roughly 1,750 cubic yards, or 43,750 kg, of mulch, from brush, branches, and tree trunks on campus.[4] According to Tricia Diggins, Senior Gardens Horticulturist, about a third of brush and branches are, at least in the Arboretum, not accounted

[3] Patrick Willoughby. Director of Sustainability. Personal Interview. 14 Mar. 2012.
[4] Patrick Willoughby. Director of Sustainability. Personal Interview. 14 Mar. 2012.

for because they are collected and left in piles to decompose.[5] Therefore, the total amount of brush, branches, and tree trunk waste is 58,333.33 kg per year. Wellesley College also collects about 1,500 cubic yards, or 54,000 kg of compost from grass, leaves, and plants each year.[6]

In our waste audit of the New Dorms Complex, we found a small amount of yard waste, mainly in the form of dead plants and bouquets thrown away by students. From our audit, we estimated that the roughly 400 students who live in the New Dorm Complex contribute 1 kg of yard waste each week. Scaling this up to Wellesley's student population of 2,300, students collectively dispose 184 kg of yard waste each academic year.

Handling of Yard Waste at Wellesley College

The distribution of how yard waste is handled on campus is displayed in Table 6.2.

Table 6.2: Estimated Handling of Yard Waste at Wellesley College

Material	% Reused	% Thrown in Trash
Brush and Tree Trunks	100%	-
Branches	100%	-
Vegetation	99.52%	0.48%
Total	**99.84%**	**0.16%**

All of the vegetation that the Grounds Maintenance crew and Botanic Gardens staff collect, including leaves, plants, and root masses, is composted or reused. Most is taken for composting to a location called the Wellesley College dump.[7] Roughly a third of the brush is left in piles in areas on campus such as the arboretum, to decompose.[8] The rest of the brush, branches, and any tree trunks are put through a tub grinder and reused as mulch.

All of the leaves and plant material that students throw out in residence halls enter the trash stream. Student yard waste represents 0.16%, of all yard waste.

Destination of Yard Waste

The destination of yard waste is estimated in Table 6.3.

Table 6.3: Destination of Yard Waste by Percentage

Material	Wellesley College Campus	SEMASS
% of Waste	99.84%	0.16%
Weight of Waste	112,333.33 kg	184 kg

Yard Waste that is either left to decompose or converted to compost or mulch is later applied directly to the Wellesley College campus grounds. We estimate that all of the yard waste handled by the grounds crew and botanic gardens stays on the campus. Thus, we estimate that 99.84%, or 112,333.33 kg, of Wellesley's yard waste remains on campus each year.

[5] Diggins, Tricia, Senior Gardens Horticulturist. Personal Interview. 13 Mar. 2012.
[6] Patrick Willoughby. Director of Sustainability. Personal Interview. 14 Mar. 2012.
[7] Diggins, Tricia, Senior Gardens Horticulturist. Personal Interview. 13 Mar. 2012.
[8] Diggins, Tricia, Senior Gardens Horticulturist. Personal Interview. 13 Mar. 2012.

However, yard waste disposed of by students, such as dead bouquets or plants, is thrown into the trash. This trash is sent to the SEMASS facility, where it is incinerated. We estimate that 0.16% of Wellesley's yard waste, or 184 kg, is sent to SEMASS annually.

Abridged Life Cycle of Yard Waste Produced at Wellesley College

At Wellesley College, yard waste is primarily produced from landscape maintenance of campus areas, including the campus grounds, botanic gardens, and Neohoiden Golf Course. An abridged lifecycle diagram for yard waste from production to disposal is displayed in Figure 6.2.

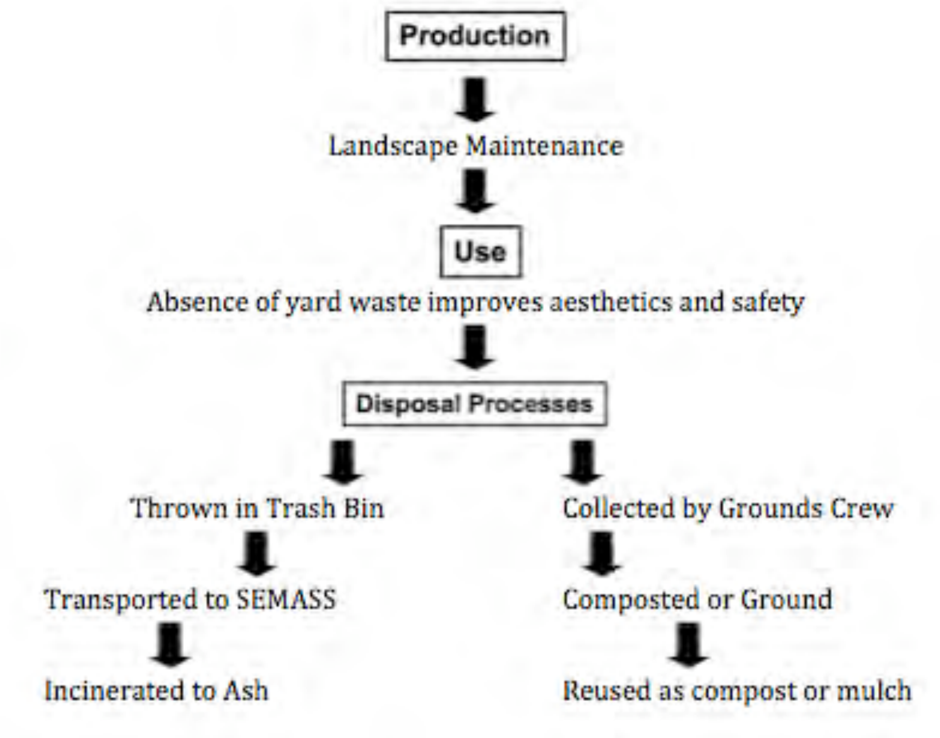

Figure 6.2: Abridged Life Cycle for Yard Waste.

Yard Waste Source Background

As mentioned earlier, yard waste is organic vegetation that is removed for aesthetic, recreational, or safety reasons. Yard waste includes lawn trimmings, leaves, brush, and removed trees or plants. Trees and plants are renewable resources. Their growth is often aided by the addition of water, nutrients, and pesticides.

Manufacturing of Yard Waste

Yard waste is removed through a combination of human and mechanical efforts at Wellesley College. Workers remove weeds and branches with their hands, shovels, or handsaws. The removal of large amounts of yard waste often requires mechanical assistance. All of the yard waste generated on the Wellesley College campus requires the use of trucks – full size or mini-dump trucks – for transportation to the dump area. These trucks run on petroleum oil for fuel. Oil is extracted from the ground by drilling. The machinery used to extract oil emits methane, a greenhouse gas, and other air pollutants. The oil extraction process requires large quantities of water and contaminates local water supplies. The oil refinement process produces solid waste containing high levels of heavy metals and toxic compounds.[9]

Manufacturing and Use Impact Assessment for Yard Waste

As yard waste on campus is composed purely of vegetation and woody debris, it is not further categorized for this analysis.

The additional ecosystem impacts of the creation of yard waste are quantified in Table #. Since the scale of yard waste collection on Wellesley College is relatively small and does not involve many additional processes or equipment, it is not quantified as an intensive activity. Fossil fuels are used in the transport of the yard waste and perhaps in the cutting of branches, but this is constitutes very little overall fuel usage. The total ecosystem impact score for yard waste at Wellesley College is 0, as shown in Table 6.4. This is the lowest possible score, indicating that the manufacture of yard waste at Wellesley College is not generally harmful to ecosystems.

Table 6.4: Additional Ecosystem Impacts for the Manufacture of Yard Waste.

Erosion	Permanent Land Disruption	Water Use	Resource Use	Biodiversity Disruption	Total Score
0	0	0	0	0	**0**

Recycling Overview of Yard Waste

Yard waste at Wellesley College is recycled and reused in a direct loop on campus. Yard waste is transported to an area on campus where it is separated by type and stored. Vegetation and small brush are composted. This compost is then used for campus landscaping. Larger brush and branches are converted into wood chips with a tub grinder. These wood chips are then used for mulching on the campus. The piles of compost and wood chips are compounded from year to year.[10]

YARD WASTE INCINERATION IMPACTS

Transportation Impacts: SEMASS

Yard waste sent to SEMASS for incineration is transported in large, diesel powered combination trucks. SEMASS is located 212.45 km away from Wellesley College. The impact factors for transport were calculated using the TRACI2 method in SimaPro7.

Facility Impacts and Credit for Yard Waste Handling: SEMASS

Yard waste that is sent to the MSW stream is incinerated at SEMASS. At SEMASS, energy produced from the incineration of yard waste is converted into electricity, some of which is used to run the facility while the rest is fed to the grid. The portion of electricity that goes to the grid displaces part of the negative impacts from conventional electricity production. We estimated the impacts avoided by calculating the impacts of producing electricity in

[9] Oil. *Environmental Protection Agency*. n.d. Web. 22 March 2012. < http://www.epa.gov/cleanenergy/energy-and-you/affect/oil.html>.

[10] Willoughby, Patrick. Director of Sustainability. Wellesley College. Personal Interview. 9 Mar. 2012.

Massachusetts, which is from a mix of fuels (coal, oil, nuclear, hydroelectric and other sources.) We used estimations for energy content to calculate the amount of energy generated through incineration with the TRACI2 method in SimaPro7. The transportation impacts, facility impacts, and facility credit for 1 kg and 184 kg of yard waste are quantified in Table 6.5 and Table 6.6 respectively.

Table 6.5: Impacts per kg for Yard Waste Sent to SEMASS.

Impact Category	Transport Impact	Facility Impact	Facility Credit	Total Impact	Unit
Global Warming	0.020	10.43	-0.00000093	10.45	kg CO2 eq
Acidification	0.0066	1.40	-0.00000041	1.41	H+ moles eq
Eutrophication	0.0000063	0.0015	-0.000000000090	0.0015	kg N eq
Carcinogens	0.0000065	0.0086	-0.00000000048	0.01	kg benzene eq
Non-Carcinogens	0.14	8.59	-0.0000040	8.73	kg toluene eq
Respiratory Effects	0.0000075	0.0017	-0.0000000016	0.0000075	kg PM2.5 eq

Table 6.6: Overall Impacts for 184 kg of Yard Waste Sent to SEMASS.

Impact Category	Transport Impact	Facility Impact	Facility Credit	Total Impact	Unit
Global Warming	3.68	1919.12	-0.00017	1,922.80	kg CO2 eq
Acidification	1.21	25.607	-0.000075	258.81	H+ moles eq
Eutrophication	0.0012	0.28	-0.000000017	0.27	kg N eq
Carcinogens	0.0012	1.58	-0.000000087	1.58	kg benzene eq
Non-Carcinogens	25.76	1580.56	-0.00074	16,056.32	kg toluene eq
Respiratory Effects	0.0014	0.31	-0.00000030	0.31	kg PM2.5 eq

Facility Credit for Yard Waste Handling: Wellesley College

The bulk of the yard waste produced at Wellesley College, 112,333.33 kg, is processed and reused on the campus grounds. The yard waste is gathered by the grounds crew or botanic gardens staff and moved to an on-site location. There it is either fed through a tub grinder to become mulch, or added to a compost pile. This mulch and compost are continuously collected and used throughout the year. The facility credit for yard waste was calculated with the TRACI2 method in SimaPro7 under the assumption that all yard waste reused was equivalent to avoiding the production of the same amount of new mulch, manufactured off site. Facility credit for these avoided impacts per 1 kg of reused yard waste is quantified in Table 6.7 and overall credit for reused yard waste at Wellesley College is displayed in Table 6.8.

Table 6.7: Credit Per 1 kg of Reused Yard Waste at Wellesley College.

Impact category	Total Credit	Units
Global warming	-0.00022	kg CO2 eq
Acidification	-0.000098	H+ moles eq
Eutrophication	-0.000000021	kg N eq
Carcinogens	-0.00000011	kg benzene eq
Non-Carcinogens	-0.00097	kg toluene eq
Respiratory effects	-0.00000039	kg PM2.5 eq

Table 6.8: Overall Credit for Reusing Yard Waste.

Impact Category	Total Credit Per 112,333.33 kg	Units
Global warming	-25.26	kg CO2 eq
Acidification	-10.99	H+ moles eq
Eutrophication	-0.0024	kg N eq
Carcinogens	-0.013	kg benzene eq
Non-Carcinogens	-108.79	kg toluene eq
Respiratory effects	-0.044	kg PM2.5 eq

YARD WASTE DISPOSAL CONCLUSIONS

A comparison of the impacts per kilogram for the two waste paths for yard waste: reuse at Wellesley College and incineration at SEMASS, are presented in Table 6.9. The comparison of cumulative impacts for yard waste that is either reused or incinerated is shown in Table 6.10.

Table 6.9: Comparison of Yard Waste Impacts per 1 kg at SEMASS and Wellesley College.

Impact Factor	Impact Per 1 kg at Wellesley	Impact Per 1 kg at SEMASS	Units
Global Warming	-0.00022	10.45	kg CO2 eq
Acidification	-9.8E-05	1.41	H+ moles eq
Eutrophication	-2.1E-08	0.0015	kg N eq
Carcinogens	-1.1E-07	0.01	kg benzene eq
Non Carcinogens	-0.00097	8.73	kg toluene eq
Respiratory	-3.9E-07	0.0000075	kg PM2.5 eq

Table 6.10: Comparison of Total Yard Waste Impacts at SEMASS and Wellesley College.

Impact Factor	Impact of 12,333.333 kg at Wellesley	Impact of 184 kg at SEMASS	Units
Global Warming	-25.26	1,923.64	kg CO2 eq
Acidification	-10.99	258.21	H+ moles eq
Eutrophication	-0.0024	0.27	kg N eq
Carcinogens	-0.013	1.58	kg benzene eq
Non Carcinogens	-108.79	1,605.00	kg toluene eq
Respiratory Effects	-0.044	0.31	kg PM2.5 eq

Critical Areas in the Life Cycle of Yard Waste

The largest environmental effects of yard waste occur during incineration at *SEMASS*. As can be seen in our comparison of yard waste sent to trash and yard waste reused on campus (Table 6.10), the negative impacts of incinerating 184 kg of yard waste are even greater than impacts of producing 12,333.33 kg of reused yard waste.

Assessment of Wellesley College's Handling of Yard Waste

Overall, Wellesley is doing a great job with yard waste. Nearly all of the College's yard waste is reused on campus, avoiding both production and incineration impacts. This is critical, as we have seen that the incineration of such a large amount of waste would have a very large, detrimental impact on the environment.

FOOD WASTE

Food Waste Background

The category of food waste contains a wide variety of organic materials used to feed people – including liquids, edible plant products and their derivatives, meat products and their derivatives, and other animal derivatives such as eggs, honey, and milk products.

Food at Wellesley College

The majority of food on campus is provided by AVI Fresh, Wellesley's food service provider, and is used to provide students and guests with meals and snacks via the five dining halls, the campus center Emporium, the Leaky Beaker, Collins Cafe, the College Club, and catering of various events such as the Ruhlman Conference, Marathon Monday, and events at the President's House. Similarly, the three student cooperatives – Cafe Hoop, El Table, and the Pub – also provide students, faculty, and staff with meals, snacks and drinks. Students themselves prepare food in the Sustainability Cooperative, residence hall kitchen areas, and any other spaces on campus with kitchen facilities. Finally, there is food that is prepared off-campus and delivered to individuals, student organizations, or administrative and academic departments. This food is brought to campus to feed individuals on campus, but also often to incentivize attendance at campus events, or as part of religious or cultural ceremonies or celebrations.

Activities and Behaviors Producing Food Waste at Wellesley College

At Wellesley, the activities and behaviors associated with food waste can be divided into two categories: pre-consumer and post-consumer food waste. Pre-consumer waste occurs when more food is purchased or ordered than is necessary. For example, if AVI Fresh purchases more chicken than it is able to prepare in a week, or a department overestimates the number of attendees who will be present at an event where food is provided, then the leftover food that is discarded would become pre-consumer food waste. Pre-consumer waste also occurs when food never makes it to the preparation stage because it is necessary to dispose of it, such as when a freezer malfunction or contamination renders the food unusable. Additionally, there are activities that produce waste during the actual preparation of food, such as peeling vegetables, trimming and chopping meat, and dropping food pieces or spilling liquids, which count as pre-consumer waste; these activities are a regular part of the food preparation process.

Post-consumer food waste occurs at the hands of individual food consumers. Post-consumer waste occurs when individuals do not consume all of the food they personally took, ordered, or made for themselves.

Amount of Food Waste Produced at Wellesley College

The amount of food waste produced annually at Wellesley College is estimated in Table 6.11.

Table 6.11: Estimated Annual Food Waste at Wellesley College.

Material	Weight per unit (kg/cubic foot)	# Units per kg	# Units Produced Annually	Total Produced Annually
AVI Pre-Consumer	17.97	0.056 cubic feet	-	60,147.836 kg
AVI Post-Consumer	17.97	0.056 cubic feet	-	90,221.754 kg
Department and Organizational Post-Consumer	17.97	0.056 cubic feet	31,700 cubic feet	284,917.5 kg
Personal Pre-consumer	17.97	0.056 cubic feet	-	2,744.034 kg
Personal Post-consumer	17.97	0.056 cubic feet	-	10,976.137 kg
TOTAL				**449,007.261 kg**

The percentage of annual food waste by usage is represented in Figure 6.3.

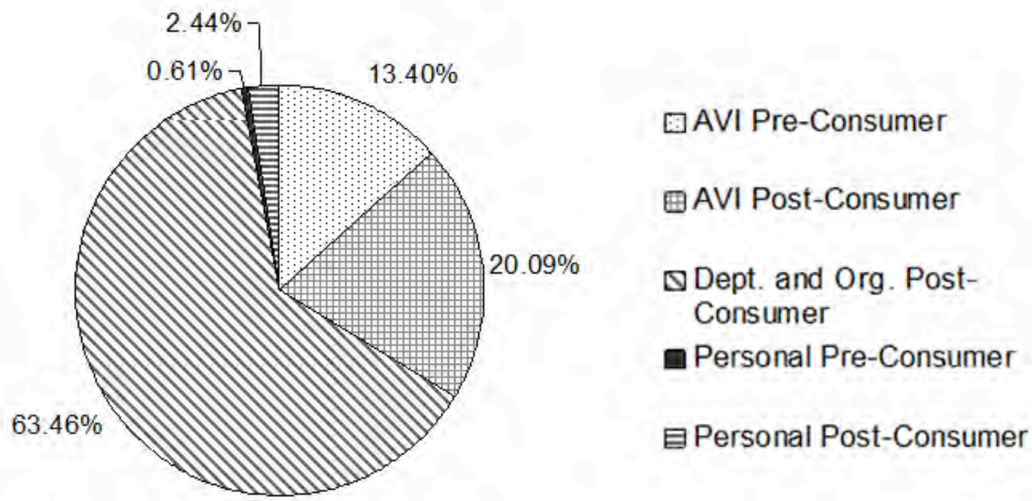

Figure 6.3: Pie Chart Illustrating the Percent Composition of Sources of Annual Food Waste at Wellesley College.

The amount of AVI Fresh and personal food waste generated on campus is estimated from our class waste audit results. We divided the total weight of the food waste collected during the audit, 860.24 kg, by the number of students who reside in Bates, Freeman, and McAfee, and multiplied by the number of weeks in an academic year. Therefore, there are 68.82 kg of personal and AVI Fresh food waste per student per academic year, amounting to 158,283.80 kg of food waste per academic year.

We estimate that 95% of the food waste the campus produces each year is AVI Fresh waste, 60,147.836 kg of which is pre-consumer and 90,221.754 kg of which is post-consumer.

We estimate that 5% of the combined personal and AVI Fresh food waste is personal waste. Therefore, we estimate that the campus produces 7,914.19 kg of personal waste per academic year. For Wintersession and summer break, we estimate that there are 200 students on campus who produce .91 kg of personal food waste per week. This amounts to 5,805.98 kg of food waste produced outside the academic year annually. When we combine academic year and non-academic year personal food waste, assuming that 20% is pre-consumer and 80% is post-consumer, we estimate that the campus produces 13,720.17 kg of personal food waste per year, 2,744.034 kg of which is pre-consumer and 10,976.137 kg of which is post-consumer.

The Wellesley Events Calendar provides an overview of all programs that have been scheduled using 25Live. Using this calendar, we estimated that approximately 75 small-scale catering events, serving 20-50 people, happen per month, 3 medium-scale events, serving 75 to 125 people, happen per month, and 5 large-scale special occasion events occur per semester. An example of a small-scale event is a department hosting a lecture with a lunch provided or organizational lunch and dinner meetings. From observations of small-scale events, we estimated that 5 half-pan containers of food (12x10x4) are used at each small-scale event. An example of a medium-scale event would be a campus dinner dialogue. From observations of a medium-scale event we estimated that 8 full pan aluminum containers (20x12x3) are used at each medium-scale event. Large-scale special occasion events include Lake Day and Tanner

Conference. We estimated 75 full pan containers (12x10x4) are used at each large-scale event. Therefore, 158,000 cubic feet of food is ordered per academic year by departments and students organizations. From observations of small-scale events and a medium-scale event, we estimated that 10 percent of this food is wasted, or 31,700 cubic feet of food annually. Using an estimate of 17.97 kg per cubic foot of food waste, we calculated that 284,917.5 kg of food waste is produced by organizations and departments annually.[11]

Handling of Food Waste at Wellesley College

The distribution of how food waste is handled when disposed of on campus is displayed in Table 6.12.

Table 6.12: Estimated Handling of Food Waste at Wellesley College.

Material	% Composted	% Thrown in Trash
AVI Pre-Consumer	0%	100%
AVI Post-Consumer	0%	100%
Department and Organizational Post-Consumer	0%	100%
Personal Pre-Consumer	20%	80%
Personal Post-Consumer	20%	80%
TOTAL	**0.61%**	**99.39%**

Wellesley has no form of institutionalized on-site composting, does not separate and collect food for shipment to a composting or anaerobic digestion, and does not have an institutionalized system to donate unused food. Therefore, nearly one hundred percent of Wellesley's food waste is thrown in the trash. A small percentage of food waste on campus, estimated at 0.61 percent, is produced by the Sustainability Cooperative and is composted. There is occasional institutional composting at an off-site facility from some large campus events, but we have not estimated the impact of that activity in this study.

Destination of Food Waste

The portions of food waste sent to MSW, recycling, and reuse handling facilities are estimated in Table 6.13.

Table 6.13: Destination of Food Waste by Percentage.

	Conigliaro	SEMASS	Regeneration Farm
% of Waste	0%	99.389%	0.611%
Weight of Waste	0	446,263.83	2,743.43

Food waste disposed of in the trash is sent to SEMASS where it is incinerated. We estimated that 99.39% of food waste, or 446,263.83 kg, is sent to SEMASS annually. Food waste that is composted is sent to the student-run Regeneration Farm for use as fertilizer. We estimated that 0.61% of food waste, or 2,743.43 kg, is composted and transported to the farm annually.

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[11] Volume to Weight Conversion Factors. *The New Mexico Environment Department*, n.d. Web. 29 Apr. 2012. <www.nmenv.state.nm.us/swb/doc/Conversiontable.doc>.

Abridged Life Cycle of Food Produced at Wellesley College

At Wellesley College, a primary generation of food waste is excess food at meals prepared by AVI Fresh. An abridged lifecycle diagram for food waste from production to disposal is displayed in Figure 6.4.

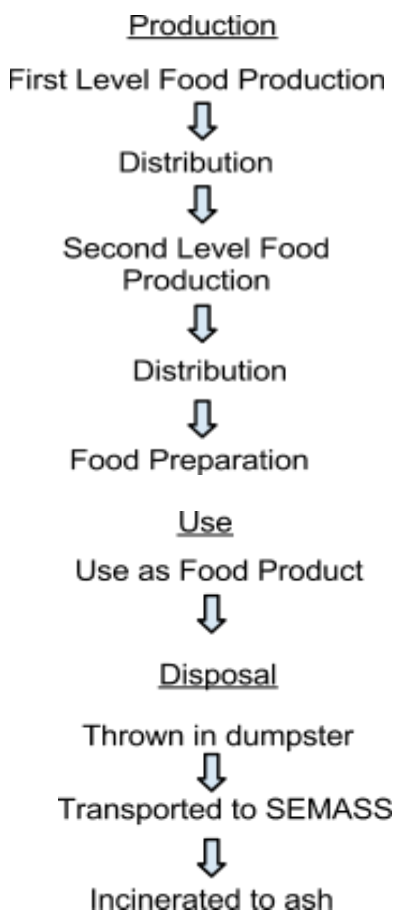

Figure 6.4: Abridged Life Cycle for Food.

Manufacturing of Food

The manufacturing of food requires significant combustion of fossil fuels to transport food both locally and globally. Additionally, fossil fuels are necessary to power the many vehicles and machinery needed to grow and process food. Water is needed for irrigation of crops and processing of food. Resources must be extracted to produce food, and the petro-chemical fertilizers, pesticides, the disposal of livestock waste involved in the food process, all contaminate natural resources. Finally, resources and land are necessary to grow crops, keep livestock, and grow food to feed livestock. The total ecosystem impacts per 1 kg and for 449,007.26 kg of food manufactured are quantified in Table 6.14. For additional details, see Table E.1 in Appendix E.

Table 6.14: Ecosystem impacts for Food Material Extraction and Manufacture of Potatoes, Grain, and Meat.

Impact Category	Total Impact per 1 kg	Total Impact for 449,007.26 kg	Unit
Global Warming	1.98	889,034.38	kg CO2 eq
Acidification	0.43	193,073.12	H+ moles eq
Eutrophication	0.0063	2,828.75	kg N eq
Carcinogens	0.0042	1,885.83	kg benzene eq
Non-Carcinogens	93.41	41,941,768.25	kg toluene eq
Respiratory Effects	0.03	13,470.22	kg PM2.5 eq

The additional ecosystem impacts of the manufacture of food are quantified in Table 6.15. The environmental impact of Wellesley's food waste is dependent not only on the quantity of food waste produced by the college, but on the types of foods contained in the waste and how that food was produced. For example, the production of beef produces greater carbon emissions than the production of carrots or potatoes;[12] and the production of crops using organic methods with less tilling produces fewer carbon emissions and less soil erosion than conventional farming equivalents.[13]

Table 6.15: Additional Ecosystem Impacts for the Manufacture of Food.

Erosion	Permanent Land Disruption	Water Use	Resource Use	Biodiversity Disruption	Total Score
1	**.5**	**.5**	**0**	**0**	**2.5**

The food choices made by Wellesley College students, faculty, and staff can have a drastic effect on the ecosystem impacts of Wellesley's food waste.[14] One of the primary ecosystem impacts of food production is erosion. The widespread overuse and single use of agricultural land leads to erosion, a phenomenon which has increased in intensity worldwide; each year more than 10 million hectares of the world's arable land is lost by erosion due to unsustainable farming and grazing practices.[15] In the United States alone, 90% of cropland is losing topsoil above a sustainable rate, and 54% of pastureland is overgrazed.[16]

Another primary ecosystem impact of food production is water use. Worldwide, 70% of all freshwater is used for agriculture.[17] The decline of available water supplies in the United

[12] Carlsson-Kanyama, A. Climate Change and Dietary Choices - How Can Emissions of Greenhouse Gases from Food Consumption be Reduced? *Food Policy*. 1998. Web. 29 April 2012. <http://smmi.nu/karlsson_kanyama.pdf>.

[13] Liebig, M.A., Doran, J.W. Impact of Organic Production Practices on Soil Quality Indicators. *Journal of Environmental Quality.* 1999. Web. 29 April 2012. <http://naldc.nal.usda.gov/download/16715/PDF>.

[14] Weber, C. and Matthews, H.S. Food-Miles and the Relative Climate Impacts of Food Choices in the United States. *Environmental Science and Technology.* 2008. Web. 29 April 2012. <http://mmm.comuv.com/wordpress/wp-content/uploads/2010/06/Food-Miles-and-the-relative-impacts-of-food-choices-Weber-and-Matthews-2008.pdf>.

[15] Pimentel, D. Environmental and Economic Costs of Soil Erosion and Conservation Benefits *Science* 1995. Web. 29 April 2012. <http://www.rachel.org/files/document/Environmental_and_Economic_Costs_of_Soil_Erosi.pdf>.

[16] Pimentel, D. et. al. Environmental and Economic Costs of Soil Erosion and Conservation Benefits *Science* 1995. Web. 29 April 2012. <http://www.rachel.org/files/document/Environmental_and_Economic_Costs_of_Soil_Erosi.pdf>.

[17] Berrittellaa, M. et. al. The Economic Impact of Restricted Water Supply:

States and elsewhere that can be attributed to agriculture is due to the inefficiency of irrigation systems, the establishment of large-scale agriculture in unsuitable landscapes, and the salinization (the increase of salt content) resulting from overdrawing groundwater.

Permanent land disruption is also notable. Many tropical nations have experienced significant deforestation of rainforests due to the expansion of cash crop agriculture. In Malaysia, for example, it is estimated that 55% of the 1,874,000 ha of rainforest that was deforested between 1990 and 2005, was cleared for the cultivation of oil pam.[18] In Brazil, deforestation of rainforest for the cultivation of crops, particularly soybeans and the grazing of cattle, has resulted in the clearing of over 576,000 acres of rainforest, a rate of deforestation that continues to increase.[19] Because the United States is a significant importer of tropical products including palm oil, soybeans, and beef, the analysis of food waste at Wellesley must incorporate land disruption impacts associated with imported food. The total ecosystem impact score for food production is 2.5. This is a medium score, indicating that the manufacturing of food is moderately harmful to ecosystems.

Composting Overview of Food

At Wellesley College, a negligible amount of food is 'recycled' through composting. This recycling occurs in the Sustainability Cooperative, where compostable food waste is collected, composted, and used as fertilizer for a student-run farm near the college campus. Wellesley College currently has no campus-wide system of recycling or reusing food. Periodic (but not systematized) off-site industrial composting of food waste from large campus events is not considered here because it is not sufficiently institutionalized in College processes. Table 6.16 and Table 6.17 show the environmental impacts that are avoided because fertilizer is not produced due to the composting of food waste for 1 kg and for 2,743.43 kg of food respectively.

A Computable General Equilibrium Analysis. *Water Research.* 2007. Web. May 5 2012. <http://www.mi.uni-hamburg.de/fileadmin/fnu-files/publication/working-papers/RM4393.pdf>.

[18] Koh, L.P., Lian, S. and Wilcove, D. Is Oil Palm Agriculture Really Destroying Tropical Biodiversity? *Conservation Letters*. 2008. Web. 29 April 2012. <http://courses.washington.edu/cr2008/oilpalmConservationLettersarticle.pdf>.

[19] Morton, D.C. et al. Cropland Expansion Changes Deforestation Dynamics in the Southern Brazilian Amazon. *Proc. Natl. Acad. Sci .USA.* n.d. Web. 29 April 2012. <http://www.pnas.org/content/103/39/14637.full>.

Table 6.16: Impacts per kg of Composted Food Waste.

Impact Category	Transport Impact	Facility Impact	Facility Credit	Total Impact	Unit
Global Warming	-	-	-0.31	-0.31	kg CO2 eq
Acidification	-	-	-0.12	-0.12	H+ moles eq
Eutrophication	-	-	-0.00020	-0.00020	kg N eq
Carcinogens	-	-	-0.000096	-0.000096	kg benzene eq
Non-Carcinogens	-	-	-1.43	-1.43	kg toluene eq
Respiratory Effects	-	-	-0.000044	-0.000044	kg PM2.5 eq

Table 6.17: Impacts per 2,743.43 kg of Composted Food Waste.

Impact Category	Transport Impact	Facility Impact	Facility Credit	Total	Unit
Global Warming	-	-	-850.46	-850.46	kg CO2 eq
Acidification	-	-	-329.21	-329.21	H+ moles eq
Eutrophication	-	-	-0.55	-0.55	kg N eq
Carcinogens	-	-	-0.26	-0.26	kg benzene eq
Non-Carcinogens	-	-	-3,923.11	-3,923.11	kg toluene eq
Respiratory Effects	-	-	-0.12	-0.12	kg PM2.5 eq

FOOD INCINERATION IMPACTS

Transportation Impacts: SEMASS

Food waste sent to SEMASS for incineration is transported in large, diesel powered combination trucks. SEMASS is located 212.45 km away from Wellesley College. The impact factors for transport were calculated using the TRACI2 method in SimaPro7.

Trace substances in Food Waste

The kilograms of the six substances, dioxin, lead, copper, arsenic, nitrogen, carbon, sulfur, that determine the impacts of incinerating food waste are described in Table E.2, found in Appendix E.

Facility Impacts and Credit for Food Waste Handling: SEMASS

Food waste that is sent to the MSW stream is incinerated at SEMASS. At SEMASS, energy produced from the incineration of food waste is converted into electricity, some of which is used to run the facility while the rest is fed to the grid. The portion of electricity that goes to the grid displaces part of the negative impacts from conventional electricity production. We estimated the facility impact by calculating the impacts of producing electricity in Massachusetts, which is from a mix of fuels (coal, oil, nuclear, hydroelectric and other sources.) We used estimations for energy content to calculate the amount of energy generated through incineration with the TRACI2 method in SimaPro7. The trucking impact, facility impact, and facility credit per 1 kg and per 449,007.26 kg are quantified in Table 6.18 and 6.19 respectively.

Table 6.18: Impacts per 1 kg for Food Waste Sent to SEMASS.

Impact Category	Transport Impact (Per 1 kg)	Facility Impact (Per 1 kg)	Facility Credit	Total	Unit
Global Warming	0.020	0.43	-0.0017	0.45	kg CO2 eq
Acidification	0.0066	71.74	-0.00074	71.75	H+ moles eq
Eutrophication	0.0000063	0.35	-0.00000016	0.35	kg N eq
Carcinogens	0.0000065	0.25	-0.00000086	0.25	kg benzene eq
Non-Carcinogens	0.14	42.08	-0.0073	42.21	kg toluene eq
Respiratory Effects	0.0000075	-	-0.0000029	.0000046	kg PM2.5 eq

Table 6.19: Overall Impacts for 449,007.26 kg of Food Waste Sent to SEMASS.

Impact Category	Transport Impact	Facility Impact	Facility Credit	Total	Unit
Global Warming	8,980.15	193,073.12	-763.31	201,289.96	kg CO2 eq
Acidification	2,963.45	32,211,780.83	-332.27	32,214,412.01	H+ moles eq
Eutrophication	2.83	157,152.54	-0.07	157,155.30	kg N eq
Carcinogens	2.92	112,251.82	-0.39	112,254.35	kg benzene eq
Non-Carcinogens	62,861.02	18894225.5	3,277.75	18,960,364.27	kg toluene eq
Respiratory Effects	3.37	-	-1.30	2.07	kg PM2.5 eq

Critical Areas of the Life Cycle of Food Waste

Per kilogram, the portion of the food waste life cycle with the most negative impacts is incineration. The incineration of food waste has significant negative environmental consequences, especially in the cases of acidification and non-carcinogens. In addition, because there is simply so much food waste generated at Wellesley College, the large volume means that transportation is also a critical factor; when accounting for the total weight of Wellesley's annual food waste, we see that significant ecosystem impacts, particularly from global warming, acidification, and non-carcinogens, result from the transportation of food waste.

Assessment of Wellesley College's Handling of Food Waste

Figure 6.5: Bins being filled with organic waste during the

February waste audit of the New Dorms.

The most important factor of Wellesley College's handling of food waste that can be improved is the sheer amount of food waste that the institution produces annually. To reduce the environmental impact of this form of waste, it is important that Wellesley College continues to implement practices already in place for the reduction in quantity of pre- consumer and post-consumer food waste, and the creation of new methods for reducing the production of food waste.

We can also reduce the quantity of food waste that is incinerated. As we see from the case of yard waste at Wellesley, composting organic waste is extremely environmentally beneficial; we therefore highly encourage Wellesley to consider the option of composting the College's food waste.

COMPOSTABLE DISHWARE AND UTENSILS

Compostable Dishware Background

Compostable dishware and utensils are used in the home and business sectors to reduce clean-up time, dishwasher use, and (especially for caterers) business costs from hiring workers to wash dishes.[20] Compostable dishware is manufactured from renewable raw materials like starch (found in corn, potato, tapioca), cellulose, soy protein and lactic acid.[21] Some compostable plastics can be made from petroleum, while others can be chemically manufactured from bacteria.[22] The most commonly used raw material to make compostable dishware is cornstarch.[23] The reasons compostable items are purchased over traditional disposable plastic products are most likely socially and culturally-based; people may hope to avoid the stigma of using disposable products by replacing them with something that seems more environmentally friendly. However, the extent of the actual environmental benefit depends on the materials from which the compostable dishware is made, and how it is disposed of after use.

During manufacture, cornstarch is processed into a bio-based resin that mimicks the properties of normal plastic products.[24] There are currently several types of compostable plastic resins available in today's market, derived from different plant-based materials.[25] Polylactic acid, known as PLA, is a popular option for plastic resin.

As defined by the American Society for Testing & Materials (ASTM) International Standards, compostable plastic can undergo biological decomposition in a composting facility at similar rates to known compostable materials such as cellulose, without leaving toxic residues or

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20 Paper Plates. *Saawariya Enterprises.* 2010. Web. 8 May 2012. <http://www.saawariyaenterprices.com/paper-plates.htm>.

21 Compostable Plastics. *WorldCentric.* n.d. Web. 27 Feb 2012. <http://www.worldcentric.org/biocompostables/bioplastics>.

22 Compostable Plastics. *WorldCentric.* n.d. Web. 27 Feb 2012. <http://www.worldcentric.org/biocompostables/bioplastics>.

23 Compostable Plastics. *WorldCentric.* n.d. Web. 27 Feb 2012. <http://www.worldcentric.org/biocompostables/bioplastics>.

24 Compostable Plastics. *WorldCentric.* n.d. Web. 27 Feb 2012. <http://www.worldcentric.org/biocompostables/bioplastics>.

25 Compostable Plastics. *WorldCentric.* n.d. Web. 27 Feb 2012. <http://www.worldcentric.org/biocompostables/bioplastics>.

being distinguishable from overall compost.[26] However, compostable dishware should not be confused with degradable or even bio-based plastics.[27] All three categories have differing rates of decomposition and can vary in their chemical composition.[28]

Uses of Compostable Dishware at Wellesley College

Compostable dishware includes plates, bowls, and cups, while compostable utensils include forks, knives, and spoons. Both are used for eating and drinking purposes. Most of the compostable dishware found on campus is supplied by dining services to feed the student body during meal times. It is not generally composted after use.

Activities and Behaviors Producing Compostable Dishware Waste at Wellesley College

Compostable dishware is often used for campus-wide events catered by AVI Fresh, such as Lake Day or Marathon Monday, when dining takes place outside. Compostable dishware is also used by some student organizations and departments to serve food at events like lectures and film screenings. There are additional unplanned situations that lead to the use of compostable dishware on campus, such as cases where dishwashing equipment breaks down or enough reusable dishware has disappeared from the dining halls (see Chapter 7) that disposable dishware is needed to meet needs of diners. Some compostable dishware may come from students purchasing products transported or packaged in compostable dishware for their personal use in dorms.

Amount of Compostable Dishware Produced at Wellesley College

An estimated total of 8,878 kg of compostable dishware and utensils waste is produced every year at Wellesley College. The breakdown of compostable dishware and utensil waste is presented in Table 6.20.

Table 6.20: Amount of Compostable Dishware Produced at Wellesley College.

Material	**# Units Produced Annually**	**# Units per kg**	**Weight per unit (kg/unit)**	**Total kg Produced Annually**
Plates	32,600 plates	883 plates	.04	1,304
Bowls	10,000 bowls	883 bowls	.04	1,304
Cups	13,000 cups	1183 cups	.03	390
Forks	39,000 forks	592 forks	.06	2,340
Knives	17,000 knives	592 knives	.06	1,020
Spoons	42,000 spoons	592 spoons	.06	2,520
Total				**8,878 kg**

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[26] Compostable Plastics. *California Integrated Waste Management Board (CIWMB)*. June 2009. Web. Apr 25 2012. <http://www.calrecycle.ca.gov/publications/Plastics/2009001.pdf>.

[27] About Bio-based, Degradable and Compostable Plastic. *Earth911*. n.d. Web. 24 Feb 2012. <http://earth911.com/recycling/plastic/innovative-plastics/about-biobased-degradable-compostable-plastic/>.

[28] About Bio-based, Degradable and Compostable Plastic. *Earth911*. n.d. Web. 24 Feb 2012. <http://earth911.com/recycling/plastic/innovative-plastics/about-biobased-degradable-compostable-plastic/>.

The percentage of annual compostable dishware waste by usage is represented in Figure 6.6.

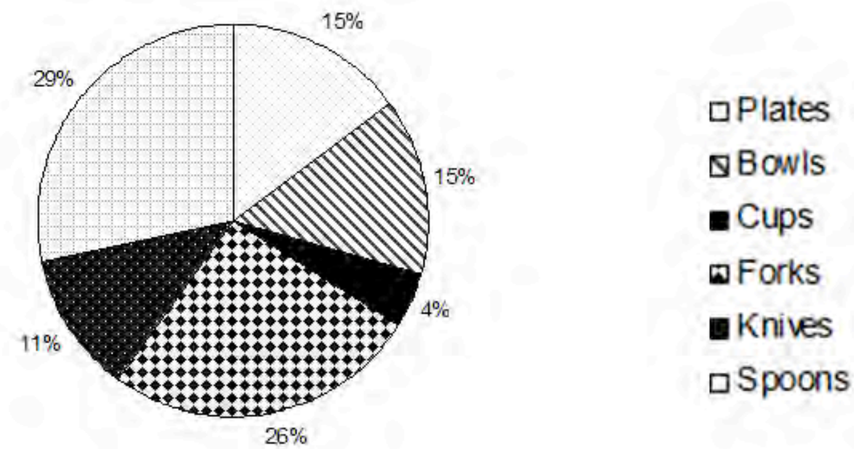

Figure 6.6: Percent Composition by Source of Annual Compostable Dishware Waste at Wellesley College.

We used a replacement dinnerware spreadsheet provided by AVI Fresh as the estimation of compostable dishware and utensil waste is produced on campus each year. The spreadsheet includes a purchasing breakdown (by individual count) of the compostable plates, cups, bowls, forks, etc. bought by AVI for the 2011 year. We then estimated the weight per unit for each compostable dishware material. We estimated the weights for each compostable dishware type to be close in range because of their similar manufactured composition.

Handling of Compostable Dishware Waste at Wellesley College

After use, all compostable dishware waste at Wellesley College goes into the garbage can. Occasionally, composting occurs at big campus-wide events such as the Tanner and Ruhlman Conferences. These events represent a small component in the overall compostable dishware and utensil waste generated on campus and there is currently no predictable pattern to when composting will occur. Since compostable plates and utensils are designed for composting only at industrial composting facilities, special arrangements for pickup and transport of compostable dishware to an industrial composting facility must occur in order to compost this type of waste. Such special arrangements typically only occur for large on campus events. Wellesley College does not offer any regular composting service to an industrial facility, thus compostable dishware and utensils are almost always put into the trash.

Destination of Compostable Dishware Waste

Under the current system, compostable dishware and utensil waste from Wellesley College is sent to the SEMASS facility. This means that 8,878 kg of Wellesley College's compostable dishware is incinerated on an annual basis.

Abridged Life-Cycle of Compostable Dishware Produced at Wellesley College

Figure 6.7: Abridged life cycle of compostable dishware and utensils.

Compostable Dishware Source Background

Most compostable dishware and cutlery is made from starch, bagasse, or wheat straw. Wheat straw is the by-product of cereal grain stalks after the grain and chaff have been removed (Figure 6.8).[29]

[29] Wheat Straw as a Paper Fiber Source. *The Clean Washington Center: A Division of the Pacific Northwest Economic Region (PNWER).* June 1997. Web. 8 May 2012. <http://www.cwc.org/paper/pa971rpt.pdf>.

Figure 6.8. Wheat straw is often collected and then shaped into straw bales. [30]

Bagasse is the pulpy by-product of sugar-cane stalks after they've been processed for juice extraction.[31] Bagasse and wheat straw are often used to manufacture compostable plates and bowls. Once processed, bagasse has the visual consistency of paper,[32] and wheat straw allows some compostable tableware and cutlery to have a "natural beige" look.[33]

Corn is the most common type of raw material starch used, while other less common sources include potato, soybean, and tapioca.[34] Cornstarch used in most American-made compostable products is sourced from the U.S. Midwest. Wheat starch is primarily located in the Great Plains area (from Texas to Montana)[35] and sugarcane is grown commercially in Florida, Hawaii, Louisiana, and Texas.[36]

Manufacturing of Compostable Dishware and Utensils

During the manufacture of compostable tableware and utensils, cornstarch is processed to create polylactic acid (PLA), a resin that simulates the same properties of plastic used in cups, utensils, and other disposable dishware.[37] The process from cornfield to PLA incorporates aspects of both biotechnology and chemistry.[38] Once starch is derived from the raw material

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30 Wheat Straw as a Paper Fiber Source. *The Clean Washington Center: A Division of the Pacific Northwest Economic Region (PNWER).* June 1997. Web. 8 May 2012. <http://www.cwc.org/paper/pa971rpt.pdf>.
31 Compostable Products for Food Services: Making Sense of What's Available. *Eco-cycle: Working to Build Zero Waste Communities*. April 2011. Web. 25 Mar. 2012. <http://ecocycle.org/files/pdfs/compostable_products_for_food_services.pdf>.
32 Compostable Products for Food Services: Making Sense of What's Available. *Eco-cycle: Working to Build Zero Waste Communities*. April 2011. Web. 25 Mar. 2012. <http://ecocycle.org/files/pdfs/compostable_products_for_food_services.pdf>.
33 Biodegradable Sugar Cane (Bagasse) Plates, Cups, Bowls, Clamshells, Boxes, & Trays. *TreeCycle Recycled Paper*. 2010. Web. 26 Mar. 2012. <http://www.treecycle.com/bagasse.html>.
34 Compostable Plastics. *WorldCentric.* n.d. Web. 25 Mar. 2012. <http://www.worldcentric.org/biocompostables/bioplastics>.
35 Major Crops Grown in the United States. *Environmental Protection Agency.* September 2009. Web. 25 Mar. 2012. <http://www.epa.gov/agriculture/ag101/cropmajor.html>.
36 Meagher, R.L. Sugarcane IPM. Radcliffe's IPM World Textbook. *University of Minnesota*. 2009. Web. 25 Mar. 2012. <ipmworld.umn.edu>.
37 Compostable Plastics. *WorldCentric.* n.d. Web. 25 Mar. 2012. <http://www.worldcentric.org/biocompostables/bioplastics>.
38 Using Polylactic Acid. *RSC:Advancing the Chemical Sciences.* n.d. Web. 29 Mar. 2012. <http://www.rsc.org/education/teachers/Resources/inspirational/resources/3.1.11.pdf>.

source crop, dextrose is processed and fermented from the starch to create PLA. The PLA is then processed further and molded into compostable dishware used to hold food.[39]

The primary environmental and social benefits created by the use of corn starch, bagasse, and wheat straw in disposable dishware, are a reduced demand for fossil fuels, and a smaller volume of municipal waste related to food consumption.[40] Compostable dishware and cutlery is made from renewable resources that can take the place of disposable plastic products that require the use of non-renewable resources like petroleum. If the rate of compostable dishware use were to surpass the rate of regular plastics, then the country could see a reduced need for oil. Additionally, in using compostable dishware, the volume of MSW generated can be reduced if the items in question are collectively added with food scraps (or yard waste) and sent to industrial composting facilities.[41] However, each substitute renewable material does contain tradeoffs regarding their environmental and social impacts. For example, bagasse uses extensive amounts of water during product processing, and requires the "harmful exposures of pulp fiber" to people in the compostable dishware manufacturing industry.[42]

Manufacturing and Use Impact Assessment for Compostable Dishware and Cutlery

The ecosystem impacts associated with compostable dishware are quantified in Table 6.21. For greater detail, see Table E.3 in Appendix E.

Table 6.21: Total Ecosystem Impacts per 1 kg and 8,878 kg of Compostable Cups (PLA-based) Material Extraction and Manufacture.

Impact Category	Impact Per 1 kg	Impact for Total of 8,878 kg	Unit
Global Warming	5.12	45,455.36	KgCO2 eq
Acidification	1.17	10,387.26	H+ moles eq
Eutrophication	.03	302.74	kg N eq
Carcinogens	.02	151.81	kg benzene eq
Non-carcinogens	119	1,056,482	kg toluene eq
Respiratory Effects	.0047	42.08	kg PM2.5 eq

The additional ecosystem impacts associated with the manufacture of compostable dishware and cutlery are summarized in Table 6.22. The manufacture of compostable tableware has fairly low overall ecosystem impact. Erosion and Water Use are the two biggest additional impact factors. Since most compostable plastics use cornstarch as their raw material, the

[39] Recycle or Compost? Sorting Out the Cornstarch from the Plastic. *Promega Connections.* March 2011. Web. 25 Mar. 2012, < http://promega.wordpress.com/2011/03/25/recycle-or-compost-sorting-out-the-cornstarch-from-the-plastic/>.
[40] What are the Benefits of Biodegradable Plastic? *National Geographic: Green Living.* n.d. Web. 25 Mar. 2012, < http://greenliving.nationalgeographic.com/benefits-biodegradable-plastic-2226.html>.
[41] What are the Benefits of Biodegradable Plastic? *National Geographic: Green Living.* n.d. Web. 25 Mar. 2012, < http://greenliving.nationalgeographic.com/benefits-biodegradable-plastic-2226.html>.
[42] Kimmanleyort. Sugarcane Bagasse – Biodegradable Compostable Cups, Plates, and Cutlery. *Squidoo.* n.d. Web. 29 Mar. 2012. <http://www.squidoo.com/bagasse-biodegradable-compostable-dishware-cups-plates-cutlery>.

manufacture of compostable dishware involves soil erosion as corn is grown using high till agricultural methods that encourage the erosion of topsoil.

Table 6.22: Additional Ecosystem Impacts Associated with the Manufacture of Compostable Dishware and Cutlery.

Erosion	Permanent Land Disruption	Water Use	Resource Use	Biodiversity Disruption	Total
0.5	0	1	0	0	**1.5**

Alternative Reuse and Recycling of Compostable Tableware and Cutlery

In terms of disposal options for compostable tableware and cutlery, Wellesley College only offers the option of putting these items into the MSW waste stream. MSW is transported to the SEMASS facility where it is incinerated and turns into ash. This ash gets transported to the Carver M Warriam landfill. The only other alternative for compostable dishware to be disposed is if it is sent to a professional composting facility. Although industrial composting has been pursued for specific large-scale events on campus in the past, systematic changes are necessary to incorporate industrial composting into the disposal options for compostable dishware on a regular basis. Without the option of an industrial composting facility to regularly process our compostable dishware waste, we cannot maximize the environmental benefits of purchasing and using compostable dishware at Wellesley College.

COMPOSTABLE DISHWARE AND CUTLERY INCINERATION IMPACTS

Transportation Impacts: SEMASS

Compostable dishware sent to SEMASS for incineration is transported in large, diesel powered combination trucks. SEMASS is located 212.45 km away from Wellesley College. The impact factors for transport were calculated using the TRACI2 method in SimaPro7. The transport impacts for compostable dishware sent to SEMASS are displayed in Table E.4, in Appendix E.

Facility Impacts and Credit for Compostable Dishware and Cutlery Handling: SEMASS

Compostable dishware that is discarded as trash is incinerated at SEMASS. At SEMASS, energy produced from the incineration of compostable dishware is converted into electricity, some of which is used to run the facility while the rest is fed to the grid. The portion of electricity that goes to the grid displaces part of the negative impacts from conventional electricity production. We estimated the impacts avoided by calculating the impacts of producing electricity in Massachusetts, which is from a mix of fuels (coal, oil, nuclear, hydroelectric and other sources.) We used estimations for energy content to calculate the amount of energy generated through the incineration of compostable dishware with the TRACI2 method in SimaPro7. The trucking impacts, facility impacts, and facility credit for 1 kg and 8,878 kg of compostable dishware and cutlery sent to SEMASS are displayed in Table 6.23 and Table 6.24 respectively.

Table 6.23: Impacts per 1 kg for Compostable Dishware and Cutlery Sent to SEMASS.

Impact Category	Transport Impact	Facility Impact	Facility Credit	Total Impact	Unit
Global Warming	0.0198	1.33	-0.00066	1.35	kg CO2 eq
Acidification	0.00656	0.20	-0.00029	.21	H+ moles eq
Eutrophication	0.00000626	0.00028	-0.00000063	.00022	kg N eq
Carcinogens	0.00000645	0.27	-0.00000034	.270	kg benzene eq
Non-Carcinogens	0.136	0.40	-0.0029	.53	kg toluene eq
Respiratory Effects	0.0000075	0.00020	-0.00000115	.00021	kg PM2.5 eq

Table 6.24: Overall Impacts for 8,878 kg of Compostable Dishware and Cutlery Sent to SEMASS.

Impact Category	Transport Impact	Facility Impact	Facility Credit	Total Impact	Unit
Global Warming	175.85	11,808	-5.88	11,977.97	Global Warming
Acidification	58.2	1,740	-2.56	1,795.64	Acidification
Eutrophication	0.06	1.93	-0.00056	1.99	Eutrophication
Carcinogens	0.06	2,358.86	-0.003	2,358.91	Carcinogens
Non-Carcinogens	1,207.80	3,526.22	-25.39	4,708.63	Non-Carcinogens
Respiratory Effects	0.07	1.81	-0.01	1.87	Respiratory Effects

Critical Areas in the Life Cycle of Compostable Dishware and Cutlery

In the life cycle of compostable dishware and cutlery, the largest environmental effects occur during raw material extraction and manufacture, with non-carcinogens and global warming representing the highest impact categories. As mentioned previously, the life cycle of compostable dishware and cutlery begins with the production of PLA pellets from natural raw materials (such as corn starch.) During manufacture, PLA pellets are transformed into plates and cups via a thermoforming process, which also has significant environmental impacts. The thermoforming process is energy-intensive and contributes to air and water pollution.[43]

Assessment of Wellesley College's Handling of Compostable Dishware and Cutlery

The only regularly available option for disposal of compostable dishware at Wellesley College is incineration. Because of their bio-based composition, compostable dishware and cutlery will contaminate the recycling stream, so unless an industrial composting option is available and regularly established, trash will unfortunately continue to be the best choice for disposal of compostable dishware.

ORGANICS DISPOSAL CONCLUSIONS

For all three subcategories of Organics, incineration at SEMASS results in high global warming and non-carcinogen impacts. Interestingly, the extraction and manufacture of compostable dishware has a higher set of impacts than incineration. Food waste had an additionally high impact in terms of acidification.

Given the difference between incineration and composting as demonstrated by yard waste, composting food waste and compostable dishware on campus appears to be a venture that is worth serious consideration. The establishment of an industrial composting facility disposal option would maximize the environmental benefits associated with compostable dishware, while simultaneously minimizing the overall environmental impact and volume of our organic waste. If done efficiently, industrial composting could result in both environmental and financial savings for the College. The production of organic waste on campus is unavoidable, but efforts focused on the reduction of food waste and pursuit of alternative disposal options such as composting, could significantly reduce the overall environmental impacts associated with organic waste produced at Wellesley College.

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[43] Brota, M. A Comparative Analysis of the Environmental Impacts of Ceramic Plates and Biodegradable Plates (Made of CornStarch) using the Life Cycle Assessment Tool. Report. *Teri University: Department of Natural Resources*. June 2008. Web. Apr 25 2012.
<http://sustainability.yale.edu/sites/default/files/mita_broca_report.pdf>.

2.7 Durable, Composite, Electronic, and Special Goods

Durable goods refer to products that were designed for use over an extended period of time. This category is 2.6 percent of Wellesley's overall annual waste stream, and includes books, clothing, electronics, personal appliances, institutional durable goods, batteries, printer cartridges, compact fluorescent light bulbs, and melamine dishware. Due to the variation within this category, every material has very different components, impacts, waste management scenarios, and therefore varying recommendations.

BOOKS

Books Background

Books are a mixture of several materials combined to hold written, illustrated, or printed information. The three most common book types are paperback, hardcover, and spiral-bound (also known as punch and bind). Depending on the type of book, materials used in construction and purpose can vary. Paperback books are stacks of thin paper glued into a heavy weight nylon coated cardstock or paperboard cover.[1] Some common paperbacks include romance novels or test preparation workbooks. Paperback books are cheap to print and bind, but do not stay together under heavy use or over long periods of time.

Hardcover books are the sturdiest type of book and usually have the longest lifespan. Books that are referenced or used often, like textbooks and library books, benefit most from hardcover binding. Hardcover books contain high quality sheets of paper sewn or glued together, then sewn or glued into a leather- or canvas-covered cardboard cover. They are often finished with a nylon coated paper dust cover to protect the interior cover.[2] Hardcover books can last decades with minimal care. Many books that are originally available in paperback are rebound by libraries into hardcover to prevent damage and to increase their lifespan.

Spiral-bound or Punch-and-Bind books are the most flexible type of book. Cardboard or plastic covers and sheets of printed-paper are punched along one side and then threaded by a piece of heavy gauge wire or plastic spiral coil. [3] Often used for notebooks, atlases, and other books that must lie completely flat, spiral binding allows for the largest margins around blocks of text. If the contents of a spiral book need editing, the binding can be removed and replaced without damage to the contents.

Use of Books at Wellesley College

Books at Wellesley College are owned and used daily by almost every individual on campus. The majority of books on campus are housed in library collections, which have grown to include 1.6 million items.[4] In the library collections, almost every book is either laminated, hardcover, or rebound into a hardcover to ensure durability. Since the libraries serve as archives of information both past and present, they hold onto texts until bookbindings and paper falter.

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[1] Film Laminates: Full Plastic Jacket - Ed #4 Protective Covering. n.d. Web. 23 Apr 2012. <http://edliveshere.com/content/protective_covering/7/film_laminates_full_plastic_jacket>.

[2] Parker, S.P. McGraw-Hill Encyclopedia of Science & Technology. *McGraw-Hill*. 1997. Print.

[3] Parker, S.P. McGraw-Hill Encyclopedia of Science & Technology. *McGraw-Hill*. 1997. Print.

[4] Annual Statistics for 2006-2007. *Wellesley College Library*. 2007. Web. 23 Apr 2012. <http://www.wellesley.edu/Library/Collections/collstats06-07.html>.

Library texts are constantly being borrowed and returned, minimizing the impacts from manufacturing a new book for each person or use. If a book is damaged, it will either be rebound or recycled. If a book is out-of-print or extremely rare, the Special Collections Department will try to restore or preserve the text.[5]

The second largest use of books at Wellesley College consists of class texts. At the beginning of each semester, students purchase, rent, or borrow approximately eight hundred dollars worth of textbooks.[6] These books are used for a variety of purposes, including permanent references, texts for class discussion, or repositories of problem sets for student practice.

Smaller uses of books on campus include Spiral-bound notebooks and sketchpads for note taking or drawing, and personal collections for entertainment or reference.

Activities and Behaviors Producing Book Waste at Wellesley College

During move-out, books may become burdens that make boxes and luggage overweight. Filled notebooks, entertainment texts, and completed workbooks are often the first to end up in the waste stream. Fortunately, there are programs in place like Sustainable Move-out and campus-wide paper recycling (for more information, please see the Office Paper section of this report) to minimize books that end up in the trash.

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[5] Lianna Lee. LTS Student Assistant. Personal Interview. 14 Apr 2012.

[6] Detailed Tuition & Costs | Wellesley College . *Wellesley College*. n.d. Web. 23 Apr. 2012. <http://new.wellesley.edu/admission/finaid/detailed>.

Amount of Book Waste Produced at Wellesley College

Table 7.1: Estimated Annual Book Waste at Wellesley College.

Material	Weight per unit (kg/unit)	# Units (books) per kg	# Units Produced Annually	Total kg Produced Annually
Books (School Year) in MSW	0.34 [7]	3	560	186.67
Books (Summer and Winter-session) in MSW	0.34 [7]	3	78	26
Books (School Year) in Recycling	0.34 [7]	3	4,200	1,400
Books (Summer and Winter-session) in Recycling	0.34 [7]	3	581	193.67
Spring and Fall Move-outs	0.34 [7]	3	1,897	632.34
Misc.	-	-	-	243.86
Total				**2,682.53 kg**

Using data from the New Dorms Waste audit and New Dorms Recycling Audit, we calculated the number of books disposed of annually. In our Audits, two books were found in the MSW dumpster and 15 books were recycled. Assuming that those audits represent the weekly average book disposal for 400 students, we calculated a per capita weekly disposal rate. During the Academic Year, the population, including students, faculty and staff, is 3,500. Assuming that faculty have roughly double the mass of books as the average student and staff possess no books, the per capita rate was weighted accordingly. During summer and wintersession, the population is 400 and 1,157 respectively. In Table 7.1, we calculated the total mass of 2,682.52 kg of books disposed annually by multiplying the weekly per capita rate of book disposal by the population on-campus, the number of weeks of occupancy at that population, and the average weight of a book.

[7] Google Answers: Weight of an average-size book. *Google.com*. n.d. Web. 17 Apr. 2012. <http://answers.google.com/answers/threadview?id=234855>.

Handling and Destination of Book Waste

Table 7.2: Estimated Handling of Book Waste at Wellesley College.

Material	Conigliaro (Recycling)	SEMASS (MSW)	Reuse
% of Waste	59%	8%	33%
Weight of Waste (kg)	1,582.69	214.60	885.23

Using data from the New Dorms Student Recycling Audit, the percentage of books recycled was calculated. Of the books disposed of during the academic year, 59 percent are recycled at Conigliaro Industries and 8 percent are thrown in the trash and go to SEMASS for incineration. According to the Wellesley College Bookstore, 35 percent of the books they sell are pre-owned.[8] Therefore, we assumed that 33 percent of the books that go to SEMASS and Conigliaro Industries were previously re-used, giving us a total of 632.34 kg. Figure 7.1 displays the handling of book waste by percent. Since the majority of the books that are re-used are sold to other students, donated to the Sustainable Move-out, or sold back to the Bookstore at the end of semester, the re-use mass represents the increased disposal rate at the end of the semester. The miscellaneous category is 10 percent of all the previous categories. It represents any books that are re-used via peer-to-peer reselling, the El Table Book Exchange shelf, and Student Aid Society's lending bookshelf. The distribution of book waste handling is shown in Table 7.2.

[8] Wellesley College: Sustainability. *Wellesley College Office of Sustainability*. n.d. Web. 17 Apr 2012. <http://www.wellesley.edu/AdminandPlanning/Sustainability/bookstore.html>.

Abridged Life Cycle of a Book

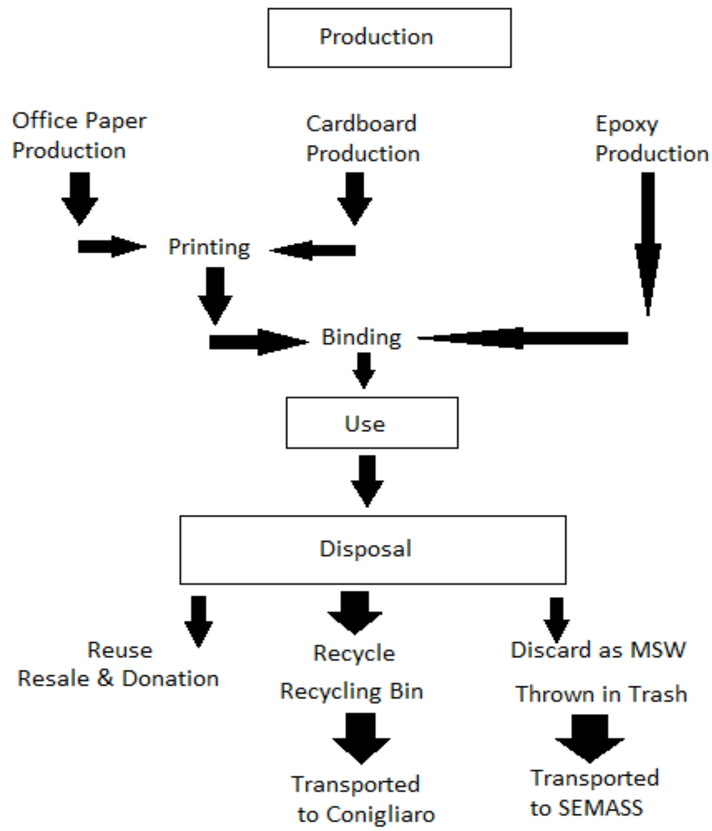

Figure 7.1: Abridged Life Cycle of Books Used at Wellesley College.

Manufacturing and Use Impact Assessment for the Model Book

In Figure 7.1, the manufacture of books has been simplified to calculate the relative impacts of each step in the process. Simapro7 does not contain a specific book material; therefore a model book was manufactured from other materials in order to estimate impacts. We used our general knowledge of book binding to put together a model book. Our model book is 85 percent office paper, bound with 2 percent epoxy to a cardboard cover comprising of 13 percent. Using the impacts from the Paper chapter of this report, we weighted the impacts based upon the percent of total mass. Since the model book manufactured is composed of 98 percent paper products and treated as paper in all waste disposal scenarios, we calculated all manufacture, incineration, and recycling impacts using Paper impact figures. Books, like paper, use absolutely no energy in the use phase. Thus, use phase energy was not calculated. However, binding paper into books creates a reusable object, thereby changing the disposal dynamics associated with paper.

The environmental impacts of the manufacture and use of 1kg and 2,682.53 kg of books are displayed in Table 7.3, below. The largest impact category by far is non-carcinogens, which contribute 88 kg toluene equivalents for every kg of books. The other impacts factors appear to be small and are similar to paper.

Table 7.3: Total Impact Values for Book Material Extraction and Manufacture per 1 kg and for 2,682.53 kg of Material.

Impact Factor	Total Impact per 1 kg	Total Impact for 2,682.53 kg	Units
Global Warming	0.81	2,172.85	kg CO2 eq
Acidification	0.42	1,126.66	H+ moles eq
Eutrophication	0.0062	16.63	kg N eq
Carcinogens	0.0047	12.61	kg benzene eq
Non Carcinogens	88.00	236,062.64	kg toluene eq
Respiratory	0.0023	6.17	kg PM2.5 eq

The additional ecosystem impacts of the manufacture of books are recorded in Table 7.4. The manufacture of epoxy is resource intensive. Paper production contributes to deforestation and is extremely resource intensive. Additionally, books log many transportation miles during production and distribution to the consumer, causing a high level of air emissions. Since many of the raw materials used in epoxy production are toxic or carcinogenic, its manufacture poses a high risk to human health.

Table 7.4: Additional Ecosystem Impacts for the Manufacture of Books.

Erosion	Permanent Land Disruption	Water Use	Resource Use	Biodiversity Disruption	Total Score
0.5	1	1	1	1	**4.5**

BOOK INCINERATION IMPACTS

The impacts of incinerating books were divided into 3 parts: transportation, facility impacts, and facility credits. Books that leave campus as MSW travel to the SEMASS incineration facility via a transfer station by truck for a distance of 99 km. Using Simapro 7, we calculated the impacts of 1kg traveling 99 km by truck. Facility Impact and Credit numbers were obtained from the Chapter 4. Please see Chapter 4 for further details. The impact for incinerating 1 kg and 214.60 kg of books is shown in Table 7.5 and 7.6 respectively.

Table 7.5: Total Impacts from Incineration of 1 kg of Books at SEMASS.

Impact Category	Transport Impact	Facility Impact	Facility Credit	Total	Unit
Global Warming	0.0092	1.21	-0.0021	1.22	kg CO2 eq
Acidification	0.0030	0.82	-0.00094	0.82	H+ moles eq
Eutrophication	0.0000029	0.82	-0.00000021	0.82	kg N eq
Carcinogens	0.0000030	177.40	-0.0000022	177	kg benzene eq
Non-Carcinogens	0.063	177.40	-0.0092	177	kg toluene eq
Respiratory Effects	0.0000035	0.82	-0.0000037	0.82	kg PM2.5 eq

Table 7.6: Total Impacts from Incineration of 214.60 kg Books at SEMASS.

Impact Category	Transport Impact	Facility Impact	Facility Credit	Total	Unit
Global Warming	1.97	259.67	-0.45	261.19	kg CO2 eq
Acidification	0.64	175.97	-0.20	176.41	H+ moles eq
Eutrophication	0.00062	175.97	-0.000045	175.97	kg N eq
Carcinogens	0.00064	38,070.04	-0.00047	38,070.04	kg benzene eq
Non-Carcinogens	13.52	38,070.04	-1.97	38,081.59	kg toluene eq
Respiratory Effects	0.00075	175.97	-0.00079	175.97	kg PM2.5 eq

BOOK RECYCLING IMPACTS

We calculated the net impact for recycling books by dividing the recycling process into three steps: Transportation, processing facility impacts, and processing facility credits. Recycled books leave campus as part of the mixed paper flow by diesel truck. They travel to Conigliaro Industries for shredding and baling, Casella Recycling for further sorting, and finally a paper mill for use as a feedstock for cardboard production. The total distance travelled was 102 km. Using Simapro7, we calculated the impacts of 1 kg of waste material being transported 1km and multiplied that number by 102 to figure out the total impacts of transporting 1 kg of books for recycling.

We calculated facility impacts by summing up the energy use impacts of the three recycling facilities. Conigliaro Industries is completely solar powered, so their impacts for processing were zero for all impact categories. Casella and the paper mills used energy from the Massachusetts grid. Using Simapro7, we calculated the impacts for energy use from the Massachusetts electricity grid.

Recycling credit numbers per kg of books were obtained from the Paper section. See Chapter 4 for more details. The overall impacts for recycling 1 kg and 1,582.69 kg of books is shown in Table 7.7 and 7.8 respectively.

Table 7.7: Total Impacts from Recycling of 1 kg of Books.

Impact Category	Transport Impact	Facility Impact	Facility Credit	Total Impact	Unit
Global Warming	0.010	0.41	-1.31	-0.89	kg CO2 eq
Acidification	0.0032	0.18	-0.36	-0.18	H+ moles eq
Eutrophication	0.0000030	0.00021	-0.01	-0.01	kg N eq
Carcinogens	-	1.77	-82.20	-80.40	kg benzene eq
Non-Carcinogens	-	0.00071	-0.0023	-0.0016	kg toluene eq
Respiratory Effects	0.0000036	0.000039	-0.06	-0.06	kg PM2.5 eq

Table 7.8: Total Impacts from Recycling 1,582.69 kg of Books.

Impact Category	Transport Impact	Facility Impact	Facility Credit	Total Impact	Unit
Global Warming	15.83	648.90	-2,073.32	-1,408.59	kg CO2 eq
Acidification	5.06	284.88	-569.77	-279.82	H+ moles eq
Eutrophication	0.0047	0.33	-15.83	-15.49	kg N eq
Carcinogens	-	2801.36	-130,097.12	-127,295.76	kg benzene eq
Non-Carcinogens	-	1.12	-3.64	-2.52	kg toluene eq
Respiratory Effects	0.0057	0.06	-94.96	-94.89	kg PM2.5 eq

BOOK REUSE IMPACTS

Figure 7.2: Book Reuse Program at Wellesley College During End of the Semester Move-out.

Like recycling and incineration impacts, we calculated reuse impacts in 3 parts: transportation impacts, reuse facility impacts, and reuse credit. Since the majority of books that are reused remain on campus, we assumed that the transportation impacts were zero for all categories. Similarly, books do not require any processing in order to be reused. Thus, reuse impacts were also assumed to be zero. In part 2, we found that roughly 35 percent of books that the Campus Center Bookstore sells are pre-owned. Assuming that those pre-owned books are replacing books that would have otherwise been manufactured, we calculated the reuse impact by taking a credit for 35 percent of the total manufacturing impacts calculated. The overall impact for reusing 1 kg and 885.23 kg of books is shown in Table 7.9 and 7.10 respectively.

Table 7.9: Total Impacts from Reuse of 1 kg of Books.

Impact Category	Transport Impact	Reuse Impact	Reuse Credit	Total Impact	Unit
Global Warming	-	-	-0.28	-0.28	kg CO2 eq
Acidification	-	-	-0.15	-0.15	H+ moles eq
Eutrophication	-	-	-0.0022	-0.0022	kg N eq
Carcinogens	-	-	-0.0017	-0.0017	kg benzene eq
Non- Carcinogens	-	-	-30.80	-30.80	kg toluene eq
Respiratory Effects	-	-	-0.00079	-0.00079	kg PM2.5 eq

Table 7.10: Total Impacts from Reusing 885.23 kg of Books.

Impact Category	Transport Impact	Reuse Impact	Reuse Credit	Total	Unit
Global Warming	-	-	-247.86	-247.86	kg CO2 eq
Acidification	-	-	-132.78	-132.78	H+ moles eq
Eutrophication	-	-	-1.95	-1.95	kg N eq
Carcinogens	-	-	-1.50	-1.50	kg benzene eq
Non-Carcinogens	-	-	-27,265.08	-27,265.08	kg toluene eq
Respiratory Effects	-	-	-0.70	-0.70	kg PM2.5 eq

CUMULATIVE IMPACTS OF BOOK DISPOSAL

The impacts of throwing 1kg of books in the trash, recycling, or reuse categories are compared in Table 7.11 and the cumulative impacts of Wellesley College's book waste being thrown in the trash or placed in the recycling is compared in Table 7.12.

Table 7.11: Comparison of Impacts for 1kg of Books Incinerated, Recycled, or Reused.

Impact Category	Incineration Impact	Recycling Impact	Reuse Impact	Unit
Global Warming	1.22	-0.89	-0.28	kg CO2 eq
Acidification	0.82	-0.18	-0.15	H+ moles eq
Eutrophication	0.82	-0.01	-0.0022	kg N eq
Carcinogens	177	-80.4	-0.0017	kg benzene eq
Non-Carcinogens	177	-0.0016	-30.8	kg toluene eq
Respiratory Effects	0.82	-0.06	-0.00079	kg PM2.5 eq

Table 7.12: Comparison of Impacts of all Books Incinerated, Recycled, or Reused.

Impact Category	Total Trash	Total Recycled	Total Reuse	Unit
Global Warming	261.19	-1,408.59	-247.86	kg CO2 eq
Acidification	176.41	-279.82	-132.78	H+ moles eq
Eutrophication	175.97	-15.49	-1.95	kg N eq
Carcinogens	38,070.04	-127,295.76	-1.50	kg benzene eq
Non-Carcinogens	38,081.59	-2.52	-27,265.08	kg toluene eq
Respiratory Effects	175.97	-94.89	-0.70	kg PM2.5 eq

Assessment of Wellesley College's Handling of Books

The current disposal breakdown of books is not ideal, but not as bad as it could be. Our first priority with books should be to keep them away from the trash. Despite the high heating value of paper in an incinerator, the incinerator energy credits per kilogram could not compensate for the debits involved with transportation and incineration of books. Recycling and reuse both achieved net credits for the college. Encouraging further recycling and reuse should improve the College's overall waste impact profile. Even though recycling begets a larger credit than reuse, reuse should be encouraged. Current reuse practices impose no additional impacts, whereas recycling imposes additional impacts. If we want to eliminate disposal impacts altogether, reuse is the easiest way.

MELAMINE DISHWARE

Dishware Background at Wellesley College

Dishware can be made of a variety of materials including but not limited to glass, plastics, porcelain, wood and metal. Dishware also comes in many forms: Plates, glasses, dishes, bowels, silverware, chopsticks etc.

Uses of Dishware at Wellesley College

Wellesley College dishware is provided by the company Sysco. Sysco orders most of its plates from Carlisle Kingline, meaning they are made from melamine with a gloss finish. The Silverware is Sysco Winser Flatware 1810, which is composed of stainless steel.[9] The main dining hall cups are composed of plastic #7 while the mugs used for coffee and tea are made of porcelain. The deep-dish bowls, like the main cups, are made of plastic #7. Chopsticks are also

[9] Equipment and Supplies Catalogue. *Sysco Food Services of Seattle*. n.d. Web. 25, Feb. 2012. <http://www.syscoseattle.com/Sysco_SeattleEScatalog.pdf >.

used for many of the Asian fusion meals, which means they end up in the trash as they are designed to be disposable. Disposable, but compostable, paper cups are also used and thrown out on a daily basis on the campus: for more information on this material please refer to the disposable dishware section of the report.

Dishware is used to assist in food preparation and consumption as a clean surface on which to consume one's food.

Activities and Behaviors producing this waste at Wellesley College

At Wellesley College, dishware is taken out of the dining hall by students for their convenience, and sometimes never brought back. Many of the plates are thrown out as trash either purposely, due to laziness, or accidentally when in a rush to brush one's scraps in the garbage. On any given day it would not be unusual to see an abandoned plate or glass sitting in an academic building. There is also the possibility of students taking dishware for their own personal use at home, though in this instance the dishware would not be entering Wellesley College's specific waste stream.

Amount of Dishware Produced at Wellesley College

Dishware is purchased each year based on the dining needs of students and staff members that eat on campus. It is most often purchased when dishware runs low. To estimate the weight of dishware disposed of annually on campus, we multiplied the weight of each item with the amount purchased, as displayed in Table 7.13.

Table 7.13: AVI Replacement Dinnerware for Jan. 11' – Dec. 11' [10]

Material	Weight per unit (kg)	Amount Discarded Annually	Total Weight Discarded Annually (kg)
Oval casserole dish 12 oz.	0.34	432	146.88
Tumblers 12 oz.	0.34	4200	1,428.00
Coffee Mugs 1	0.3	120	36
Coffee Mugs 2	0.3	2148	644.4
Forks	0.06	9540	534.24
Knives	0.06	2760	154.56
Spoons	0.06	8208	492.48
Soup spoons	0.06	2400	144
8" square plates	0.45	1536	695.81
4 oz flare bowl	0.11	72	8.06
9" Plate	0.47	3768	1,770.96
6" plate	0.25	1176	470.4
Soup cups	0.06	360	90
2 oz sauce dish	0.08	72	4.03
3" sauce dish	0.34	72	5.76
12 oz. Bowl	0.34	2184	742.56
Total For All Dishware:			7,325.71
Total Melamine Dishware			**3,084.05**

Destination and Handling of Dishware Waste at Wellesley College

All of the dishware waste produced at Wellesley College goes to SEMASS for incineration, along with all other MSW. To estimate how much dishware waste will end up in MSW each year, one can either assume the amount of dishware purchased each year is equivalent to the amount that was disposed of the year prior, or one can use the amount of dishware found in the New Dorm Complex waste audit to extrapolate for dishware waste across campus. Our waste audit found 12 forks, 8 knives, 7 plates, 6 cups and 2 bowls disposed of as trash, which totaled only 1,163.89 kg of dishware once the number of dining halls and weeks within a year were factored in. This sample did not serve as an accurate reflection of the amount of dishware disposed of annually by students. The sample did not cover non-residential buildings

[10] Equipment and Supplies Catalogue. *Sysco Food Services of Seattle*. n.d. Web. 25, Feb. 2012. <http://www.syscoseattle.com/Sysco_SeattleEScatalog.pdf >; AVI replacement Dinnerware for Jan11-Dec-11. *AVI Fresh.* 2011. Web. 11 Mar 2012. <https://docs.google.com/a/wellesley.edu/spreadsheet/ccc?key=0Aoxe5GkHK88idDNpV293MHNrRXJxNVNFdWFQbElCREE#gid=0>

on campus, and the amount of discarded dishware is more likely to increase towards the end of each semester, skewing the total expected weight. The most accurate method proved to be utilizing the Wellesley AVI Fresh purchasing information for dishware over the course of the year 2011. Using purchasing information under the assumption that every item purchased replaced one that was disposed of the year before we concluded that the Wellesley College campus discards of 7,325.71 kg of dishware and 3,084.05 kg of melamine dishware waste on an annual basis.

Wellesley College dishware that is disposed of as trash can be the result of student laziness or accidental disposal when in a rush to brush food scraps in the garbage. As shown in table 7.14, none of the dishware found on campus is recycled. All dishware waste is sent to SEMASS for incineration.

Table 7.14: Handling and Destination of Melamine Dishware Waste by Percentage.

	Conigliaro	SEMASS
% of Waste	0%	100%
Weight of Waste (kg)	0 kg	3,084 kg

Abridged Life Cycle of Melamine Dishware at Wellesley College

At Wellesley College, melamine is primarily found in plates used in the campus five main dinning halls. An abridged lifecycle diagram for melamine plates from production to disposal is displayed in Figure 7.3.

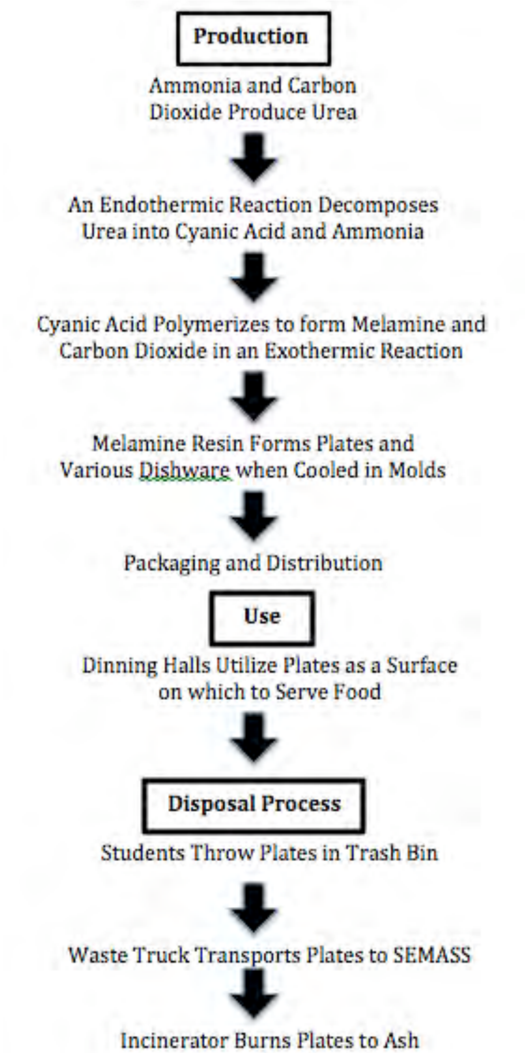

Figure 7.3: Abridged Life Cycle for Melamine Dishware.

Melamine Source Background

Melamine is an organic base, with a 1,3,5- triazine skeleton. It contains 66% nitrogen by mass, and if mixed with resins, has fire retardant properties due to its release of nitrogen gas when burned or charred. It is produced from the common substance urea, which is distilled chemically to produce melamine.[11] It is considered a thermoset plastic, or a synthetic material that strengthens under heat, but will burn when heated after its initial molding.[12]

Urea is an organic compound that is synthesized in the body of many organisms as part of the urea cycle, either from the oxidation of amino acids, or from ammonia. It is considered a sustainable resource since urea is produced on a scale of some 100 thousand tons per year

[11] Cyromazine: Summary Report 2. *The European Agency for the Evaluation of Medicinal Products*. 2001. Web. 25 Mar. 2012. <http://www.emea.europa.eu/docs/en_GB/document_library/Maximum_Residue_Limits_-_Report/2009/11/WC500013083.pdf>.

[12] More About Thermoset Plastics. *ThomasNet: Connecting Industry*. 2012. Web. 25 Mar. 2012. <http://www.thomasnet.com/about/thermoset-plastics-61020277.html>.

worldwide.[13] For use in industry, urea is produced from synthetic ammonia and carbon dioxide. Large quantities of carbon dioxide are emitted during the manufacture of ammonia from coal or hydrocarbons such as natural gas and petroleum-derived raw materials. Such natural and industrial sources of CO_2 help facilitate direct synthesis of urea during its production.[14]

Manufacturing of Melamine Dishware

In industry, urea is chemically distilled to produce melamine in the following reactions. First, urea decomposes into cyanic acid and ammonia in an endothermic reaction. Second, cyanic acid polymerizes to form melamine and carbon dioxide in an exothermic reaction. However, the entire process, including both reactions, is considered endothermic.[15] In one method, the manufacturer introduces molten urea onto a fluidized bed with a catalyst to produce a reaction. Hot ammonia gas is also present to fluidize the bed and inhibit de-ammonization. The effluent then is cooled. Ammonia and carbon dioxide in the exhaust are separated from the melamine-containing slurry. The slurry is further concentrated and crystallized to yield melamine. The off-gas contains large amounts of ammonia. Therefore, melamine production is often integrated into urea production, which uses ammonia as feedstock.[16] This process uses energy inputs to fuel the machinery used in the formation of plastic products.

In factories, melamine is typically shipped as a powder and then mixed in large vats to produce a resin. This resin is a mixture of melamine and formaldehyde, which becomes a thermoset plastic that is poured into molds and cooled to form plates, dishes and bowls. Melamine is also added to plastic foams to increase density and durability.[17]

Manufacturing and Use Impact Assessment for Melamine Dishware at Wellesley College

As melamine production does not require mining or the extraction of virgin materials from the earth, there is a low erosion and land disruption impact. However, crystallization and washing of melamine generates a considerable amount of wastewater, which is a pollutant if discharged directly into the environment, thereby giving it a high water use and biodiversity disruption rating. The wastewater may be concentrated into a solid (1.5–5% of the weight) for easier disposal. The solid contains approximately 70 percent melamine and 23 percent oxytriazines (ammeline, ammelide, and cyanuric acid).[18] The manufacturing impacts for 1 kg and for 3,084 kg of melamine dishware production are shown in Table 7.15.

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[13] Meessen, J.H. and Petersen, H. Urea; Ullmann's Encyclopedia of Industrial Chemistry. *Weinheim.* 2002
[14] Inorganic Chemicals: Ammonium Carbonate. n.p. n.d. Web. 25 Mar. 2012. <http://Hillakomem.com>.
[15] Kirk-Othmer. Encyclopedia of Chemical Technology, 3rd Edition. 7: 303–304, 1978. Print.
[16]Meessen, J.H. and Petersen, H. Urea; Ullmann's Encyclopedia of Industrial Chemistry. *Weinheim.* 2002
[16] Inorganic Chemicals: Ammonium Carbonate. n.p. n.d. Web. 25 Mar. 2012. <http://Hillakomem.com>.
[17] Lacoma, T. How is Melamine Made and Manufactured. n.d. Web. 25 Mar. 2012. <http://www.ehow.com/about_6499067_melamine-made-manufactured_.html>.
[18] Lahalih, S.M. and Absi-Halabi, M. Recovery of Solids from Melamine Waste Effluents and their Conversion to Useful Products. *Industrial & Engineering Chemistry Research*. 28: 500-504, 1989.

Table 7.15: Ecosystem Impacts per 1 kg and for 3,084 kg of Melamine Dishware Extraction and Manufacture.

Impact Factor	Total Impact for 1 kg	Total Impact for 3,084 kg	Unit
Global Warming	0.20	616.80	kg CO2 eq
Acidification	0.08	246.72	H+ moles eq
Eutrophication	0.00013	0.40	kg N eq
Carcinogens	0.003	9.25	kg benzene eq
Non Carcinogens	105	323,820	kg toluene eq
Respiratory Effects	0.00046	1.42	kg PM2.5 eq

As both urea and melamine are organic and sustainable materials, melamine dishware manufacture also receives a low resource use rating. The total ecosystem impact score for melamine dishware manufacture is 1.5 (Table 7.16). This is a low score, indicating that the manufacture of melamine is not extremely harmful to ecosystems.

Table 7.16: Additional Ecosystem Impacts for the Manufacture of Melamine Dishware.

Erosion	Permanent Land Disruption	Water Use	Resource Use	Biodiversity Disruption	**Total Score**
0	0	1	0	0.5	**1.5**

Recycling Overview of Melamine Dishware

The thermosets found in melamine dishes have molecules that are interconnected by "crosslinks," meaning that melamine dishes cannot be readily melted for recycling unless they are chemically reduced to low-molecular-weight species.[19] Wellesley College does not recycle dishware, as students throw the majority in the trash.

MELAMINE DISHWARE INCINERATION IMPACTS

Impacts of Dishware Incineration

Melamine dishware thrown into the trash at Wellesley College is sent to SEMASS for incineration. This waste is transported in large, diesel powered combination trucks. SEMASS is located 212.45 km away from Wellesley College. The impact factors for transport were calculated using SimaPro7 using the TRACI2 method. The transportation impact values for 1kg and 3,084 kg of melamine dishware sent to SEMASS are displayed in Table F.1 and Table F.2 in Appendix F respectively.

[19] Plastic. *Pollution Issues*. 2012. Web. 25 Mar. 2012. <http://www.pollutionissues.com/Pl-Re/Plastic.html>

Plastics that are sent to the MSW stream are incinerated at SEMASS. Depending on the composition of dishware, the burning of such products carries unique impacts. The impacts for 1 kg and for 3,084 kg of melamine dishware waste sent to SEMASS annually are displayed in Table F.3 and F.4 in Appendix F respectively.

At SEMASS, energy produced from the incineration of MSW is converted into electricity, some of which is used to run the facility while the rest is fed to the grid. The portion of electricity that goes to the grid displaces part of the negative impacts from conventional electricity production. We estimated the impacts avoided by calculating the impacts of producing electricity in Massachusetts, which is from a mix of fuels (coal, oil, nuclear, hydroelectric and other sources), using the TRACI2 method on SimaPro7.[20] The avoided impacts for 1 kg and the cumulative avoided impacts are quantified in Table F.5 and F.6 found in Appendix F respectively.

The overall impacts for 1kg of Melamine Dishware are presented in Table 7.17. Impacts for total annual waste are shown in Table 7.18.

Table 7.17: Overall Impacts for 1kg of Melamine Dishware.

Impact Category	Transport Impact	Facility Impact	Facility Credit	Total	Unit
Global Warming	0.020	0.36	-0.0015	0.38	kg CO2 eq
Acidification	0.007	0.08	-0.00066	0.08	H+ moles eq
Eutrophication	0.0000065	0.000013	-0.00000015	0.000019	kg N eq
Carcinogens	0.0000065	0.00019	-0.00000065	0.000191	kg benzene eq
Non-Carcinogens	0.14	0.20	-0.01	0.33	kg toluene eq
Respiratory Effects	0.02	3.57	-0.01	3.58	kg PM2.5 eq

[20] Composition of Municipal Solid Waste- Need for Thermal Treatment in the present Indian context. *Columbia University*. n.d. Web. 5 Apr 2012 <http://www.seas.columbia.edu/earth/wtert/sofos/DBSSRS_Article_-_WTE_INDIA_BRIEF_Revised.pdf>.

Table 7.18: Cumulative Impacts for Total Annual Melamine Dishware Waste.

Impact Category	Transport Impact	Facility Impact	Facility Credit	Total	Unit
Global Warming	61.09	1,098.66	-4.66	1,155.09	kg CO2 eq
Acidification	20.21	233.63	-2.02	251.82	H+ moles eq
Eutrophication	0.02	0.04	-0.00045	0.06	kg N eq
Carcinogens	0.02	0.57	-0.002	0.59	kg benzene eq
Non-Carcinogens	419.56	615.4	-20.04	1,014.92	kg toluene eq
Respiratory Effects	0.02	1.4	-40.71	-39.29	kg PM2.5 eq

CLOTHING

Clothing Background

Clothing can serve a wide variety of functions and is made up of a large range of materials. It can be an expression of personal style, a religious symbol, modesty, protection from the weather, a barrier preventing injury in harsh work conditions, or hold useful objects the wearer might want at hand. At its most basic level, clothing covers bodies. The materials used can vary depending on the purpose. Common fibers used come from both natural and synthetic sources. Some common fibers used in clothing and towel production include: cotton, wool, cashmere, linen, nylon, polyester, nomex, kevlar, acrylic, silk, modal, rayon, and many others.[21]

Depending on the purpose of the clothing, the material and material maintenance can vary. Depending on how a garment is constructed, for example with reinforced stitching or lining, the laundering method can extend or decrease the life of the garment. Some of the most common articles of clothing seen on campus including towels, jeans, and t-shirts, are made of cotton and are fairly easy to launder; cotton clothing can be thrown in a washing machine with detergent when dirty and still last many years. Blazers, slacks, skirts, and sweaters are often

[21] Textile --- Textile machine and textile products: Types of Fabrics used for Apparel. *Abouttextile.com*. n.d. Web. 23 Apr. 2012. <http://www.abouttextile.com/2009/03/types-of-fabrics-used-for-apparel.html>.

wool, requiring dry-cleaning.[22] Clothing that is made with many different materials can often only be spot or dry cleaned. [23]

Also included in the clothing category are towels. Towels are generally dense cotton or cotton-polyester blends woven roughly into terry cloth.[24] Students in residence halls generally use highly absorbent, reusable fabric towels after bathing or washing their hands. Terry cloth is easy to launder and durable. Thus, towels, if properly cared for, can last a Wellesley student's entire college education.

Use of Clothing at Wellesley College

As an educational facility with minimal access to dry cleaning, the majority of the clothing worn by students at Wellesley College is made of easy to launder materials like cotton and polyester. Students own some specialty clothing for parties and interviews of wool or silk. Protective gear made of heavier material is generally not used or disposed of on-campus and was omitted.

Clothing worn by Food Service workers, postal workers, and members of the janitorial staff belong to either AVI Fresh or the staff member in question and are disposed of off-campus. Therefore, their waste is not included in these calculations.

Activities and Behaviors Producing Clothing Waste at Wellesley College

As with books and other durable goods, the majority of clothing and fabric waste at Wellesley College is produced during move-out. Clothing can be heavy and difficult to pack in limited luggage, and is easy to replace. These qualities make clothing an ideal item to discard if extra space is needed for end of the year packing. In addition, many students come from or are moving to climates where the cold weather clothing is unnecessary. Thus they dispose of much of their winter gear when they leave Wellesley.

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[22] Wool Fabric Care. *Denver Fabrics*. n.d. Web. 23 Apr. 2012. <http://www.denverfabrics.com/content/wool/wool-fabric-care.aspx>.

[23] Fabric Care and Cleaning | All Fabrics Deserve Special Treatment. *Fabrics.net*. n.d. Web. 23 Apr. 2012. <http://info.fabrics.net/fabric-facts/fabric-care/>.

[24] How a Bath Towel is Made - Material, Production Process, Etc. n.p. n.d. Web. 23 Apr. 2012. <http://www.madehow.com/Volume-4/Bath-Towel.html>.

Amount of Clothing Waste Produced at Wellesley College

Table 7.19: Estimated Annual Clothing Waste at Wellesley College.

Material	Weight in Waste Audit (kg)	Weeks at Capacity level	Total Produced Annually (kg)
Clothing (School Year)	19.50	32	3,588
Clothing (Summer and Winter Sessions)	19.50	16	902.46
Spring Move-out	-	-	6,605.66[25]
Misc. (incl. Sports Center Towels)	-	-	1,109.61
Total			**12,205.73 kg**

In this section, we have calculated the total amount of clothing discarded on campus, using data from the New Dorms Waste Audit and the Wellesley Sustainability Office. Since the New Dorms represent one-sixth of the total student population, we calculated a weekly per capita clothing disposal rate and multiplied that number by the population of students on campus and the number of weeks at that population. The types of clothes found during the waste audit were a mixture including jeans, tops, sweaters, jackets, towels (both industrial and household), socks, and underwear, and their masses displayed in Table 7.19 are an accurate representation of the variation of clothing disposed of as waste during the school year. The clothing data collected in our New Dorms waste audit were used as a representation of the average week at Wellesley.

Handling and Destination of Clothing Waste

Table 7.20 displays the percentages of clothing waste that are thrown away or reused.

Table 7.20: Estimated Handling of Disposed Clothing at Wellesley College.

Material	% Thrown in Trash	% Re-use
Clothing	36.79%	63.21%

During normal operation, Wellesley College does not have clothing recycling. Therefore, all clothing and towels that enter the waste stream anytime except the Sustainable Move-out go

[25] Wellesley College: Sustainability. *Office of Sustainability*. 2012. Web. 17 Apr. 2012. <http://www.wellesley.edu/AdminandPlanning/Sustainability/moveinmoveout.html>.

to the SEMASS incineration facility. The amount and weight of clothing waste handled either by SEMASS or reused is shown in Table 7.21.

Table 7.21: Estimated Handling of Disposed Clothing at Wellesley College.

Material	SEMASS	Reuse
% of Waste	36.79%	63.21%
Weight of Waste (kg)	4,490.49	7,715.24

Clothing donation is available year round in the Student Aid Society office as well as during the Spring Move-out period. During the Spring Move-out period the Office of Sustainability organizes donation collection for Big Brothers Big Sisters. This donation collection absorbs most of the clothing disposed of during the Spring Move-out period; therefore, we used it to represent the move-out as a whole. Donated clothing is reused. Therefore, this move-out period makes up the majority of clothing re-use on-campus. Other re-use categories, such as the Student Aid Society Clothing closet, Sports Center Towels, and direct reselling from peer-to-peer are included in the miscellaneous category. A diagram of the life cycle of clothing manufacture, use and waste is showing in Figure 7.4.

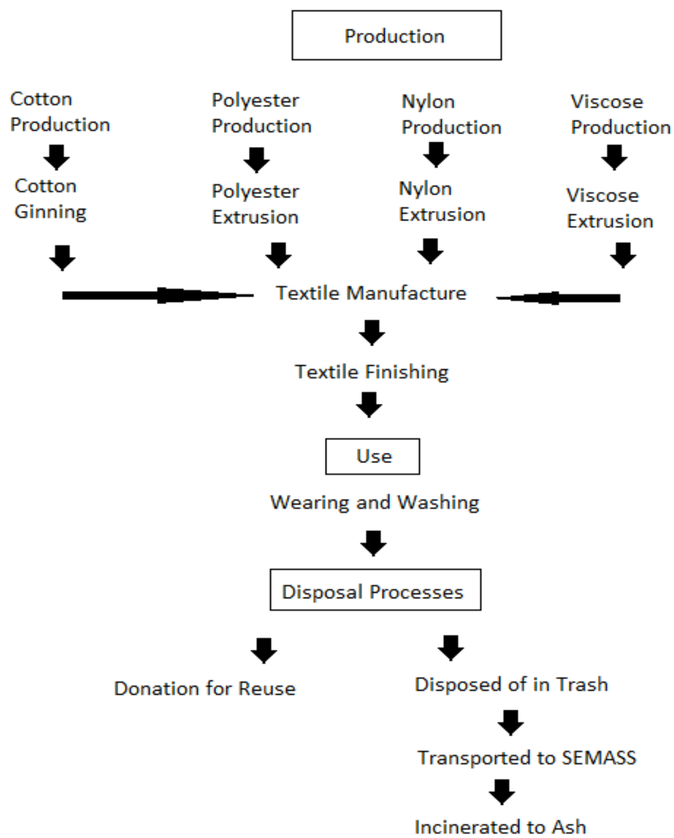

Figure 7.4: Abridged Life Cycle of Clothing Used at Wellesley College.

Manufacturing and Use Impact Assessment for the Model kilogram of Textiles

We calculated the manufacture impacts of clothing by creating a model 1kg garment in Simapro7 and analyzing it using the TRACI 2 method. Simapro7 has a large array of synthetic fabrics, but comparatively few natural fabrics. The model kilogram of clothing is comprised of 50% percent Cotton, 30% Polyester, 10% Nylon, and 10% Viscose. After we calculated the raw material extraction, using the textile finishing and manufacturing methods we calculated the water and energy use of clothing production. Then adding the raw material extraction numbers to the fabrication numbers, we calculated the total impacts of materials production and manufacture, shown in Table 7.22

We calculated the usage impacts of clothing by assuming that the average garment lasts for about 75 wash and dry cycles.[26] In Simapro7, the textile finishing and maintenance process was repeated 75 times to replicate the impacts of washing and drying clothing several times. In Table 7.23, total impacts for using 1kg of clothing for 75 cycles was calculated.

Table 7.22: Total Impact Values for Clothing Material Production and Manufacture per 1kg and for 12,205.73 kg of Material.

Impact Factor	Total Impacts per 1 kg	Total Impacts for 12,205.73 kg	Units
Global Warming	15.60	190,409.39	kg CO2 eq
Acidification	7.16	87,393.03	H+ moles eq
Eutrophication	0.019	231.91	kg N eq
Carcinogens	0.050	610.29	kg benzene eq
Non Carcinogens	287.00	3,503,044.51	kg toluene eq
Respiratory	0.035	427.20	kg PM2.5 eq

[26] Alcover, F.C. Life Cycle Analysis of a T-Shirt. *Upcommons.upc.edu*. Universite De Haute-Alsace. Jul 2011. Web. 8 May 2012. <http://upcommons.upc.edu/pfc/bitstream/2099.1/14307/1/Mem%C3%B2ria.pdf>.

Table 7.23: Total impact values for Clothing Usage per 1kg and for 12,205.73 kg of Material for 75 cycles.

Impact Factor	Clothing Usage Impact per 1 kg	Clothing Usage Impact per 12,205.73 kg	Units
Global Warming	384	4,687,000.32	kg CO2 eq
Acidification	86.50	1,055,795.65	H+ moles eq
Eutrophication	0.77	9,398.41	kg N eq
Carcinogens	0.65	7,933.72	kg benzene eq
Non Carcinogens	5,020	61,272,764.60	kg toluene eq
Respiratory	0.44	5,370.52	kg PM2.5 eq

We calculated the additional impacts of the manufacture of clothing in Table 7.24. The vast majority of all impacts of manufacturing came from growing cotton. In order to grow cotton, fields must be permanently cleared destroying wilderness areas. When these fields remain uncultivated, large quantities of topsoil and debris get swept into surface waters. In order to produce 1 kg of cotton fiber roughly 8,500 liters of water are required. In addition, cotton as a crop is prone to many diseases. Large quantities of fertilizers and pesticides are used to compensate for the plants weaknesses. Due to these reasons, the manufacture clothing receives the highest composite score of 5.[27]

Table 7.24: Additional Ecosystem Impacts for the Manufacture of Clothing.

Erosion	Permanent Land Disruption	Water Use	Resource Use	Biodiversity Disruption	**Total Score**
1	1	1	1	1	**5**

CLOTHING REUSE IMPACTS

We calculated the impacts of reusing clothing by dividing the process into three parts. The first step was transportation. Clothing from the Sustainable Move out was donated to Big Brothers, Big Sisters in Framingham by diesel truck and then sold to the Savers thrift store in

[27] Agriculture and Environment: Cotton. *World Wildlife Fund*. n.d. Web. 4 May 2012. <http://wwf.panda.org/what_we_do/footprint/agriculture/cotton/environmental_impacts/>.

Framingham.[28] The total distance travelled was 17.158 km. We multiplied the distance by the impacts of a truck travelling 1km to tabulate the transportation impacts. Reuse facility impacts we assumed to be zero, because the clothing does not need reprocessing in order to be reused. Finally, reuse credits were calculated by assuming that 80% of the clothing donated replaces clothing or textiles that would have been otherwise been manufactured. The overall impacts from reuse per 1 kg of clothing are displayed in Table 7.25 and the cumulative impacts from reuse of total annual clothing produced at Wellesley College are summarized in Table 7.26.

Table 7.25: Total Impacts from Re-use of 1 kg of Clothing.

Impact Category	Transport Impact	Reuse Impact	Reuse Credit	Total	Unit
Global Warming	0.0016	-	-12.50	-12.50	kg CO2 eq
Acidification	0.00054	-	-5.73	-5.73	H+ moles eq
Eutrophication	5.17E-07	-	-0.015	-0.015	kg N eq
Carcinogens	0.00000053	-	-0.040	-0.040	kg benzene eq
Non-Carcinogens	0.011	-	-230	-230	kg toluene eq
Respiratory Effects	0.00000062	-	-0.028	-0.028	kg PM2.5 eq

[28] Good Deeds, Great Deals. *Savers.com.* n.d. Web. 4 May 2012. <http://www.savers.com/About-Us.aspx>.

Table 7.26: Total Impacts from Re-use of 7,715.24 g of Clothing.

Impact Category	Transport Impact	Reuse Impact	Reuse Credit	Total	Unit
Global Warming	12.70	-	-96,400	-96,400	kg CO2 eq
Acidification	4.17	-	-44,200	-44,200	H+ moles eq
Eutrophication	0.0039	-	-117	-117	kg N eq
Carcinogens	0.0041	-	-310	-3.10	kg benzene eq
Non-Carcinogens	86.40	-	-1,770,000	-1,770,000	kg toluene eq
Respiratory Effects	0.0048	-	-217	-217	kg PM2.5 eq

CLOTHING INCINERATION IMPACTS

We calculated the impacts from incinerating Clothing at SEMASS in 3 parts: transportation, facility impacts, and facility credits. Clothing disposed of as trash travels 98 km to the SEMASS incinerator. The impacts of moving 1 kg, 1 km were calculated using Simapro7 and then multiplied by the total distance the clothing needs to travel.

We calculated facility impacts by figuring out the rough percentage various elements in textiles then multiplying it by the fraction that ends up in the air and water post-incineration, shown in Table F.7 in Appendix F.

Facility credits were calculated by taking the heating value of textiles, multiplying by the efficiency factor of SEMASS (76.7%), and then multiplying the resulting energy value by negative one and impacts of producing the energy in the general Massachusetts market. Textiles produce roughly 16,120 kJ/kg due to their high carbon content.

The overall impacts per kg of clothing sent to SEMASS are shown in Table 7.27 and the cumulative impacts for all clothing sent to SEMASS are summarized in Table 7.28.

Table 7.27: Total Impacts from Disposal of 1 kg of Clothing at SEMASS.

Impact Category	Transport Impact	Facility Impact	Facility Credit	Total	Unit
Global Warming	0.0092	1.46	-1.75	-0.28	kg CO2 eq
Acidification	0.0030	0.047	-0.76	-0.71	H+ moles eq
Eutrophication	0.0000029	0.00099	-0.00089	0.000098	kg N eq
Carcinogens	0.0000029	0.21	-7.55	-7.34	kg benzene eq
Non-Carcinogens	0.063	92.58	-0.0030	92.60	kg toluene eq
Respiratory Effects	0.0000035	0.00039	-0.00017	0.00022	kg PM2.5 eq

Table 7.28: Cumulative Impacts from Disposal of 4,490.49 kg of Clothing at SEMASS.

Impact Category	Transport Impact	Facility Impact	Facility Credit	Total	Unit
Global Warming	41.10	6,560	-7,860	-1,260	kg CO2 eq
Acidification	13.60	210	-3,430	-3,200	H+ moles eq
Eutrophication	0.01	4.44	-4.01	0.44	kg N eq
Carcinogens	0.01	921	-33,900	-33,000	kg benzene eq
Non-Carcinogens	282.00	416,000	-13.70	416,000	kg toluene eq
Respiratory Effects	0.02	1.73	-0.75	0.99	kg PM2.5 eq

CLOTHING DISPOSAL CONCLUSIONS

The relative impacts by disposal option per 1 kg of clothing manufactured are displayed in Table 7.29, and the overall impacts by disposal option for the manufacture of clothing are shown in Table 7.30.

Table 7.29: Comparison of Impacts for 1kg of Clothing Incinerated or Reused.

Impact Category	Incineration Impact	Reuse Impact	Unit
Global Warming	-0.28	-12.50	kg CO2 eq
Acidification	-0.71	-5.73	H+ moles eq
Eutrophication	0.000098	-0.015	kg N eq
Carcinogens	-7.34	-0.040	kg benzene eq
Non-Carcinogens	92.60	-230.00	kg toluene eq
Respiratory Effects	0.00022	-0.028	kg PM2.5 eq

Table 7.30: Comparison of Impacts of all Clothing disposed or reused.

Impact Category	Total Trash	Total Reuse	Unit
Global Warming	-1,260	-96,400	kg CO2 eq
Acidification	-3,200	-44,200	H+ moles eq
Eutrophication	0.44	-117	kg N eq
Carcinogens	-33,000	-3.10	kg benzene eq
Non-Carcinogens	416,000	-1,770,000	kg toluene eq
Respiratory Effects	0.99	-217	kg PM2.5 eq

INSTITUTIONAL DURABLE GOODS

Institutional Durable Goods Background

Institutional Durable Goods are made primarily out of metal, plastic, glass, wood and textiles. They may also include parts made of rubber, insulating foam and porcelain. Depending on when a product was manufactured, the amounts of each type of material will vary. For example, an older model may contain more metal parts than a newer model made primarily of plastic. Most of these materials are finite resources, and only wood and certain forms of textiles are renewable resources. Of the finite resources, metal and plastic are probably the most common.

The main metals used in institutional durable goods are steel, aluminum and copper. Steel is made from iron, which is obtained within mineral deposits of hematite, magnetite, and taconite, and extracted through a number of mining techniques. Some steel is created from recycled iron, but since the recycling rate of scrap iron is not high, this is not common.[29] Aluminum is extracted from bauxite ore. The solid material is a mixture of hydrated aluminum

[29] Mineral Photos - Iron. *Mineral Information Institute*. n.d. Web. 28 Feb. 2012. <http://www.mii.org/minerals/photoiron.html>.

oxide and hydrated iron oxide.[30] Copper is mined and extracted from ore, which usually contains less than 1% copper. This ore is ground, concentrated and slurried with water and chemical agents. When air blows through the mixture, it attaches to the traces of copper and allows it to float to the surface and skimmed off. Copper can be produced as either a primary product or as a co-product of gold, lead, zinc or silver.[31]

Plastics can be manufactured from petrochemicals or from vegetable matter. While resins were historically created from cellulose, furfural, oils and other starch derivatives, most plastics are currently made from fossil fuels. The low price and wide availability of petrochemicals have incentivized this form of plastic manufacturing.[32] Petroleum is first drilled and extracted from the Earth, then sent to a refinery where it is transformed into ethane, propane, and other petrochemicals. Ethane and Propane are heated and become Ethylene and Propylene, which are then combined with a catalyst to for a polymer "fluff." This fluff is combined with various other substances, is melted, cooled, and then chopped into pellets, which get shipped to manufacturers to be remelted and molded for use in products.[33] The majority (in terms of total weight) of the plastic found in institutional durable goods is probably thermosetting polymers, although some of the smaller plastic pieces may be thermoplastics. Thermoplastics are suitable for durable goods because retain their strength and shape even when exposed to heat, and they last longer as permanent components than more malleable plastics.[34]

Glass for commercial use is created by heating sand and introducing soda ash and lime to make the sand melt more easily into a consistent product. This mixture is melted until it becomes a syrup. After it is molded, the mixture is allowed to cool and become used as glass.[35]

Other non-renewable materials found in institutional durable goods are china and rubber. The china found in these materials is most likely vitreous china. This type of china is a mixture of ball and china clay, silica and a fluxing agent. The clay mixture is dried in air and then glazed before it is fired in a kiln.[36] Natural rubber is extracted as liquid latex from the bark of the rubber tree (*Hevea Brasiliensis*). Synthetic rubber, however, is more likely to be used in institutional durable goods, and is produced from polymers found in crude oil rather than harvested.[37] Foam rubber may also appear in some durable goods, and consists of mostly polyol and polyisocyantates, with smaller amounts of water and additives (CO2, HCFCs, HFCs and surfactants, etc.).[38]

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[30] How Aluminum Works. *How Stuff Works Inc*., n.d. Web. 28 Feb. 2012 <http://science.howstuffworks.com/aluminum2.htm>.

[31] Copper processing. *Illinois Sustainable Technology Center.* University of Illinois n.d. Web. 28 Feb. 2012. <http://www.istc.illinois.edu/info/library_docs/manuals/primmetals/chapter5.htm>.

[32] Manufacture of Plastics. *University of Nebraska-Lincoln.* n.d. Web. 28 Feb. 2012. <http://dwb.unl.edu/Teacher/NSF/C06/C06Links/qlink.queensu.ca/~6jrt/chem210/Page4.html>.

[33] How are Plastics Made? *Reach Out Michigan*. 1997. Web. 28, Feb. 2012. <http://www.reachoutmichigan.org/funexperiments/quick/plastic.html>.

[34] More about Thermoset Plastics. *Thomas Publishing Company*. n.d. Web. 28 Feb. 2012. <http://www.thomasnet.com/about/thermoset-plastics-61020277.html>.

[35] How Is Glass Made? *Big Site of Amazing Facts*. n.d. Web. 28 Feb. 2012. <http://www.bigsiteofamazingfacts.com/how-is-glass-made>.

[36] Toilet: How Products are Made. *Advameg Inc.,* n.d. Web 28 Feb 2012. <http://www.madehow.com/Volume-5/Toilet.html>.

[37] Tire: How Products are Made. *Advameg, Inc*. n.d. Web 28 Feb 2012. <http://www.madehow.com/Volume-1/Tire.html>.

[38] Foam Rubber: How Products are Made. *Advameg Inc.* n.d. Web 28 Feb 2012 <http://www.madehow.com/Volume-5/Foam-Rubber.html>.

The two main renewable materials found in institutional durable goods are wood and textiles. Wood is harvested from trees all around the world, depending on its characteristics and uses (for example, hardwoods vs. softwoods). Trees are logged, and then converted into sawed lumber through debarking, sawing, edging, crosscutting to standardize and remove defects and then finally graded by strength and appearance. Preservatives are also applied to the wood to keep it from deteriorating and decomposing.[39]

Textiles can be created from natural or synthetic fibers. Historically, textiles were derived from natural materials like wool, flax and cotton. More recently, however, textiles have been created from synthetic, petroleum-based materials like nylon and polyester.[40]

Uses of Institutional Durable Goods at Wellesley College

Many institutional durable goods are mechanical appliances, such as refrigerators, dishwashers, stoves, microwave ovens, washing machines, clothes dryer, air conditioners, furniture, carpeting, vehicles, toilets and the equipment used in laboratories and by facilities. These products are not made from only one material, but rather are manufactured by putting together smaller pieces of metals, plastics, rubber, textiles and wood. These products are purchased and maintained by Wellesley College as an institution, for community use.

Activities and Behaviors Producing Institutional Durable Goods Waste at Wellesley College

Many of these institutional durable goods are purchased and maintained to keep the campus running relatively smoothly. For the most part, many of the larger durable goods are necessary to heat buildings, clean and sanitize food ware and clothes, and other support the lifestyle students, staff and faculty lead at the College. Thus, the behavior is primarily that of purchasing the item in the first place, and this action can be compartmentalized into two subsections with different causes: the purchase of the product and the replacement of the product. As Wellesley purchases these institutional durable goods, it makes certain decisions that influence how the material will eventually be discarded. The purchase could be made with item's durability in mind, which could take planned obsolesce into consideration. On the other hand, the primary factor in the decision to purchase an item may be price instead, and this might lead to the purchase of a less sustainable product, thus possibly leading to different environmental effects along the waste stream.

The treatment of durable goods while used affects the when they will need to be discarded. If the Wellesley College community treats durable goods poorly, they will need to be discarded, and replaced more frequently. Additionally, the decision to replace a durable item at all also places a different burden on the waste stream.

Institutional Durable Good Waste Produced at Wellesley College

The number and weight of institutional durable goods disposed of annually at Wellesley College is estimated in Table 7.31.

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[39] Lumber. *Encyclopedia Britannica Online Academic Edition*. n.d. Web. 28 Feb. 2012. <http://www.britannica.com/EBchecked/topic/351178/lumber>.

[40] Carpet Don't Get No Respect. *The Green Home*. Mortgage News Daily. 4 Mar 2009. Web. 28 Feb. 2012. <http://www.mortgagenewsdaily.com/channels/green_home/57409.aspx>.

Table 7.31: Estimated Annual IDGs Disposal at Wellesley College.

Material	Weight per unit (kg/unit)	# Units per kg	# Units Produced Annually	Total kg Produced Annually
Microwaves	19.96	0.60	15.20	303.40
Refrigerators - Dorms	66.67	0.21	6.57	438.12
Refrigerators - Non-dorms	29.21	0.17	12.00	350.52
Furniture	-	-	-	684.93
Carpets	0.54	1.85	2,059.26 sq. m	1,112.00
Washers and Dryers	65.32	0.015	1.6	200.34
TOTAL				**3,089.31**

We calculated that there are about 146 active microwaves on-campus. If there are 29 microwaves in the Residential Quad (Cazenove, Beebe, Shafer, Pomeroy and Munger), and 755 students currently living these residential halls, then we assume in these buildings there are .04 microwaves per student. Thus, in residence halls across campus that house 2300 students, there are 92 microwaves in the dorms. Then, we assumed there are approximately 60 other microwaves scattered across different buildings on-campus, with approximately 3-5 per building. Based on the microwave on Cazenove 3rd floor, microwaves purchased by the College weigh 19.96 kg.[41] We assumed a microwave has a lifetime of 10 years,[42] and divided the total weight by its lifetime.

If there are as many fridges per student as there are microwaves, then we assume that 92 fridges are on campus. A Hotpoint fridge, which is similar to the ones found in residence halls, weighs 66.67 kg, so we used this number as an estimate.[43] If these fridges last for 14 years, then we can divide their weight by this amount to find an annual 'waste' total, of 438.12 kg. In non-residential buildings, microwaves and fridges are often paired together in kitchenettes, hence we can assume there are as many mini-fridges as there are microwaves, which amounts to 60. If they are all one type of fridge, each weighs approximately 29.21 kg.[44] Since these fridges have a lifetime of 5 years instead of 10, we separated the residential and non-residential fridges.[45]

There are 16 large-occupancy residence halls on campus, and each has 4 sets of washers and dryers. In addition to large-occupancy residence halls, there are also six small-occupancy

[41] Sharp Medium Duty Commercial Microwave - 1000 Watt. *Amazon.com Inc*., n.d. Web. 13 Mar. 2012. <http://www.amazon.com/Sharp-Medium-Duty-Commercial-Microwave/dp/B000T905D4/ref=sr_1_3?s=kitchen&ie=UTF8&qid=1331816635&sr=1-3>.

[42] Appliance Life Expectancy. *Demesne*. n.d. Web. 13 Mar. 2012. <http://www.demesne.info/Home-Maintenance/Appliance-Life-Expectancy.htm>.

[43] Hotpoint. n.p. n.d. Web. 12 Mar. 2012. <http://www.appliancesconnection.com/i124779-hotpoint-htn16bbxww.html>.

[44] Danby DAR440BL Refrigerator. *Amazon.com Inc.* n.d. Web. 13 Mar. 2012. <http://www.amazon.com/Danby-DAR440BL-4-4-Cubic-Designer-Refrigerator/dp/B002TKJTNI/ref=sr_1_3?s=kitchen&ie=UTF8&qid=1331846076&sr=1-3>.

[45] Appliance Life Expectancy. *Demesne*. n.d. Web. 13 Mar. 2012. <http://www.demesne.info/Home-Maintenance/Appliance-Life-Expectancy.htm>.

residence halls where each has only one washer and one dryer. This results in the presence of 70 sets of washers and dryers on campus. We assumed the washers weigh 65.32 kg each, and that the dryers weigh 59.87 kg each.[46] We divided the total weight of existing washers and dryers by their life expectancies, 11 and 13 years, respectively.[47] The sports center has an additional two sets of washers and dryers, as well as two sets of institutional washers and dryers, which are an additional 200.34 kg annually, assuming that each machine lasts five years.

Furniture is disposed of and replaced at Wellesley College primarily during renovations. While people residing in dorms and offices may choose to replace their personal furniture, we did not include this source under institutional durable goods. Medium renovations are done approximately every five years at Wellesley, and that this produces 453.59 kg during each renovation, resulting in 90.72 kg of waste annually. In addition, every year several pieces of furniture are probably disposed of. Using the Conigliaro recycling logs, we assume the College recycles 594.21 kg of furniture annually in addition to the larger-scale renovations.

Lastly, approximately 30 percent of Wellesley's 723,900 square feet of indoor area is carpeted. According to the EPA's online Durable Goods Calculator, a square foot of carpeting weighs 0.54 kg, which means there are 402,167.61 kg of carpeted space at Wellesley College. Wellesley is not on a scheduled replacement for carpets, meaning that carpet replacement is done based on location and condition. We assumed that 1 percent of the carpeted surface is sporadically removed due to mold or wear, but that the bulk of the carpet waste comes from large renovations every 10 years.[48] Thus, every year, 4,021.67 kg of carpet waste is disposed of, as well as one-fifth of carpet on campus is replaced every 10 years (8,416.98 kg). To get an annual measure, we added the sporadic removal to the regular replacement rate to get 1,112 kg of institutional durable goods waste per year.

Handling of Institutional Durable Goods at Wellesley College

The distribution of how institutional durable goods are handled when disposed of at Wellesley College is displayed in Table 7.32.

[46]Maytag White Commercial. *Amazon.com Inc*. n.d. Web. 13 Mar. 2012. <http://www.amazon.com/Maytag-White-Commercial-Top-LoadWasher/dp/B001BWVAHS/ref=sr_1_9?s=appliances&ie=UTF8&qid=1331839946&sr=1-9>; GE Commercial DCCB330GJWC. *Amazon.com Inc*. n.d. Web. 13 Mar. 2012. <http://www.amazon.com/Commercial-DCCB330GJWC-Operated-Dryer-Capacity/dp/B005WKVHIC/ref=sr_1_31?s=appliances&ie=UTF8&qid=1331839370&sr=1-31>.

[47] Appliance Life Expectancy. *Demesne*. n.d. Web. 13 Mar. 2012. <http://www.demesne.info/Home-Maintenance/Appliance-Life-Expectancy.htm>.

[48] Patrick Willoughby. Director of Sustainability. Personal Interview. 12 Mar. 2012.

Table 7.32: Estimated Handling of IDGs at Wellesley College.

Material	% Recycled	Thrown in Trash	% Reused
Microwaves	100%	0%	0%
Refrigerators	100%	0%	0%
Furniture	15%	45%	40%
Carpets	5%	95%	0%
TOTAL	**70%**	**23.33%**	**6.67%**

Due to existing Massachusetts disposal laws, microwaves, refrigerators, washers and dryers cannot be thrown in the trash, and thus Wellesley is required by law to recycle them. Conigliaro captures the Freon in refrigerators and then outsources the remaining recycling stages. Microwaves are also disassembled at Conigliaro, valuable materials are sold and the remainder is recycled in other locations. The washers and dryers used at Wellesley are leased by Mac-Gray, and the Mac-Gray Company collects old washers and dryers once they break down, and handles all waste. Since Mac-Gray's headquarters is in MA, they have to follow the Massachusetts DEP Waste Ban as well.[49]

When furniture is disposed of, it is thrown away into the trash only if it is in bad condition (damaged, soiled, etc.). If furniture is in good condition, then it is sometimes placed in the Distribution Center for use by other departments or people. On occasion, furniture is donated to other schools, or recycled with the Institution Recycling Network (IRN). The IRN provides furniture to a variety of institutions, for little to no money.[50] We assume that 15 percent of furniture on campus is recycled, 45 percent is thrown in the trash, and 40 percent is recycled.

Carpet replacement is almost always contracted out to other companies, and so the contractor is responsible for proper disposal of the carpeting. It is likely that most discarded carpeting is simply thrown into the trash. Most carpets removed by college personnel are also thrown into the dumpster, unless it is a large load. There is some push at Wellesley College towards more frequent carpet recycling and the purchase of carpets with higher recycled content, but this is not currently the norm.[51]

Destination of Institutional Durable Goods Waste

The portions of IDGs waste sent to reuse, recycling, and MSW handling facilities are estimated in Table 7.33.

[49] Your Business and the Waste Bans: What You Need to Know. *Massachusetts Department of Environmental Protection*. n.d. Web. 13 Mar. 2012. <http://www.mass.gov/dep/recycle/reduce/toolkit/wrtbus.pdf>.
[50] Justin Finne. Personal Interview. 12 Mar. 2012.
[51] Patrick Willoughby. Personal Interview. 14 Mar. 2012.

Table 7.33: Destination of IDGs Waste by Percentage.

	Conigliaro	SEMASS	Reuse
% of Waste	70%	23.33%	6.67%
Weight of Waste	2,162.52	720.74	206.057

Institutional durable goods handled as recycling at Wellesley College are sent to the Conigliaro Industries recycling facility in Framingham, MA or Institutional Recycling Network. We estimated that 70 percent of the IDGs from Wellesley College, or about 2162.517 kg, is sent to Conigliaro annually. The high recycling rates are most likely because of the waste ban in place in MA, which encourages large waste producers to recycle a variety of materials.

Institutional durable goods that are disposed of as trash are sent to the SEMASS WTE facility in West Wareham, MA, where these products are incinerated. We estimate that this encompasses 23.33 percent of IDGs. On a smaller scale, some furniture is reused at Wellesley, making up 6.67 percent of the total waste stream. Furniture that is in relatively good condition is generally in high demand, and therefore is easier to distribute than more worn and ragged durable goods.

Abridged Life Cycle of #1 Institutional Durable Goods Used at Wellesley College

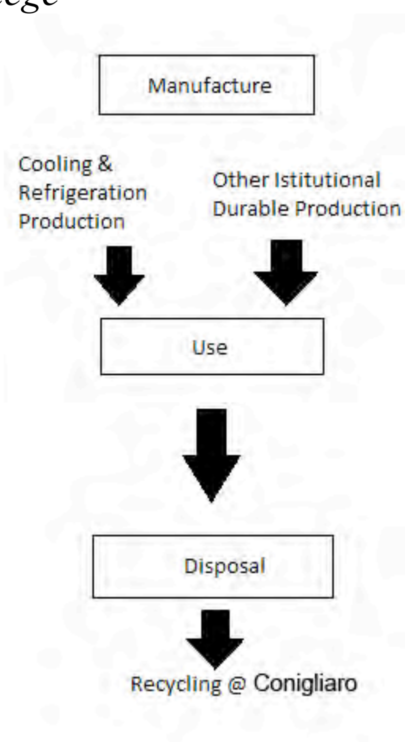

Figure 7.5: Abridged life cycle of institutional durable goods.

Manufacturing Impact Assessment per Kilogram of IDGs

Since IDGs comprise of many different materials and come from a variety of industries, calculating the impact of 1 kg for IDGs using a bottom up LCA in Simapro7 would prove to be extremely difficult. By using the economic Input-Output model for industries included in the Category of IDGs, we calculated the total impact of White Appliances, (i.e. Microwaves, Refrigerators, Washing Machines, and Dryers), Furniture, and Carpeting and divided that number by the total annual weight calculated above. For example, assuming Wellesley College pays the manufacturer's suggested retail price for carpet (about $4.50 per square foot) we calculated the value of our consumption to be $9,266.67 on carpeting per annum. In the US Input-Output Simapro7 models, we input the total spent on carpeting and Simapro7, using the TRACI 2 method, calculates the impacts of our total consumption. We then divided our total impacts by our total weight to calculate impacts per kilogram of IDGs. This is a rough approximation averaging out the impacts over several industries; the method includes impacts of processes such as retailing the finished good and advertising. Additionally, environmental justice considerations are not included in US Input-Output models. Table 7.34 quantifies the impacts per 1 kg and the cumulative impact of the extraction and manufacturing process for institutional durable goods.

Table 7.34: Total Impact Values Per 1 kg and for 3,089.31 kg of Institutional Durable Goods Material Extraction and Manufacture.

Impact Factor	Impacts per 1kg	Impacts for 3,089.31 kg	Units
Global Warming	15.70	48,502.17	kg CO2 eq
Acidification	0.08	247.14	H+ moles eq
Eutrophication	0.0038	11.74	kg N eq
Carcinogens	0.36	1112.1	kg benzene eq
Non-Carcinogens	156	481,932.40	kg toluene eq
Respiratory Effects	0.0017	5.25	kg PM2.5 eq

Since IDGs are composite products, mostly containing materials such as Plastic #4, Nylon, Polyester, wood (furniture) and Wool (in carpeting) the Additional Ecosystem Impacts for IDGs are similar to those of other chapters. Wood use for furniture contributes to deforestation, erosion, Biodiversity Disruption. The molded plastics used as casings for microwaves, fridges, washers, and dryers use non-renewable resources. When in use, washers require copious quantities of water and detergents. Thus, IDGs receive the worst possible score: 5 (Table 7.35).

Table 7.35: Additional Ecosystem Impacts for the Manufacture of Institutional Durable Goods.

Erosion	Permanent Land Disruption	Water Use	Resource Use	Biodiversity Disruption	Total Score
1	1	1	1	1	**5**

INSTITUTIONAL DURABLE GOODS RECYCLING IMPACTS

Figure 7.6: Institutional durable goods at Conigliaro Industries.

As composite goods, IDGs must go through a multi-step recycling process. We chose a Microwave as our model IDG since it was the IDG with fewest deviations from the norm. Since there is a Waste Ban in the State of Massachusetts, all White Appliance type IDGs must be recycled. We recycle all of our White Appliances with Conigliaro Industries in Framingham, MA.

We calculated the impacts of a microwave in three steps: Transportation, Facility Impacts, and Facility Credits. In the case of IDGs such as Microwaves, minor dismantling can yield valuable materials such as metal casing and powerful magnets[52]. Thus, IDGs travel to two locations. First, we calculated the impact of truck transport to Conigliaro and added it to the impacts of shipping the material to Shanghai for further dismantling, the worst-case scenario. Since Conigliaro operates solely using solar energy, facility impacts were assumed to be zero. Conigliaro guarantees that they can retrieve or recycle at a rate of 25 to 50 percent of recyclable

[52] How a Microwave Oven Is Made - Manufacture, Making, Used, Parts, Components, Structure, Product, Design, Raw Materials, The Manufacturing Process of Microwave Oven, Quality Control. n.p. n.d. Web. 4 May 2012. <http://www.madehow.com/Volume-1/Microwave-Oven.html#b>.

materials in a product.[53] Thus we set the recycling credit equal to 25% of manufacturing impacts. The overall impacts of recycling per 1 kg of IDGs are represented in Table 7.36 and the overall impacts of recycling all IDG waste produced annually on campus are summarized in Table 7.37.

Table 7.36: Total Impacts from Recycling of 1 kg of a Microwave at Conigliaro & Shanghai.

Impact Category	Transport Impact	Facility Impact	Facility Credit	Total	Unit
Global Warming	0.79	-	-3.93	-3.14	kg CO2 eq
Acidification	0.04	-	-0.20	0.21	H+ moles eq
Eutrophication	0.0014	-	-0.00095	0.00044	kg N eq
Carcinogens	0.00068	-	-0.09	-0.089	kg benzene eq
Non-Carcinogens	5.47	-	-39	-0.34	kg toluene eq
Respiratory Effects	0.00097	-	-0.0004	0.00055	kg PM2.5 eq

[53] Manufacturing and Distribution Recycling. Conigliaro Industries. n.d. Web. 4 May 2012. <http://conigliaro.com/recycling/manufacturing.cfm>.

Table 7.37: Total Impacts from Recycling 2,162.52 kg of Institutional Durable Goods at Conigliaro & Shanghai.

Impact Category	Transport Impact	Facility Impact	Facility Credit	Total	Unit
Global Warming	1,708.39	-	-8,498.70	-6,790.31	kg CO2 eq
Acidification	86.50	-	-432.50	-346	H+ moles eq
Eutrophication	3.03	-	-2.05	0.97	kg N eq
Carcinogens	1.47	-	-194.63	-193.16	kg benzene eq
Non-Carcinogens	11,828.98	-	-84,338.28	-72,509.30	kg toluene eq
Respiratory Effects	2.10	-	-0.87	1.23	kg PM2.5 eq

Personal Appliances

Personal Appliances Background

Personal Appliances consist of a range of items such as blenders, mini fridges, coffee pots, scales, hair strengtheners, hot plates, microwaves, toaster ovens, fans, and crock-pots. These appliances can be broken down into parts, such as plastics, metals, ceramics, insulation, glass, electronic components, and rubber.

Plastics are used in many of these goods. There are many types of plastics that are used for different appliances, but the general process is discussed in the Institutional Durable Goods section. The major metals used can range from steel, aluminum and copper, which are also discussed in the Institutional Durable Goods section. Glass and rubber are also discussed in the Institutional Durable Goods Section.

Gold is one of the many trace metals that can be found in trace amounts, such as in circuit boards and other electrical components. These circuit boards consist of many different materials in tiny amounts, upwards of 10 metals, plastics, and other substances are used.[54] For further discussion on the electronic components of personal appliances please see the Electronics section of this chapter.

[54] Xiang, D. et al. Printed Circuit Board Recycling Process and its Environmental Impact Assessment. *The International Journal of Advanced Manufacturing Technology.* 2007. Web. 28 Feb 2012 <http://www.springerlink.com/content/p83285r2627876pl/>.

Insulation is used in appliances such as mini fridges and microwaves. Insulation is typically manufactured from human-made fibers, such as alkaline earth silicate fibers (AES) and fiberglass, (which constitute about 95% of fiber insulation.)[55] Fiberglass is made through a process called pultrusion that begins with saturating strands of glass in a thermoset resin, and then that material is pulled through a heated dye. Fiberglass cannot be melted down once it is made.[56]

Ceramics include clay products, silicate glass and cement.[57] (MAST) Clay, the most well known ceramic, can be mined through strip mines or underground mines. It is usually transported via rail to manufacturing and refining plants.[58]

One last category of materials in personal appliances is chemicals, such as HCFCs, which are used as refrigerant in mini fridges. Chemicals are generally discovered and produced in laboratories. HCFC's are used in refrigerators, but it is required by law that these chemicals be removed and disposed of properly before he appliance can be land filled, recycled, or incinerated. HCFCs are replacement chemicals for the O-Zone degrading CFCs. However, HCFCs also degrade the O-Zone layer, but to a lesser extent.[59]

Uses of Personal Appliances at Wellesley College

The most common uses of personal appliances at Wellesley College tend to be in the form of rice cookers, mini-fridges, hair straighteners, scales, coffee pots, fans, and similar items. Some of these are banned for use in the residence halls,[60] but used nonetheless.

Activities and Behaviors Producing Personal Appliance Waste at Wellesley College

At the end of the year when students move out, many throw away their small appliances, such as coffee makers, as they are relatively inexpensive to replace and students do not want to bring them home. Additionally, when these products break, seem old, or a better version comes out, students dispose of their old appliance.

Number of Personal Appliances Used at Wellesley College

The amount of Personal Appliance waste produced annually at Wellesley College is estimated at 11,470.56 kg, as presented in Table 7.38.

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[55] Thermal Insulation in Appliances. *Morgan Thermalceramics.* 2009. Web. 28 Feb. 2012 <http://www.morganthermalceramics.com/resources/technical-articles/thermal-insulation-in-appliances/>.

[56] How is Fiberglass Made? *Fiberglass Windows.* 2006. Web. 28 Feb 2012 <http://www.fiberglasswindows.com/made.htm>.

[57] What are Ceramics? *University of Illinois.* MAST. n.d. Web. 28 Feb 2012 <http://matse1.matse.illinois.edu/ceramics/ware.html>.

[58] Clay Mining. *The West Virginia Encyclopedia.* 2012. Web. 28 Feb 2012 http://www.wvencyclopedia.org/articles/1291>.

[59] Complying with the Section 608 Refrigerant Recycling Rule. *Environmental Protection Agency.* 2011. Web 16 April 2012. <http://www.epa.gov/ozone/title6/608/608fact.html?>;
What Happens to Recycled Appliances? *Top Ten USA.* 2012. Web 16 Apr 2012. <http://www.toptenusa.org/Energy-Saving-Tips-News/What-Happens-to-Recycled-Appliances>.

[60] Life on Campus. *Wellesley College*. n.d. Web 16 April, 2012. <www.wellesley.edu>.

Table 7.38: Estimated Annual Personal Appliance Waste at Wellesley College.

Material	Weight per unit (kg/unit)	# Units per kg	# Units Produced Annually	Total Produced Annually (kg)
Mini Fridges	29.21 [61]	0.05	336	9,814.56
Fans	1.50	0.30 fans	288	432
Electric Tea Kettles	1	1 kettle	320	320
Lamps	1	1 lamp	575	575
Rice cookers	.52	2.4 appliances	920	480
Total				**11,612.56 kg**

To estimate the number of mini fridges produced as waste annually at Wellesley College, we assumed that 70% of the 2300 students on campus have one personal mini fridge, meaning that 1680 students have a mini fridge each. The life span of a fridge is about 5 years[62], so we divided the number of fridges by the lifetime, which came to 336 fridges as waste each year. Even though some students may not want their fridges after a shorter period of time, if the appliance is still in working order the student almost always gives it away or sells it. Therefore we kept the expected lifetime of the fridge at 5 years. We then multiplied the 336 fridges of waste by 29.21 kg (which is approximately the weight per unit) and got a total weight estimate of 9814.56 kg for mini fridges disposed of each year.

To estimate the number of fans produced as waste annually we estimated that 60% of the 2300 students at Wellesley College have a personal fan, meaning that 1,440 students have one fan each. This estimate is based on observation and informally asking students if they own a personal fan. The life span of a fan is about 5 years; so about 288 fans are produced as waste each year. We then multiplied that by the weight per unit and got a total weight estimate of 432 kg for fans discarded each year.

To estimate the number of electric teakettles produced as waste annually, we assumed that 40% of the 2,300 students at Wellesley College have an electric kettle, meaning that about 960 students have one electric kettle each. The life span of an electric teakettle is about 3 years,[63]

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[61] Danby DAR440BL Refrigerator. *Amazon.com Inc.* n.d. Web. 13 Mar. 2012. <http://www.amazon.com/Danby-DAR440BL-4-4-Cubic-Designer-Refrigerator/dp/B002TKJTNI/ref=sr_1_3?s=kitchen&ie=UTF8&qid=1331846076&sr=1-3>.

[62] Damewood, C. Life Expectancy of Major Appliances. *Demand Media Inc.* 2012. Web. 13 March 2012. <http://www.ehow.com/about_5640478_life-expectancy-major-appliances.html>.

[63] Lohwengk. Cordless Kettle Review. *Hinzi Media Inc.* 2008. Web. 16 April, 2012 <http://www.infobarrel.com/Cordless_Kettle_Review_-_Four_Famous_Brand-Name_Electric_Tea_Kettles_Which_Became_Duds>.

so about 320 electric kettles are produced as waste each year. We then multiplied by the weight per unit and got a total weight estimate of 320 kg of waste for kettles discarded each year.

We believe that 100% of the 2300 students at Wellesley College have a lamp (either personal or given by the college), plus at least one for every professor's office, but the lifespan of a lamp in a professor's office (who does not need to move in and out each year) is probably quite long, and very few enter the waste stream from professors' offices each year. Thus, we are only counting the students lamps (2300). We assumed that the life span of a student owned lamp is four years, since students usually buy cheap lamps that they will not want after college, even though it could probably last longer. Therefore about 575 lamps become waste, (or unwanted) each year. We then multiplied that by the weight per unit and got a total weight estimate of 575 kg for lamps.

To estimate the number of hair curlers and straightening irons produced as waste annually, we estimated that 80% of the 2300 students at Wellesley College have one hair curler or straightening iron, even if they no longer, or rarely use it, totaling 1,920 appliances. This estimate also comes from observations and informal surveying of students. The life span of a hair appliance is about 2 years[64], therefore 1920 units divided by the 2-year lifespan equals 960 units produced as waste each year. We then multiplied by the weight per unit and got a total weight estimate of 480 kg for hair appliances discarded as waste each year.

Handling of Personal Appliances Waste at Wellesley College

The distribution of how Personal Appliances are handled when disposed of on campus is displayed in Table 7.39.

Table 7.39: Estimated Handling of Personal Appliance Waste at Wellesley College.

Material	% Recycled	% Thrown in Trash	% Sold or Given Away for Reuse
Mini Fridges	25%	0%	75%
Fans	0%	60%	40%
Electric Tea Kettles	0%	60%	40%
Lamps	0%	60%	40%
Curling/Straitening Irons	0%	70%	30%
TOTAL	**5%**	**50%**	**45%**

At the Sustainable Move-Out at the end of the 2010-2011 school year, 42 mini fridges were donated to later be sold at the Sustainable Move-In the next fall, and 9 of the 42 were

[64] How Long Do Hair Straighteners Last? *YahooAnswers*. 2009. Web. 13 Mar 2012. <http://answers.yahoo.com/question/index?qid=20090103160837AACrcYD>

disposed of. Wellesley College recycles all fridges and mini fridges (as it is illegal not to).[65] Thus, we extrapolated from these numbers that approximately 21.42% are recycled, 0% are thrown in the trash (and those that are put with the trash are easily separated) and 78.57% are reused.

For fans, electric teakettles, lamps, and hair appliances there is a 0% recycling rate at the college because there is no recycling program for them.[66] We also estimated the percent thrown away and the percent that is sold or reused based on observations and informal surveying.

We calculated that an average of 5% of personal electronics are recycled, 50% are thrown in the trash, and 45% are sold or given away for reuse when the owner is done with them.

Destination of Personal Appliance Waste

The portions of personal appliance waste reused, sent to recycling facilities, or sent to MSW facilities, are estimated in Table 7.40:

Table 7.40: Destination of Small Appliance Waste by Percentage.

	Conigliaro	**SEMASS**	**Reuse**
% of Waste	21.11%	9.74%	69.14%
Weight of Waste (kg)	2,453.64	1,132.20	11,621.56

Most personal appliances are very difficult to recycle at Wellesley College, as there is no recycling program for them on campus. This results in a 0 percent recycling rate for all but the mini fridges, so the overall recycling rate is only 21.11%, 2,453.64 kg of mini fridges. This waste goes to the Conigliaro Industries recycling facility in Framingham, MA.

Approximately 9.74% percent of personal appliances discarded on campus are thrown in the trash, which get transferred to the SEMASS facility in West Wareham, MA for incineration. This means that Wellesley College is transporting about 1,132.20 kg of broken or rejected Personal Appliances to SEMASS for incineration each year.

A personal appliance is easy to give away or sell once the owner ceases to need it. Many students do not wish to bring home or store things like cheap lamps and fans over the summer, so they are donated or sold, (and in some cases they are simply thrown out.) We estimated that 69.14% percent, or 11,621.56 kg, are sold or given away for reuse each year. This an estimate based on the information from Patrick Willoughby about the Sustainable Move-Out,[67] and also from observations and informal surveys conducted over the Spring 2012 semester.

Abridged Life Cycle of Personal Appliances Produced at Wellesley College

A variety of personal appliances exist on the Wellesley College campus, including rice cookers, mini fridges, and fans. A rice cooker is a common appliance, and like most personal appliances, it is comprised mainly of metal, plastic, and various electronic components.

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[65] Patrick Willoughby. Personal Interview. 12 Mar. 2012.
[66] Patrick Willoughby. Personal Interview. 12 Mar. 2012.
[67] Patrick Willoughby. Personal Interview. 12 Mar. 2012

Electronic components were left out of the following analysis because when they were included, too much uncertainty was introduced. The uncertainty is so drastic since there is a great deal of variation among the electronic components. For example, the percentage of the appliance that electronic components make up varies greatly among different personal appliances, they contain a variety of different materials, and those materials are an even smaller percentage of the whole appliance. Additionally, when we did try to include the electronic components we encountered technical difficulties, data problems, and time limitations. By excluding the electronic parts of personal appliances we are underestimating the negative consequences of their creation, use, and disposal. The electronics section analyzed similar components that may be found in some personal appliances. Please see the electronics section of this chapter of the report for more detailed information.

Rice cookers were used as a proxy for all personal appliances on the Wellesley College campus. Rice cookers were not elected for any specific reason, although mini fridges were intentionally not used because they are recycled, whereas the other 95 percent of personal appliance waste is either thrown out and sent to SEMASS, or reused. The rice cooker example is extrapolated throughout this study to overall personal appliance waste. A diagram of the life cycle for a rice cooker in shown below in Figure 7.7.

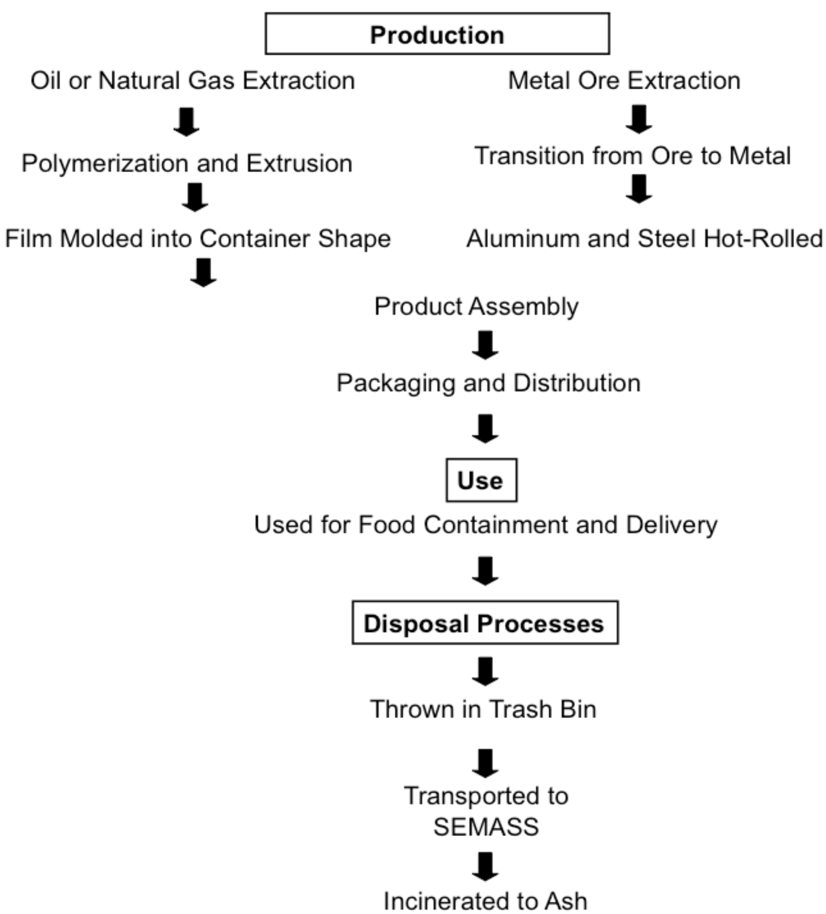

Figure 7.7: Abridged Life Cycle for Personal Appliances (extrapolated from a Rice Cooker)

Personal Appliances Source Background

Rice Cookers, like most other personal appliances, are made primarily from metals and plastics. Rice Cookers specifically, are made from stainless steel, aluminum, Polyamide 6.6 fibers (PA 6.6), and PVC.[68] We used an LCA from a previous study as a guide in our analysis.[69] We assumed that a rice cooker is about 2.4kg, and that each material component is about one quarter of the overall weight (.6kg each). Steel and aluminum are extracted from the earth as an ore, and must be refined and combined with other elements. PA 6.6 (also known as Nylon) and PVC are processed and synthetic, but the ingredients are derived mainly from coal, petroleum, and gas, which are drilled from the earth. The impacts of metal, coal, petroleum, and gas extraction include water pollution, air pollution, and land degradation.[70]

Manufacturing of Personal Appliances

Aluminum is made by first mining iron ore, and then reducing the iron ore by combining it with limestone and a form of carbon called "coke" in a hot furnace.[71] To make steel, aluminum is combined with chromium and nickel. First the ore is concentrated (usually using a method called "froth filtration") and then molded into products (aluminum), or combined with chromium and nickel to become steel.[72] PA 6.6 (also known as nylon) is a synthetic fiber made from chemicals extracted from coal, petroleum, and gas.[73] PVC is made in a similar manner, but the main ingredients, which are extracted from petroleum and seawater, are ethylene and chlorine.[74]

These material components can then be molded into screws, plates, the plastic casing, and other parts associated with personal appliances. The personal appliances are then assembled, packaged, and shipped to the various facilities where they are sold.[75]

Manufacturing and Use Impact Assessment for Personal Appliances

We looked at a previous LCA study of a rice cooker by Zhenghui and Ameta[76] and used its data to guide our own LCA. Simapro7 was used to conduct this LCA. The inputs were

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[68] Ameta, G. and Zhenghui, S. Life-Cycle Assessment of Electric Rice Cooker: A Case Study. *International Mechanical Engineering Congress and Exposition.* 2011. Web. 27 Mar 2012. <ftp://202.38.89.18/incoming/ASME/data/pdfs/trk-16/IMECE2011-64356.pdf>.

[69] Ameta, G. and Zhenghui, S. Life-Cycle Assessment of Electric Rice Cooker: A Case Study. *International Mechanical Engineering Congress and Exposition.* 2011. Web. 27 Mar 2012. <ftp://202.38.89.18/incoming/ASME/data/pdfs/trk-16/IMECE2011-64356.pdf>.

[70] Leigh, E. What Aluminum Extraction Really Does to the Environment. *Electronic Recyclers International*. 2010. Web. 28 Mar 2012.<http://1800recycling.com/2010/11/aluminum-extraction-recycling-environment/>.

[71] Davyson, S. Aluminum. *Sam.Davyson.* n.d.Web. 27 Mar 2012. <http://sam.davyson.com/as/physics/aluminium/siteus/extraction.html>.

[72] Clark, K. Iron and Steel. *ChemGuide*. 2005. Web. 27 Mar 2012. <http://www.chemguide.co.uk/inorganic/extraction/introduction.html#top>.

[73] How Nylon is Made. *BigSiteofAmazingFacts.* 2008. Web. 27 Mar 2012, <http://www.bigsiteofamazingfacts.com/how-is-nylon-made>.

[74] How is PVC Made? *PVC.* n.d. Web. 27 Mar 2012. <http://www.pvc.org/en/p/how-is-pvc-made>.

[75] Ameta, G. and Zhenghui, S. Life-Cycle Assessment of Electric Rice Cooker: A Case Study. *International Mechanical Engineering Congress and Exposition.* 2011. Web. 27 Mar 2012. <ftp://202.38.89.18/incoming/ASME/data/pdfs/trk-16/IMECE2011-64356.pdf>.

[76] Ameta, G. and Zhenghui, S. Life-Cycle Assessment of Electric Rice Cooker: A Case Study. *International Mechanical Engineering Congress and Exposition.* 2011. Web. 27 Mar 2012. <ftp://202.38.89.18/incoming/ASME/data/pdfs/trk-16/IMECE2011-64356.pdf>.

"Aluminum, secondary, shape casted/RNA," "Stainless steel hot rolled coil," "PVC injection molding E," and "Polyamide 6.6 fibers (PA6.6)." These were also the main input components in the Zhenghui and Ameta LCA. We assumed that there are about equal amounts of each used in the production of a rice cooker, therefore, when we calculated the LCA for 1kg of a rice cooker, each of the inputs accounted for .25 kg of material. The environmental impacts associated with the manufacture of a rice cooker are summarized in Table 7.41, and the substances attributed to each impact category are summarized in Table F.8 found in Appendix F.

Table 7.41: Impact Values for Material Extraction and Manufacture of Personal Appliances.

Impact category	Total Impact per 1 kg	Total Impact for 11,621.56	Unit
Global warming	5.00	58,107.80	kg CO2 eq
Acidification	1.28	14,875.60	H+ moles eq
Carcinogens	0.064	743.78	kg benzene eq
Non carcinogens	73.21	850,814.41	kg toluene eq
Respiratory effects	0.005	58.11	kg PM2.5 eq
Eutrophication	0.0009	10.46	kg N eq

The additional ecosystem impacts of the manufacture of a rice cooker are quantified in Table 7.42. The majority of ecosystem impacts associated with the manufacture of rice cooker materials are the result of mining. Steel and aluminum must be mined, and then processed before assembly. Mining involves severe land disruption, and local pollution as chemicals are used to extract the desired material. Overall ecosystem impacts associated with the manufacture of a rick cooker include land disruption, erosion, and biodiversity disruption.[77] Water use is also a concern because it is heavily used in the mining, extraction, and separation processes of mining and manufacturing metal.[78] Mining itself, also depletes non-renewable resources. The manufacture of personal appliances received a total score of 5, this is our highest additional ecosystem impact score.

Table 7.42: Additional Ecosystem Impacts for the Manufacture of a Personal Appliance.

Erosion	Permanent Land Disruption	Water Use	Resource Use	Biodiversity Disruption	Total Score
1	1	1	1	1	**5**

[77] What's the Problem? Environmental Impacts of Mining. *EcosystemRestoration.* Montana State University. 2004. Web. 3 Apr 2012. <http://ecorestoration.montana.edu/mineland/guide/problem/impacts/default.htm>.
[78] Mavis, J. Water Use in Industries of the Future: Mining Industries. *Center for Waste Reduction Technologies; US Department of Energy*. 2003.Web. 3 April, 2012. <http://www1.eere.energy.gov/manufacturing/industries_technologies/mining/pdfs/water_use_mining.pdf>.

Recycling Overview of Personal Appliances

Personal Appliances, such as a rice cooker, are fairly difficult to recycle. They can be broken down into metals and plastics, some of which can be recycled independently. Fans, lights, and teakettles are similar. Mini fridges, on the other hand, must be recycled separately because they contain Freon.[79] Otherwise, these appliances may be repaired, used as pots for plants, storage containers, or they can be sold or given away if they are in working condition. Many times unwanted and broken rice cookers simply end up in a landfill or incinerator. If the appliance is sent to SEMASS to be incinerated, it gets crushed up and the metal parts are taken out with a magnet to be recycled, while the rest is incinerated. If appliances are repaired or reused, it prevents the ecosystem impacts associated with mining and processing the metal, mining petroleum and using chemicals to make plastics, assembly, packaging, and shipping of personal appliances from virgin materials. Therefore, there is much less environmental damage associated with reused personal appliances since their lifespan is lengthened, and therefore the ecosystem impacts of making a new appliance to replace it are avoided.

PERSONAL APPLIANCES INCINERATION IMPACTS

Personal appliances that are thrown into the trash at Wellesley College are sent to SEMASS for incineration. The transportation impact values for 1kg of personal appliances and 1,132.20 kg of personal appliances sent to SEMASS are displayed in Tables F.9 and F.10 in Appendix F respectively.

Personal Appliances that are sent to the MSW stream are incinerated at SEMASS. Personal appliances are made of a variety of materials, so the impacts are the average of each material category (i.e. for Global Warming, we took the average kg CO2 eq for incinerating the various materials in a rice cooker). The impacts for 1kg and 1,132.20 kg of personal appliance waste sent to SEMASS in a year are displayed in Table F.11 and Table F.12 in Appendix F. The impacts that are avoided at SEMASS through energy production from MSW incineration are quantified in Table F.13 and Table F.14 in Appendix F for 1 kg and 1,132.20 kg of personal appliance waste respectively.

The overall impacts for 1kg and for 1,320.20 kg of personal appliance waste generated annually on campus (extrapolated from a rice cooker) are presented in Table 7.43 and 7.44 respectively.

[79] Complying with the Section 608 Refrigerant Recycling Rule. *Environmental Protection Agency*. 2011. Web 16 Apr 2012. <http://www.epa.gov/ozone/title6/608/608fact.html?>; What Happens to Recycled Appliances? *Top Ten USA* Top Ten USA. 2012. Web 16 Apr 2012. <http://www.toptenusa.org/Energy-Saving-Tips-News/What-Happens-to-Recycled-Appliances>.

Table 7.43: Overall Impacts Per 1kg of a Rice Cooker Going to SEMASS.

Impact Category	Transport Impact	Facility Impact	Facility Credit	Total	Unit
Global Warming	0.0058	275.85	-6.13	270.79	kg CO2 eq
Acidification	0.0019	177.98	-2.67	175.66	H+ moles eq
Eutrophication	-	0.06	-0.00059	0.059	kg N eq
Carcinogens	-	110.62	-0.0031	110.62	kg benzene eq
Non-Carcinogens	0.040	3581601.20	-26.41	3,581,582.14	kg toluene eq
Respiratory Effects	-	0.30	-0.011	0.29	kg PM2.5 eq

Table 7.44: Cumulative Impacts for Personal Appliances Sent to SEMASS.

Impact Category	Transport Impact	Facility Impact	Facility Credit	Total	Unit
Global Warming	6.57	312,317.37	-6,940.39	305,383.55	kg CO2 eq
Acidification	2.15	201,508.96	-3,022.97	198,488.14	H+ moles eq
Eutrophication	-	67.93	-0.67	67.26	kg N eq
Carcinogens	-	125,243.96	-3.51	125,240.45	kg benzene eq
Non-Carcinogens	45.29	4,055,088,879	-29,901.40	4,055,059,023	kg toluene eq
Respiratory Effects	-	339.66	-12.45	327.21	kg PM2.5 eq

ELECTRONIC WASTE

Electronic Waste Background

Electronic waste, or e-waste, consists of discarded electronic materials. It ranges from small personal products like cell phones, Ipods and mp3 players, e-readers, and tablets, to larger products like computers, scanners, and televisions. No clear boundaries exist to define what constitutes electronic waste versus household goods, like electronic kitchen and bathroom appliances.[80] Although e-waste makes up only five percent of the municipal solid waste stream, it is the fastest growing (and one of the most hazardous) portions.[81]

Electronics are composed of multiple different components. For instance, a typical laptop includes a circuit board, memory, hard drive, processor, screen, cooling fan, transformer, capacitor, and battery.[82] Each part has an array of potentially hazardous components. For

[80] What is E-Waste? *California State Government*. 15 Feb 2012. Web. 29 Feb. 2012. <http://www.calrecycle.ca.gov/Electronics/WhatisEwaste/ >.
[81] What is E-Waste? *Greenpeace*. n.d. Web. 29 Feb. 2012. <http://www.greenpeace.org/usa/en/campaigns/toxics/hi-tech-highly-toxic/e-waste/>.
[82] All main laptop and notebook parts explained. *Laptop Parts 101*. n.d. Web. 29 Feb. 2012. <www.laptopparts101.com/>.

example, circuit boards are treated with flame-retardants that are potentially toxic and transformers and capacitors contain PCBs (polychlorinated biphenyls). Heavy metals like lead, zinc, cadmium, and chromium comprise several different parts of electronic products. E-waste also contains valuable rare earth and base metals like lithium, bismuth, ruthenium, nickel, platinum, and gold, whose prices have risen dramatically in recent years.[83] Electronic waste typically contains both valuable and hazardous components.

Uses of Electronics at Wellesley College

The two main categories of electronics at Wellesley College are personal and institutional. Personal e-waste includes equipment such as laptops, cell phones, ipods, tablets, or e-readers used by students, faculty, or staff at the college. Institutional waste includes computers, scanners, projectors, and photocopy machines from libraries and academic buildings that are owned by the institution. Institutional waste is created when the college or a certain office decides to upgrade its equipment. Hence, institutional equipment is discarded in larger quantities and at fewer times than personal waste, which is discarded at a steadier rate.

Activities and Behaviors Producing Electronic Waste at Wellesley College

Individual electronics waste is mainly created when students replace their outdated or broken electronics and discard them, either in the normal waste stream or in specialized boxes for used electronics placed in residential halls and academic buildings around campus. The frequency varies depending on each person's use patterns, as well as the quantity and quality of the goods he or she possesses. Many people store their used electronics in their rooms, especially if they are unsure of how to discard them properly. Thus, during move-out, when students rediscover their stored e-waste, there would be a sharp rise in the amount of electronic waste. Institutional waste is created in larger scale upgrades when the college decides to update, for instance, the computers in the libraries on campus. Faculty computers, however, are replaced regularly approximately every four years.

Institutional and personal electronic waste are both influenced by the rapid technological advancements taking place. There is pressure on Wellesley College as an institution to keep pace with other top-notch schools in having the newest technology. Individuals also strive to keep up with the latest technology, which leads to many pieces of electronic equipment being discarded before they have reached the end of their lifespan. Typical lifespans of electronics have also decreased significantly in the past two decades. In 1997 the average computer lasted six years while by 2005 that had dropped to two years.[84] At Wellesley, this leads to more frequent laptop and desktop computer purchases and more discards.

Amount of Electronic Waste Produced at Wellesley College

To calculate the amount of Electronic Waste produced annually, we divided the electronic waste stream into two broad categories: personal and institutional. Since the categories contain different materials and disposal is carried out by different groups of people, we estimated them separately. The estimates of personal electronics waste stream are displayed in Table 7.46.

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[83] Burger, A.K. A Recycled Laptop's Journey, Part 2: Doing the Job Right. *Tech News World*. 10 Jan 2008. Web. 29 Feb 2012. <http://www.technewsworld.com/story/61106.html>.
[84] What is E-Waste? *Greenpeace.* n.d. Web. 29 Feb. 2012. <http://www.greenpeace.org/usa/en/campaigns/toxics/hi-tech-highly-toxic/e-waste/>.

Table 7.45: Personal Electronic Waste Estimate.

Monthly Waste (kg)	Month Equivalents/Year	Total (kg)
63.31	11	696.43

In the month from February 14 and March 15, Wellesley College disposed of a total 633.12 kg[85] of electronic waste. According to estimates from the College's official electronics waste handlers, between five and 10 percent of that waste is typically personal waste collected from recycling drop-boxes placed around the campus.[86] We rounded up and calculated the amount of personal waste discarded as 10 percent of the total monthly load. Assuming that this was a typical month of Wellesley College waste production, we can extrapolate that information and assume that every year has eight months in the academic year. If the equivalent of one month's worth is disposed of during the weeklong move-out process, and roughly half of that is discarded each month during the four months of vacation, then the total personal electronic waste generated at Wellesley on a yearly basis would be 696.43 kg.

Institutional electronic waste is more difficult to calculate, as college-owned electronics are discarded en masse, approximately every four years. We determined the amount of waste by estimating the amount of institutional electronic goods and dividing it the products' lifetime. Although the actual electronic waste stream would be much less uniform from year to year, for the purposes of our calculations we took an average yearly value. This information is displayed in Table 7.47. Each of the categories displayed was estimated including Faculty/Staff equipment as well as publicly available electronics.

Table 7.46: Institutional Waste Estimate.

Type of Electronic	Number of Pieces	Weight per Piece (kg)	Total Weight (kg)
Desktop Computer	600	14	8,400
Laptop Computer	30	3	90
Printer	70	20	1,400
Scanner	30	10	300
Projector	75	4	300
Televisions	20	20	400
Small Electronics	20	0.5	10
TOTAL			10,900

Wellesley College's total estimated electronics waste is 4329.77 kg per year. Since this is a bottom-up calculation, to account for any oversights, we added an additional 10%, making the total **4,792.74 kg**.

[85] Patrick Willoughby. Director of Sustainability. Personal interview. 15 Mar. 2012.
[86] Justin Finne. Environmental Health and Safety Officer. Personal interview. 9 Mar. 2012.

Handling of Electronic Waste at Wellesley College

Most of Wellesley's electronics are recycled at the end of their useful life. Every residence hall has a cardboard box to collect any used personal electronics students discard. When surveyed, students listed five different disposal options, which are displayed in Figure 7.8, below.

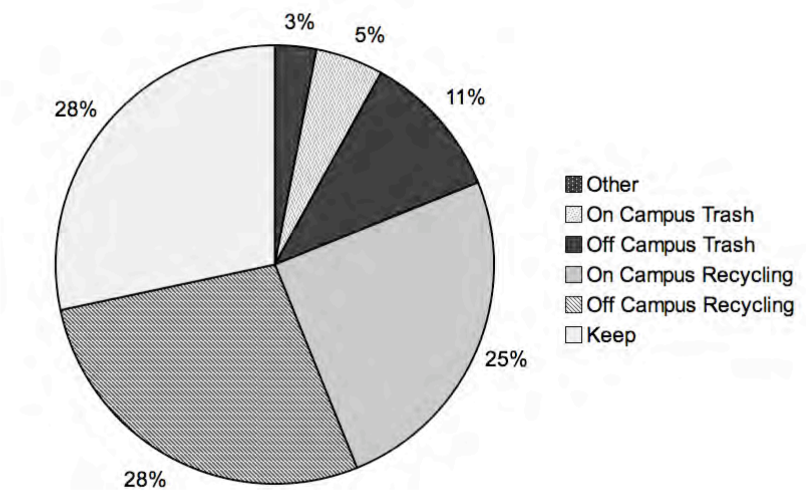

Figure 7.8: Estimated handling of electronic waste.

E-waste goes to several different locations, including off and on campus trash and recycling. One of the main destinations is simply staying put. Of the students surveyed, only 17 percent felt that they knew how to responsibly dispose of their waste electronics. 28 percent keep their broken gadgets instead of disposing them.

For the purposes of this study, we only focused on waste disposed of as trash or recycling on campus.

Destination of Electronic Waste

About 96 percent of electronic waste produced at Wellesley College is recycled and the rest is reused or thrown in the trash (Table 7.47).

Table 7.47: Electronics Transportation Destinations.

Material	% Recycled	% Reused	% Thrown in Trash
Electronics	95.95	4%	0.05

The vast majority of the electronics waste generated at Wellesley College is sent to Northeast Lamp Recycling (NLR), a recycling facility in Connecticut that handles universal waste, including lamps, batteries, and electronics waste.[87] The facility makes four annual collections at Wellesley College, in which they gather institutional waste as well as any personal products disposed of in the cardboard boxes in the dormitories. Once at NLR, the materials are

[87] Home. *NLR*. n.d. Web. 16 Mar. 2012. <http://www.nlr-green.com/index.html>.

sorted and all electronics are then sent to Allied Computer Brokers (ACB) located in Amesbury, MA, where it is either shredded or de-manufactured and sold to other distributors for reuse. [88]

A small fraction of e-waste ends up in the municipal solid waste stream where it is taken with the rest of Wellesley's waste to the SEMASS facility. One of the plant's initial processes is using two powerful magnets to extract any metal products from the waste stream. Those pieces are then taken to a metals recycling facility where they are shredded and separated according to their material.

The institution's copy machines are another exception of electronic waste. They are leased from Ikon, an office supply company, so that old or broken machines can be returned to the retailer.

Abridged Life Cycle of Electronic Waste Produced at Wellesley College

For the purposes of this section, we will be analyzing laptop electronic waste that can act as a proxy for the types of electronic waste on campus. Laptop computers are practically a necessity in academia, and most students and faculty members own one. Roughly 98.6 percent of students surveyed own one, and the average lifespan of a laptop computer is 2.9 years.[89] They are a mid-sized gadget and contain components common to many other types of electronics, making them a representative material. The life cycle of a laptop is depicted in Figure 7.9.

[88] Computers & Electronics Recycling - Boston, MA - ACB Recovery. *Computers & Electronics Recycling*. n.d. Web. 18 Apr 2012. <http://www.acbrecovery.com/>.
[89] Melissa Gallant. Electronics Survey. Raw data. Wellesley College.

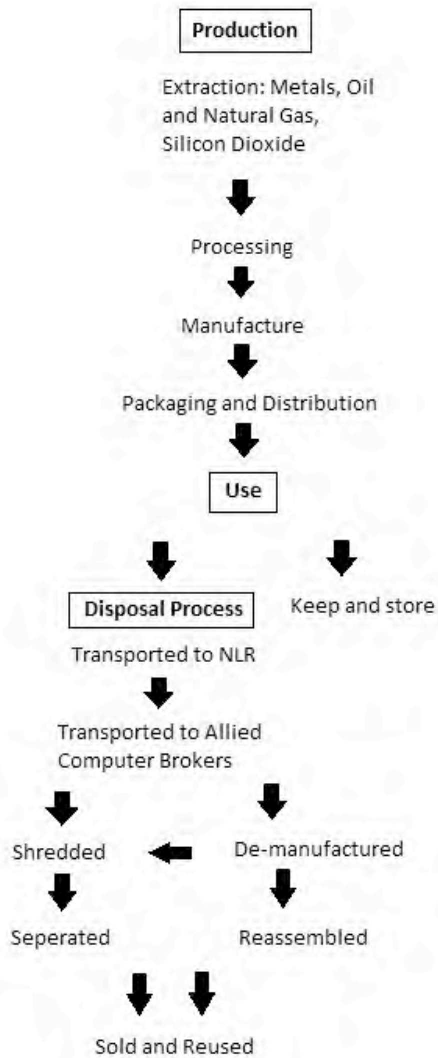

Figure 7.9: Abridged life cycle of electronics.

Electronic Waste Source Background

Electronics are composed of different material components that are assembled to create the final product. Cell phones include circuit boards, liquid crystal display (LCD) screens, rechargeable batteries (either nickel-metal hydride, lithium-ion, nickel-cadmium, or lead acid) and the cell phone's respective casing, keypad, microphone, and speaker.

Desktop computers are even more complex. Each desktop has a system unit, monitor, keyboard, mouse, and other optional pieces like speakers and external storage units. System units and monitors are the most environmentally significant, because they are two of the largest pieces and contain the most hazardous material.[90] The main information processing pieces in a system unit are motherboards, central processing units (CPUs), memory units called read-only memory **(**ROM**) or** random access memory **(**RAM), and chips called Basic Input/Output Systems

[90] Strickland, J. What's inside My Computer? *Discovery.* Web. 30 Mar. 2012. <http://computer.howstuffworks.com/inside-computer1.htm>.

(BIOS**)**.[91] Other pieces include drives, modems and Internet connection hardware, sound and graphics cards, cooling systems, and batteries.[92]

One piece of electronic equipment can contain hundreds of different types of materials. A typical piece of electronics includes:

Glass. Normal glass is made from silicon dioxide, limestone, and sodium bicarbonate, while glass in electronics is often strengthened with potassium ions and other chemicals.[93]

Plastic. Crude oil is combined with natural gas and other chemicals to produce the plastic used in the casing, circuit boards, keyboards, batteries and various other pieces of electronics.

Metals. Depending on the type of product, different amounts of certain metals are used. Virtually each piece in every electronic gadget has tiny metal pieces. Circuit boards include copper, gold, lead, nickel, zinc, baryllium, tantalum, and coltan.[94] Some electronic pieces even have metal casings. For instance, Apple's iPhone 4 is 30 percent stainless steel.[95]

Many metals are used in very small quantities in electronics, but their environmental and social impacts are disproportionately large. No matter where these metals are mined, extrusion is energy intensive and contributes to air pollution and erosion.

A number of precious metals are mined in African countries and have come to be termed "blood metals" because of the conflicts they cause. Coltan and tantalum are both mined in the Democratic Republic of Congo, where workers use basic tools and are often enslaved or paid almost nothing for their labor.[96] On a larger scale, the profits in the industry often motivate corruption and violence. The Hutu militia group associated with the 1994 Rwandan genocide is among the beneficiaries of precious metal mining.[97] From an environmental standpoint, the fewer government controls on resource management mean the fewer restrictions are placed on mining, leading to higher impacts. Once mined, these materials are shipped halfway across the African continent and across the Indian Ocean to manufacturing facilities in Asia, resulting in substantial air emissions.

China is another major supplier of precious metals. Like the Congo, China's environmental protection laws are not as strict as most Western nations, and the mining process is not as thoroughly regulated. The United States' reliance on foreign countries' supplies of rare

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[91] Strickland, J. What's inside My Computer? *Discovery.* Web. 30 Mar. 2012. <http://computer.howstuffworks.com/inside-computer1.htm>.
[92] Strickland, J. What's inside My Computer? *Discovery.* Web. 30 Mar. 2012. <http://computer.howstuffworks.com/inside-computer1.htm>.
[93] Strickland, J. What's inside My Computer? *Discovery.* Web. 30 Mar. 2012. <http://computer.howstuffworks.com/inside-computer1.htm>.
[94] The Life Cycle of a Cell Phone; Solid Waste and Emergency Response. *Environmental Protection Agency*. 2004. Print. EPA530-H-04-002.
[95] IPhone 4: Environmental Report. Report. Apple, 2011. Print.
[96] Hutcheon, S. Out of Africa: The Blood Tantalum in Your Mobile Phone. *The Sydney Morning Herald*. 8 May 2009. Web. 30 Mar. 2012. <http://www.smh.com.au/news/home/technology/blood-tantalum-in-your-mobile/2009/05/08/1241289162634.html>.
[97] Hutcheon, S. Out of Africa: The Blood Tantalum in Your Mobile Phone. *The Sydney Morning Herald*. 8 May 2009. Web. 30 Mar. 2012. <http://www.smh.com.au/news/home/technology/blood-tantalum-in-your-mobile/2009/05/08/1241289162634.html>.

metals, which are used in everything from smart phones to hybrid cars to wind turbines,[98] also has political and economic implications.

Manufacturing of Electronic Waste

Desktop computers and cell phones are manufactured in similar ways, with a series of complicated processes. First, the raw materials are processed. Next, they are distributed to the manufacturing facilities, where they are assembled into the various pieces discussed above, and then the pieces are assembled to create a final product.[99]

Most electronics manufacturing is outsourced to countries in East Asia and Southeast Asia like China, Taiwan, Thailand, and Indonesia. Labor is cheaper and environmental standards are lower in these countries than in Western countries. This arrangement has significant environmental and social impacts. For example, at the Chinese manufacturing plant owned by Foxconn, which produces over 40 percent of the world's electronics, 43 percent of the 1.2 million workers had witnessed an accident, and over two-thirds claimed that their wages did not "meet their basic needs."[100] The manufacturing process is by far the step associated with the largest consumption of renewable resources for desktop computers.[101] It is also responsible for hazardous waste disposal, various kinds of water contamination, energy use, and human health risks.[102]

Manufacturing and Use Impact Assessment for Electronic Waste

The environmental impacts of the manufacture and use of 1 kg of a laptop computer and for the total amount of electronic waste produced on campus are displayed in Table 7.48, below. The numbers were taken from a SimaPro7 model of a laptop computer. The largest category by far is non-carcinogens, which contribute 246.66 kg of toluene equivalents for every 1kg of laptop. Although the other impacts appear small, they are higher than most of the other materials in our report.

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[98] Glover, T. Eco-money: Electronics Firms Face Supply Crisis for Rare Metals. *The National*. 29 Jan 2011. Web. 30 Mar 2012. <http://www.thenational.ae/thenationalconversation/news-comment/eco-money-electronics-firms-face-supply-crisis-for-rare-metals>.

[99] How Desktop Computers Are Made. *Teachertube.com*. 27 Oct 2009. Web. 30 Mar 2012. <http://www.youtube.com/watch?v=YS6xsNilZYQ>.

[100] Foxconn Technology. *The New York Times: Business Day*. 16 Apr 2012. Web. 16 Apr 2012. <http://topics.nytimes.com/top/news/business/companies/foxconn_technology/index.html>.

[101] Socolof, M.L., Overly, J.G., Kincaid, L.E. and Geibig, J.R.. Desktop Computer Displays: A Life-Cycle Assessment. Report. EPA-744-R-01-004a. Vol. 1. 2001. Print.

[102] Socolof, M.L., Overly, J.G., Kincaid, L.E. and Geibig, J.R.. Desktop Computer Displays: A Life-Cycle Assessment. Report. EPA-744-R-01-004a. Vol. 1. 2001. Print.

Table 7.48: Manufacture and Use Impact.

Impact Category	Total Impact per 1 kg	Total Impact for 4,792.74 kg	Units
Global warming	1.12	5367.87	kg CO2 eq
Acidification	0.33	1581.60	H+ moles eq
Eutrophication	0.02	95.85	kg N eq
Carcinogens	0.02	95.85	kg benzene eq
Non carcinogens	246.66	1182177.25	kg toluene eq
Respiratory effects	0.0033	15.98	kg PM2.5 eq

The additional ecosystem impacts of the manufacture of e-waste are recorded in Table 7.49. Resource extrusion and the manufacture of electronic materials are both energy intensive operations. Additionally, electronics' raw materials log high transportation miles during processing, causing a high level of air emissions. Since many of the raw materials used in electronics are toxic or carcinogenic, they also pose a high risk to human health.

Table 7.49: Additional Ecosystem Impacts.

Erosion	Permanent land disruption	Water use	Type of resource use	Biodiversity disruption	Total
0.5	0.5	1	1	0.5	**3.5**

Recycling Overview of Electronic Waste

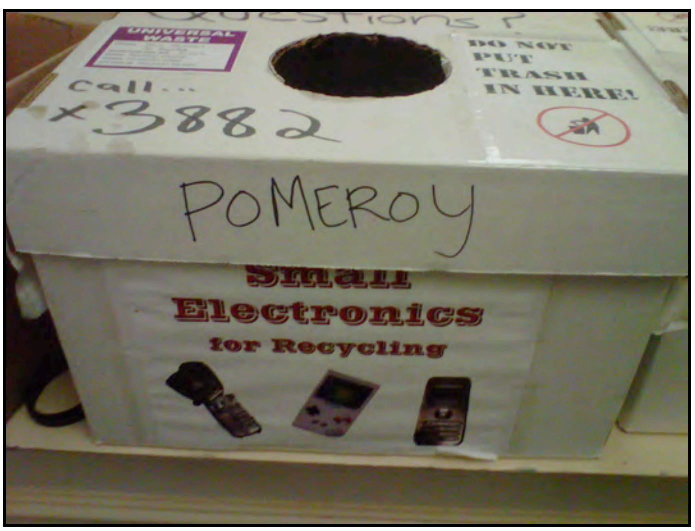

Figure 7.10: Collection bins for recycling placed in dormitories.

The least down cycled option for electronic waste disposal on campus would be reusing it as is, or with minimal repairs or refurbishing. When electronics are fully recycled, their pieces are separated, and valuable resources are sold and reused. This is the most common option for electronics recycled from Wellesley College. Wellesley's electronic waste goes to Northeast Lamp Recycling, a recycling facility in Connecticut that specializes in electronics and other specialized recyclable waste.[103] It received a Department of Environmental Protection award and State citation for excellence in waste recycling,[104] meaning the waste was responsibly handled, thereby limiting the negative social and environmental effects of the electronics' potentially hazardous materials.

ELECTRONICS INCINERATION IMPACTS

Transportation Impacts

The majority of electronic waste that is disposed of on campus is recycled, either by individuals or by the institution. According to a survey conducted of Wellesley College students, only 5 percent is discarded in the trash,[105] meaning that it gets transported along with the rest of Wellesley's MSW to SEMASS. Once it reaches SEMASS, magnetic belts separate it from the waste stream so that none of the electronics are incinerated. For the purposes of this study, e-waste separated out at SEMASS are not included past the transportation stage because they represent such a small amount of overall e-waste that the impacts are negligible. The remaining 95 percent of e-waste is transported to NLR, Northeast Lamp Recycling, in East Windsor, Connecticut.

ELECTRONICS RECYCLING IMPACTS

Facility Impacts for Electronic Waste Handling: NLR

Once the e-waste arrives at NLR, it is sorted and the electronics are transported again to Allied Computer Brokers (ACB) in Amesbury, Massachusetts. All electronics are then either shredded or dismantled, depending on the age and state of the electronic piece.[106] To calculate the facility impacts, we assumed that 60 percent of the electronics sent to ACB are being shredded and 40 percent are being dismantled. We then used SimaPro7 data for electronics shredding and dismantling processes to determine the total impacts. Credits were calculated by comparing the impacts of these recycled materials with the impacts of producing a new laptop computer. We assumed that recycling is 50 percent efficient. Detailed impact and credit values for recycling can be found in Appendix F.

Cumulative Impacts of Electronic Waste Disposal

The combined impacts of transportation impact, facilities impact, and facilities credit for 1kg of electronics recycling are given in Table 7.50. Cumulative values were also calculated per by multiplying the total impacts by the estimated amount of electronic waste Wellesley sends to NLR annually, 4,792.74 kg (Table 7.51).

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[103] Justin Finne. Environmental Health and Safety Officer. Personal interview. 9 Mar 2012.
[104] NLR: Next Level for Recycling. *Northeast Lamp Recycling*. n.d. Web. 30 Mar 2012. <http://www.nlr-green.com/about.html>.
[105] Melissa Gallant. Electronics Survey. Raw data. Wellesley College.
[106] Computers & Electronics Recycling. *Allied Computer Brokers*. n.d. Web. 10 Apr. 2012. <http://www.acbrecovery.com/facilities.html>.

Table 7.50: Recycling Impacts per 1 kg of Electronic Waste per Kilogram.

Impact Category	Transportation	Facility Impact	Facility Credit	Total	Units
Global warming	0.054	0.44	-34.68	-34.19	kg CO2 eq
Acidification	0.018	0.031	-9.03	-8.98	H+ moles eq
Carcinogens	0.000017	0.020	-0.88	-0.86	kg benzene eq
Non carcinogens	0.37	637.55	-10909.08	-10271.16	kg toluene eq
Respiratory effects	0.000019	0.00015	-0.048	-0.048	kg PM2.5 eq
Eutrophication	0.000017	0.00066	-0.56	-0.56	kg N eq

Table 7.51: Cumulative Impacts of recycling 4,792.74 kg of Electronic Waste.

Impact Category	Transportation	Facility Impact	Facility Credit	Total	Units
Global warming	257	2,099.24	-166,225.85	-163,869.61	kg CO2 eq
Acidification	85	150.61	-43,290.99	-43,055.38	H+ moles eq
Carcinogens	0.08	95.95	-4,225.55	-4,129.52	kg benzene eq
Non carcinogens	1,760.00	3,055,601.04	-52,284,382.03	-49,227,020.99	kg toluene eq
Respiratory effects	0.09	0.7	-228.92	-228.13	kg PM2.5 eq
Eutrophication	0.08	3.18	-2,702.17	-2,698.91	kg N eq

SPECIAL RECYCLABLES

Special Recyclables Background

Special recyclables involve materials that require their own individual recycling collection separate from regular recycling, due to their composite and hazardous nature. Each special recyclable item has its unique recycling process, which only certain recycling facilities provide. The special recyclables that we included in this report are compact fluorescent light bulbs (CFLs), household batteries, and ink cartridges. All of these items have individual collection bins around the Wellesley College campus, and are handled entirely separately from the regular college recycling stream.

Compact Fluorescent Light Bulbs

Compact fluorescent light bulbs have quickly replaced incandescent light bulbs at the college, and gradually throughout the country, as a more environmentally friendly option for energy use. According to Energy Star, if every American home replaced just one light bulb with an Energy Star-approved light bulb like a compact fluorescent, it would save enough energy to light 3 million homes for a year, save about \$600 million in energy costs, and prevent 9 billion pounds of greenhouse gas emissions per year, equivalent to those associated with about 800,000 cars.[107] Therefore, it is in the Wellesley College's best financial and environmental interest to continue the use of compact fluorescent light bulbs, provided that we can adequately dispose of them. Compact fluorescent light bulbs (CFLs) contain a very small amount of mercury sealed within the glass tubing (approximately 4 milligrams), which is necessary to make CFLs so energy efficient.[108] As long as the CFL bulbs are in tact or in use, no mercury is released.

Household Batteries

Household batteries are also extremely prevalent at Wellesley College, as they are used for personal appliances like alarm clocks, calculators, and remote controls. There are several types of household batteries that differ in use and composition. Alkaline batteries (AA, AAA, C, D, and 9 volt) have been available for use since 1994, and contain no added mercury; only trace amounts that are not hazardous.[109] Alkaline batteries that can be thrown out are marked with "no added mercury" or have a green tree logo. Nickel-cadmium rechargeable batteries (NiCads) exist in many sizes and shapes and are marked rechargeable. Some may be built into rechargeable appliances, while others may be used for a variety of appliances. NiCads contain cadmium, a metal that is toxic to humans when inhaled or ingested.[110] Button batteries (small, round, silver-colored) are most often used in hearing aids and watches. Many button batteries contain mercury, which is a metal that is also harmful to humans while inhaled or ingested.[111] Finally, Lithium batteries (AA, C, 9 volt and button) are mainly used in computers and cameras. Lithium is highly reactive with water, and has the potential to cause fires if not handled correctly.[112]

Ink Cartridges

Ink cartridges are made of #7, or "other" plastic that contains an engineered polymer causing them to have an extremely slow decomposition rate ranging between 450 and 1000 years depending on the ink cartridge.[113] The ink supply found in ink cartridges contains various toxic substances associated with the different colors they produce. Of these substances, the most problematic chemicals for human health found in ink cartridges are Ethyl alkyldiol, 2-Pyrrrolidone, Ammonium nitrate and metal nitrate, 1.5-Pentanediol, Alkyldiol ethoxylate #1, Alkyldiol ethoxylate #2, Substituted phthalocyanine salt, and Amino Alkyldil. Most of these substances are harmful to humans if inhaled or ingested.[114]

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107 Light Bulbs: Energy Star. *Energy Star*. n.d. Web. 25 Feb 2012. <http://www.energystar.gov/index.cfm?fuseaction=find_a_product.showProductGroup&pgw_code=LB>.

108 Frequently Asked Questions; Information on Compact Fluorescent Light Bulbs (CFLs) and Mercury. *Energy Star*. Nov 2010. Web. 27 Feb 2012. <http://www.energystar.gov/ia/partners/promotions/change_light/downloads/Fact_Sheet_Mercury.pdf>.

109 Household Batteries; Alkaline Batteries. *Massachusetts Department of Environmental Protection*. n.d. Web. 25 Feb 2012. <http://www.mass.gov/dep/recycle/hazardous/batthous.htm>.

110 Household Batteries; Nickel-Cadmium Rechargeable Batteries. *Massachusetts Department of Environmental Protection*. n.d. Web. 25 Feb 2012. <http://www.mass.gov/dep/recycle/hazardous/batthous.htm>.

111 Household Batteries; Button Batteries. *Massachusetts Department of Environmental Protection*. n.d. Web. 25 Feb 2012. <http://www.mass.gov/dep/recycle/hazardous/batthous.htm>.

112 Household Batteries; Lithium Batteries. *Massachusetts Department of Environmental Protection*. n.d. Web. 25 Feb 2012. <http://www.mass.gov/dep/recycle/hazardous/batthous.htm>.

113 Cartridge Recycling; Why Recycle Printer Cartridges? *Inkguides.com*. 2006. 25 Feb 2012. <http://www.inkguides.com/ink-toner-cartridge-recycling.asp>.

114 Material Safety Data Sheet. *Hewlett-Packard Company*. Jun 2003. Web. 25 Feb 2012. <http://support.radioshack.com/msds/msd16-3836_no-57.pdf>.

Uses of Special Recyclables at Wellesley College

Special recyclable usage at Wellesley College is fairly diverse, with compact fluorescents, household batteries, and ink cartridges all performing radically different functions. Compact fluorescent light bulbs (CFLs) are widely used at Wellesley College to light residence halls, academic buildings, and major centers on campus. As incandescent light bulbs are being phased out at Wellesley College, we must evaluate the shift in our impact depending on our newfound choices for energy use in CFLs. Household battery usage on campus varies drastically with the type of battery, but we predict that the largest uses of household batteries at Wellesley College fall under charging personal appliances like alarm clocks, calculators, and remote controls. Button batteries may also be extremely prevalent as a result of wristwatch use on campus. Finally, with the large amount of printing that goes on at Wellesley College, ink cartridges are a sizeable category of special recyclable waste generated on the Wellesley College campus. While personal printers and ink cartridges might not be as common for students, we would assume that the libraries and major printing locations on campus, like academic departments and offices, generate the bulk of ink cartridge waste.

Activities and Behaviors Producing Special Recyclable Waste at Wellesley College

As mentioned earlier, CFLs on campus were introduced as a more efficient method for energy use, specifically more energy efficient lighting, at Wellesley College. With the cultural expectation for well-lit buildings and walkways on campus, a reliable and energy efficient light source is necessary to fulfill predetermined cultural standards. Although lighting in general is necessary on any college campus, behaviors at Wellesley College that involve lighting buildings after hours when they are not in use, like the Clapp Library on weekend nights for example, may prove extremely unnecessary and inefficient uses of CFLs.

Behaviors affecting household battery usage on the Wellesley College campus vary drastically by the function and type of household battery. Behaviors that lead to alkaline and rechargeable battery waste at Wellesley College include owning a calculator, using an alarm clock, or charging personal appliances and electronics. Wristwatches and small electronic devices like pace makers or hearing aids require smaller batteries, which contribute to lithium and button battery waste on campus. Overall, the household battery usage at Wellesley College stems from the fact that they are used as chargers for our increasingly prevalent personal electronics.

The main behavior leading to ink cartridge waste at Wellesley College is the amount of printing that occurs on campus. Since students and faculty are not held accountable for their printing behavior and are instead given unlimited access to free printing, there is no incentive in place to discourage excessive printing. Additionally, there is still a strong culture of students printing out class readings, meaning that many ink cartridges are wasted to accommodate their printing demands, even though electronic reading sources are available for use. Finally, the copy center uses ink cartridges frequently to fulfill copy and spam requests on campus.

Improper disposal of overall special recyclable waste on the Wellesley College campus is a behavior potentially linked to the inconvenience of recycling in comparison to throwing special recyclables away. While collection bins exist for CFLs, household batteries, and ink cartridges on campus, they are not always placed in centralized or accessible locations. Additionally, a lack of awareness about collection bin location, as well as what constitutes a special recyclable may prevent proper disposal. For example, since some alkaline batteries are advertised as safe enough to be thrown away in the trash, people may falsely assume that all batteries can be thrown in the trash, without realizing that some types of batteries qualify as hazardous waste.[115]

Amount of Special Recyclables Waste found at Wellesley College

Table 7.52 displays the estimated amounts of overall special recyclables waste disposed of on the Wellesley College campus each year.

Table 7.52: Estimated Annual Special Recyclables Waste at Wellesley College.

Material	Weight per unit (kg/unit)	# Units per kg	# Units Produced Annually	Total Produced Annually (kg)
Compact Fluorescent Light Bulbs	0.29	3.45 CFLs	11,000 CFLs	3,190
AA Alkaline Batteries	0.024	41.6 AA batteries	276 AA batteries	6.6
AAA Alkaline Batteries	0.012	83.3 AAA batteries	2034 AAA batteries	24.4
9V Lithium Batteries	0.040	25.1 9V batteries	102 V batteries	4
C Batteries	0.067	14.95 C batteries	138 C batteries	9.23
Misc. Batteries*	0.04	25 batteries	15850 misc. batteries	634
Ink Cartridges	0.45	2.2 ink cartridges	4512 ink cartridges	2030.4
Total				**5898.63**

*Miscellaneous batteries include all types that could not be specifically accounted for.

Since the average compact fluorescent light bulb lasts approximately 7 years,[116] it is estimated that 1 in 7 students will replace 2 CFL light bulbs each year. Therefore, out of 2,300 students total, if 343 replaced 3 light bulbs each year (most dorm rooms have two lamps; one ceiling lamp, one personal lamp, and one desk lamp), then the College would dispose of approximately 1029 CFLs each year. According to a waste audit of residence hall waste, 400 students living in Bates, Freeman, and McAfee, threw out two CFLs over the course of a week, meaning that if extrapolated to 2300 students across campus, Wellesley College throws out 598 CFLs each year. Additionally, a previous ES300 report from 2008 examined the greenhouse gas emissions of Wellesley College, and in its recommendation for CFL purchasing on campus,

[115] Household Batteries; Alkaline Batteries. *Massachusetts Department of Environmental Protection*. n.d. Web. 25 Feb 2012. <http://www.mass.gov/dep/recycle/hazardous/batthous.htm>; Household Batteries; Nickel-Cadmium Rechargeable Batteries. *Massachusetts Department of Environmental Protection*. n.d. Web. 25 Feb 2012. <http://www.mass.gov/dep/recycle/hazardous/batthous.htm>.
[116] CFL Light Bulbs. *Energy Star*. Web. Mar 25 2012. <http://www.energystar.gov/index.cfm?fuseaction=find_a_product.showProductGroup&pgw_code=LB>.

referenced that in 2003, 10,943 incandescent light bulbs were purchased.[117] Assuming that all current purchasing of light bulbs on campus is devoted to CFLs, we estimated that Wellesley College purchases approximately 11,000 CFLs each year to distribute throughout campus. Therefore, 10,402 CFLs on campus are purchased each year for uses other than student residence hall room lighting. Assuming that 11,000 bulbs are purchased to replace old bulbs, we assumed that in one year, Wellesley College disposes of 11,000 bulbs on campus. From our extrapolations at the waste audit as well as informal recycling audits of CFL disposal on campus, we estimated that approximately 70% of CFLs on campus are thrown out and only 30% of CFLs are recycled.

An informal special recyclables collection bin waste audit was also conducted in the New Dorms on campus to determine recycling rates of household batteries and ink cartridges. Although it is unclear how often the special recyclable collection bins are emptied, it is assumed that the audit numbers found represent the amount of household batteries and ink cartridges recycled by students every two months. We found that for Bates, Freeman, and McAfee residence halls, representing a total of 400 students, 8AA, 59AAA, 3 9V, and 4 C batteries were recycled over the course of two months. If extrapolated to the entire 2300 student body, this would mean that students at Wellesley College recycle 46AA, 339AAA, 17 9V, and 23C batteries over the course of two months. If these numbers are extrapolated over the course of an entire year, then Wellesley College students are responsible for recycling 276AA, 2034AAA, 102 9V, and 138 C batteries annually. It is estimated that the average Wellesley student disposes 8 household batteries a year, meaning that if applied to the entire Wellesley College student body, then approximately 18,400 batteries are discarded each year. In comparing the average number of batteries discarded each year (18,400) with the recycling rates determined by our waste audit of collection bins (a total of 2,550 batteries), we can assume that the difference between the two represents how many batteries are thrown out on campus. Therefore, we can assume that Wellesley College students throw out a total of 15,850 batteries each year.

In the same special recyclable audit of New Dorms collection bins, we found that 400 students recycled 2 ink cartridges over the course of two months. If extrapolated to include the entire student body, then Wellesley College students recycle 11 ink cartridges every two months, and 66 ink cartridges each year. In addition to student use of ink cartridges, the Clapp library and copy center on campus both use a significant amount of ink cartridges annually. After a personal interview with Laura Sherriff, we found that the two larger printers in the Clapp library need ink cartridge replacements every 1-3 days, depending on the time of year (they are more frequently changed towards the beginning and end of the semester).[118] Therefore, if we estimate that on average these printers each change cartridges every two days, they would produce approximately 182 cartridges each annually. If applied to the other 15 main printers in libraries across campus, then libraries would be responsible for 2,730 ink cartridges each year. Ink cartridges associated with Wellesley College libraries are collected by OfficeMax and are shipped back to Hewlett Packard for recycling. Additionally, another large user of ink cartridges on campus is the copy center. There are 66 copiers that are leased across campus to the College by iKon. We estimated that each copier changes ink cartridges every 2 weeks, meaning that each individual copier is responsible for 26 cartridges each year. If applied to copiers across campus, then approximately

[117] Climate for Change; Greenhouse Gas Audit Wellesley College, *Environmental Studies 300*. 2008. Report.; Audit of Wellesley College's Greenhouse Gas Emissions. *Environmental Studies 300*. 2003. Report.
[118] Laura Sheriff. Manager of Public Services, Clapp Library. Personal interview. 12 Mar 2012.

1,716 ink cartridges are disposed of annually. Fortunately, these cartridges are collected by iKon to be refilled and reused.[119] The estimate handling of special recyclables is shown in Table 7.53.

Table 7.53: Estimated handling of special recyclables.

Material	% Recycled	% Thrown in Trash
Compact Fluorescent Light Bulbs	30%	70%
AA Alkaline Batteries	14%	86%
AAA Alkaline Batteries	14%	86%
9V NiCad Batteries	14%	86%
C Alkaline Batteries	14%	86%
Ink Cartridges	100%	0%
TOTAL	**31%**	**69%**

The destination and weight of special recyclable waste sent to each handling facility are shown in Appendix F. The total weights and portions of special recyclable waste are shown in Table 7.54.

Table 7.54. Destination of Special Recycling Waste by Percentage.

	SEMASS	Northeast Lamp Recycling	IKon Industries
% of Waste	42.65%	17.82%	34.42%
Weight of Waste (kg)	2516.28	1051.50	2030.4

Abridged Life Cycle of Special Recyclables Disposed of at Wellesley College

At Wellesley College, Special Recyclables are primarily Ink Cartridges, Household Batteries, and Compact Fluorescent Light Bulbs (CFLs). An abridged lifecycle diagram for special recyclables from production to disposal is displayed in Figure 7.11.

[119] Shilpa Idnani. Copy center Employee. Personal Interview. 11 Mar 2012.

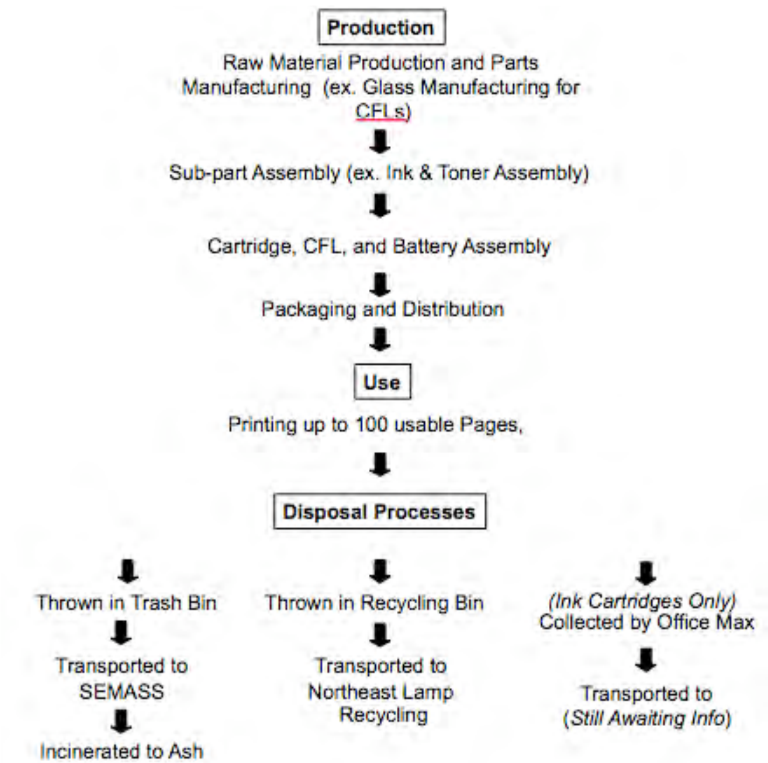

Figure 7.11: Abridged Life Cycle for Special Recyclables at Wellesley College.

Ink Cartridge Source Background

Ink cartridges are made from the assembly of a variety of raw materials and added chemicals, but for the purposes of this report, only those sources that represent the majority material composition are examined. Ink cartridge casings are primarily made from a combination of High Density Polyethylene (HDPE), a #2 plastic, and Polypropelene (PP), a #5 plastic. Since a mixture of plastic resins is used to create ink cartridge casings, the overall plastic associated with ink cartridges is Plastic #7 or "other" plastics.[120] Common ingredients in toner are styrene acrylate copolymer, iron oxide, polymethyl methacrylate, carbon black, amorphous silica, dyes, polypropylene, and waxes. Common ingredients in inks include dyes, resins, glycol ethers, polymethyl methacrylate, pigments, waxes, as well as carbon black. Many of these ingredients have been recognized by the EPA to cause serious health effects from chronic exposure.[121]

Household Battery Source Background

Household Batteries are made from the assembly of a variety of raw materials, like all composite products. Perhaps the most troubling aspect of battery source materials is that

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120 Tips on Recycling RISO's Ink Tubes. *NewsFlash.* n.d. Web. Mar 25 2012. <http://www.eojohnson.com/sites/eojohnson.com/files/uploads/RISO%20Recycling%20Tips.pdf>.

121 Barlow, L. et al. Printers, Printing, and Print Behavior: Status, Socio-Environmental Implications, and Recommendations for the University of Colorado at Boulder; Chapter 3: Life-Cycle Impact of Toner and Ink for CU-Boulder. *Sustainable Solutions Consulting*. Spring 2011. Web. Mar. 25. 2012. <http://envs.colorado.edu/uploads/undergrad/Printer_Project_Chapter_3_Life_Cycle_Impact_of_Toner_and_Ink.pdf>.

household batteries are one of the biggest uses of lead worldwide.[122] Lead is extremely suitable for battery use due to its conductivity, resistance to corrosion and the special reversible reaction between lead oxide and sulfuric acid, which all help batteries function efficiently, but have the downside of ecosystem impacts associated with lead.[123] The main components of household batteries are an active mass or lead paste that includes a cathode of metallic lead and an anode of lead oxides, electrolyte (liquid filling of sulfuric acid), casing (usually made of polypropylene and, less frequently, of hard rubber, ebonite, or bakelite), and other minor components including paper, fiberglass, and wood.[124] Of all the materials needed for the manufacturing of household batteries, the extraction and manufacture of lead for batteries by far has the largest impact. Primary lead metal extraction from its ore results in habitat destruction, water and soil contamination, and requires a good amount of oil.[125] Additionally, secondary lead extraction through lead recycling poses serious risks to the human health of communities living near lead recycling facilities and to the workers in these facilities.

While many of the components in household batteries are harmful to human health with chronic exposure, the greatest human health and ecosystem impacts of household batteries are found in their manufacturing and disposal.[126]

Compact Fluorescent Light Bulb Source Background

A compact fluorescent light bulb (CFL) is another composite product made from the assembly of a variety of different raw materials. A typical CFL is mostly comprised of glass tubing, an electronic starter circuit, and a phosphor lined tube filled with argon and a small amount (5-10mg) of mercury vapor.[127] In comparing the environmental impact of CFLs vs. incandescent light bulbs, studies suggest that overall mercury release is reduced from 15.9 mg for incandescent light bulbs, to 5 mg per light bulb with CFLs.[128] However, despite the reduction of environmental impact in terms of mercury release from CFL light bulbs, CFLs still contribute to significant land disruption as a result of mercury mining[129] and large CO2, lead, and arsenic emissions during assembly.[130]

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[122] Stavrows, D., Costas, P., and Voutsinas, T. Applying Life Cycle Inventory to Reverse Supply Chains: A Case Study of Lead Recovery from Batteries. *Resources, Conservation, and Recycling* 37 (2003): 251-281. Print.
[123] Stavrows, D., Costas, P., and Voutsinas, T. Applying Life Cycle Inventory to Reverse Supply Chains: A Case Study of Lead Recovery from Batteries. *Resources, Conservation, and Recycling* 37 (2003): 251-281. Print.
[124] Stavrows, D., Costas, P., and Voutsinas, T. Applying Life Cycle Inventory to Reverse Supply Chains: A Case Study of Lead Recovery from Batteries. *Resources, Conservation, and Recycling* 37 (2003): 251-281. Print.
[125] Stavrows, D., Costas, P., and Voutsinas, T. Applying Life Cycle Inventory to Reverse Supply Chains: A Case Study of Lead Recovery from Batteries. *Resources, Conservation, and Recycling* 37 (2003): 251-281. Print.
[126] Stavrows, D., Costas, P., and Voutsinas, T. Applying Life Cycle Inventory to Reverse Supply Chains: A Case Study of Lead Recovery from Batteries. *Resources, Conservation, and Recycling* 37 (2003): 251-281. Print.
[127] Soneji, H. Life Cycle Energy Comparison of Compact Fluorescent and Incandescent Light Bulbs. *LUMES; Lund University.* Sustainability Science Report. 2008.
[128] Soneji, H. Life Cycle Energy Comparison of Compact Fluorescent and Incandescent Light Bulbs. *LUMES; Lund University.* Sustainability Science Report. 2008.
[129] Eckelman, M., Anastas, P., and Zimmerman, J. Spatial Assessment of Net Mercury Emissions from the Use of Fluorescent Bulbs. Department of Chemical Engineering, Center for Industrial Ecology; School of Forestry and Environmental Studies. *Environmental Science Technology* 42 (2008): 8564-8570. Print.
[130] Ramroth, L. Comparison of Life-Cycle Analyses of Compact Fluorescent and Incandescent Lamps Based on Rated Life of Compact Fluorescent Lamps. *Rocky Mountain Institute*. Report. 2008.

Manufacturing and Use Impact Assessment for Special Recyclables

While car batteries are of course different than household batteries, their manufacturing processes are fairly similar.[131] Battery production has a larger environmental impact in terms of global warming, photochemical smog, eutrophication, acidification, and ozone depletion than does battery use.[132]

Table 7.55 shows the environmental impacts for a baseline assessment of an HP 10A ink cartridge life cycle, and demonstrates that ink cartridge production and use contributes towards acidification, eutrophication, resource depletion, global warming, photochemical smog, and problems of human health. Overall, ink cartridges seem to have the largest impact in their eutrophication potential, with 0.00027 kg phosphate equivalents associated per unit of an HP 10A ink cartridge.

Table 7.55. Ecosystem Impacts for the Baseline Scenario of an HP10A Ink Cartridge Life Cycle[133]

Impact Category	HP 10A Catridge	Units
Acidification	.031	kg SO2 equivalents
Eutrophication	.00027	Kg PO4 equivalents
Global Warming	.093	Kg CO2 equivalents
Carcinogens	.0078	Kg benzene equivalents
Non-Carcinogens	.035	Kg toulene equivalents
Respiratory Effects	.00037	Kg PM2.5[134]

Many of the manufacturing facilities of ink and toner are located in Southeast Asia, where workers are chronically exposed to chemicals that have serious health effects.[135] The manufacturing plants where the ink and toner are made often have very low regulations of waste disposal, resulting in substantial downstream water and ecosystem pollution.[136] Since many of the chemicals in ink and toner are engineered to be resistant to ultraviolet radiation and insoluble

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[131] Stavrows, D., Costas, P., and Voutsinas, T. Applying Life Cycle Inventory to Reverse Supply Chains: A Case Study of Lead Recovery from Batteries. *Resources, Conservation, and Recycling* 37 (2003): 251-281. Print.

[132] Zackrisson, M., Avellan, L., and Orlenius, J. Life Cycle Assessment of Lithium-ion Batteries for Plug-in Hybrid Electric Vehicles. *Journal of Cleaner Production* 18 (2010): 1519-1529. Print.

[133] Laser Jet Cartridge Life Cycle Environmental Impact Comparison Refresh Study; HP LaserJet 10A Print Cartridge vs. Remanufactured Brands in Europe. *Four Elements Consulting*. Report. 2008.

[134] Laser Jet Cartridge Life Cycle Environmental Impact Comparison Refresh Study; HP LaserJet 10A Print Cartridge vs. Remanufactured Brands in Europe. *Four Elements Consulting*. Report. 2008.

[135] Barlow, L. et al. Printers, Printing, and Print Behavior: Status, Socio-Environmental Implications, and Recommendations for the University of Colorado at Boulder; Chapter 3: Life-Cycle Impact of Toner and Ink for CU-Boulder. *Sustainable Solutions Consulting*. Spring 2011. Web. Mar. 25. 2012, <http://envs.colorado.edu/uploads/undergrad/Printer_Project_Chapter_3_Life_Cycle_Impact_of_Toner_and_Ink.pdf>.

[136] The State of the Environment- Asia and the Pacific: Freshwater. *Global Environment Outlook*. 2000. Web. Mar 25 2012. <http://www.unep.org/geo2000/english/0067.htm>.

in water to ensure that the pigments do not easily fade or wash off the paper,[137] any chemicals from ink cartridges leached into local ecosystems through water pollution or improper disposal to a landfill will continue to have long-term negative health effects.

The largest ecosystem impacts associated with CFLs result from Mercury, Lead, and Arsenic emissions over the course of the light bulb life cycle. Although CFL mercury emissions are relatively small per unit compared to incandescent bulbs, the adequate disposal and extraction of the mercury from a CFL during disposal determines the majority of its life cycle ecosystem impact.[138] Additionally, unlike incandescent bulbs in which operation or use represents the bulk of mercury emissions, CFLs emit the most mercury in the disposal process, usually as a result of breakage.

The overall ecosystem impacts of special recyclables are quantified in Table 7.56. As special recyclables all contain a complex combination of raw materials and chemical additives, their impact on resource use is extremely high. Additionally, the water, land, and soil pollution associated with the manufacture, assembly, and disposal of ink cartridges, household batteries, and CFLs lead to significant ecosystem impact in terms of water use, biodiversity disruption, and permanent land disruption necessary for the extraction of raw materials. The total ecosystem impact score for special recyclables is 4 out of 5, which indicates that the manufacture and use of special recyclable is fairly harmful to ecosystems.

Table 7.56: Overall Environmental Impact Ranking for Special Recyclables.

Erosion	Permanent Land Disruption	Water Use	Resource Use	Biodiversity Disruption	**Total Score**
0	1	1	1	1	**4**

SPECIAL RECYCLABLES INCINERATION IMPACTS

Special Recyclables Transportation Impacts

Special Recyclables thrown into the trash at Wellesley College are sent to SEMASS for incineration. Special Recyclable waste is transported in large, diesel powered combination trucks. SEMASS is located 212.45 km away from Wellesley College. The impact factors for transport were calculated using SimaPro7 using the TRACI2 method. The trucking impact values for batteries sent to SEMASS are displayed in Table F.23 in Appendix F. The trucking impact values for Compact Fluorescent Light Bulbs sent to SEMASS as trash are displayed in Table F.24 found in Appendix F.

Facility Impacts for Special Recyclables Handling: SEMASS

Special recyclables that are thrown out and sent to the MSW stream are incinerated at SEMASS. The facility impacts of special recyclables were calculated using Sustainable Minds to create Life Cycle Assessments (LCAs) for each product. A generic formula was then used to translate percentage impact found in Sustainable Minds into Impact Factor Units, by converting

[137] Polymethyl Methacrylate in Toners & Astringents Guide. *Good Guide*. 2010. Web. Mar 25 2012. <http://www.goodguide.com/ingredients/261635-polymethyl-methacrylate?category_id=152768-toners-astringent>.
[138] Ramroth, L. Comparison of Life-Cycle Analyses of Compact Fluorescent and Incandescent Lamps Based on Rated Life of Compact Fluorescent Lamps. *Rocky Mountain Institute*. Report. 2008.

with numbers in the TRACI2 method: [percent impact/100] * Total Milipoints Value generated by Sustainable Minds = [# of milipoints by impact category/Weight Value[139]]/1000 * Normalization Factor[140] = Total Impact Factor Value. While Sustainable Minds is a less accurate LCA software than SimaPro, the product LCAs found in Sustainable Minds are more representative of special recyclables found at Wellesley College, and therefore are an overall more accurate representation of environmental impacts associated with special recyclables waste generated at Wellesley. The facility impacts of household batteries handled at SEMASS are displayed in Table F.25 in Appendix F. The facility impacts of compact fluorescent light bulb disposal at SEMASS are displayed in Table F.26 in Appendix F.

Overall Impacts of Special Recyclables Disposal

The overall impacts of special recyclables disposal was calculated by adding up the transport impact, facility impact, and facility impact associated with each facility for all special recyclables materials. The impact of incinerating 1kg and the total kg of special recyclables at SEMASS is displayed in Table 7.57 and 7.58 respectively.

Table 7.57: Environmental Impact Per 1 kg of Special Recyclable Disposal at SEMASS.

Impact Category	Transport Impact Per 1 kg	Facility Impact Per 1 kg	Facility Credit Per 1 kg	Total	Unit
Global Warming	.049	20.40	-	20.45	kg CO2 eq
Acidification	.014	12.12	-	12.13	H+ moles eq
Eutrophication	.000015	.013	-	.013	kg N eq
Carcinogens	0	.071	-	.071	kg benzene eq
Non-Carcinogens	0	23.55	-	23.55	kg toluene eq
Respiratory Effects	.000014	.057	-	.057	kg PM2.5 eq

[139] Meijer, J. SM2011 Impact Assessment Methodology. *Sustainable Minds*. 2011. Report.
[140] Meijer, J. SM2011 Impact Assessment Methodology. *Sustainable Minds*. 2011. Report.

Table 7.58: Overall Environmental Impact of Special Recyclable Disposal at SEMASS.

Impact Category	Transport Impact	Facility Impact	Facility Credit	Total	Unit
Global Warming	76.62	27,646.98	-	27,723.59	kg CO2 eq
Acidification	25.34	12,862.91	-	12,888.25	H+ moles eq
Eutrophication	0.024	10.30	-	10.32	kg N eq
Carcinogens	0.021	79.90	-	79.92	kg benzene eq
Non-Carcinogens	443.20	45,984.87	-	46,428.076	kg toluene eq
Respiratory Effects	0.029	64.96	-	64.99	kg PM2.5 eq

SPECIAL RECYCLABLES RECYCLING IMPACTS

Figure 7.12. One of the Special Recyclables Collection Sites at the Bell Desk in Pomeroy Hall.

Special Recyclables Transportation Impacts

Special Recyclables disposed of as recycling at Wellesley College are handled differently by material. Household batteries and compact fluorescent light bulbs are both collected and transported to the Northeast Lamp Recycling Facility in East Winsor, CT in a single-unit, diesel powered truck. The total transport distance from Wellesley College to Northeast Lamp Recycling is 141.44 km. The impact factors for transport of special recyclables to Northeast Lamp Recycling were calculated in SimaPro7 using the TRACI2 method. The trucking impacts for household batteries sent to Northeast Lamp Recycling are displayed in Table F.27 Appendix

F. The trucking impacts for Compact Fluorescent Light Bulbs sent to Northeast Lamp Recycling are displayed in Table F.28 in Appendix F.

Ink Cartridges at Wellesley College are collected separately from other special recyclables and are transported to the IKon Industries Facility in Boston, MA, in a single-unit diesel powered truck. The total transport distance from Wellesley College to IKon Industries is 26.23 km. The impact factors for transport of ink cartridges to the IKon Facility were calculated in SimaPro7 using the TRACI2 method. The trucking impacts for ink cartridges sent to IKon Industries are displayed in Table F.29 found in Appendix F.

Facility Impact of Special Recyclables Disposal: Northeast Lamp Recycling

The facility impact of special recyclables disposal was calculated by multiplying the weight of waste that goes to each facility by the impact factors found in Sustainable Minds with the formula and methodology described above for Facility Impact of disposal at SEMASS. The facility impacts of household battery disposal at Northeast Lamp Recycling are displayed in Table F.30 found in Appendix F. The facility impacts of CFL disposal at Northeast Lamp Recycling are displayed in Table F.31 in Appendix F.

Facility Impact of Ink Cartridge Disposal: IKon Industries

The facility impacts for ink cartridge disposal at Ikon Industries are displayed in Table F.33 found in Appendix F.

Facility Credit for Special Recyclable Handling: SEMASS

At SEMASS, energy produced from the incineration of special recyclables is converted into electricity, some of which is used to run the facility while the rest is fed to the grid. The portion of electricity that goes to the grid displaces part of the negative impacts from conventional electricity production. We estimated the impacts avoided by calculating the impacts of producing electricity in Massachusetts, which is from a mix of fuels (coal, oil, nuclear, hydroelectric and other sources), using the TRACI2 method on SimaPro7. Since both household batteries and compact fluorescent light bulbs have zero energy content while burned,[141] they receive zero credit for incineration at SEMASS.

Facility Credit of Special Recyclables Disposal at Northeast Lamp Recycling

At Northeast Lamp Recycling (NLR), compact fluorescent light bulbs and household batteries are collected and recycled for the manufacture of new products. For CFLs, NLR uses a Balcan MP8000 to crush and break down light bulbs to recycle the glass, phosphor powder, and metal end caps found in each unit.[142] The Balcan MP8000 processes up to 5,000 CFL bulbs an hour, and allows the NLR facility to fully recycle CFL materials for their later sale and redistribution.[143] Household batteries are also collected by NLR and processed on site. Household batteries are sent to high temperature metal reclamation, where new alloys are created from heated and smelted metal material.[144] Overall, 30% of the energy and raw materials

[141] Thermal Methods of Municipal Waste Treatment; Heat Index. *C-Tech Innovation Ltd*. 2003. Report.
[142] Stephen Rorick. Employee at Northeast Lamp Recycling Facility. Personal Interview. 4 Apr 2012.
[143] Stephen Rorick. Employee at Northeast Lamp Recycling Facility. Personal Interview. 4 Apr 2012.
[144] Stephen Rorick. Employee at Northeast Lamp Recycling Facility. Personal Interview. 4 Apr 2012.

associated with battery manufacturing is saved through battery recycling at NLR, where all battery parts are effectively recycled and reused except for the battery packaging.[145]

Facility Credit for household batteries processed at NLR was calculated based on the avoided impact of manufacturing the same weight of new household batteries as how many kg are recycled by Wellesley College. The same concept of avoided impact was used to calculate facility credit for the recycling of CFLs at Wellesley College The facility credit for household batteries and CFLs processed at NLR are displayed in Table F.33 found in Appendix F. The facility credits of ink cartridge waste processed at IKon Industries are displayed in Table F.34 Appendix F.

The Per 1 kg impacts of special recyclables disposal at NLR are displayed in Table 7.59. The overall environmental impacts of special recyclables disposal at Northeast Lamp Recycling are summarized in Table 7.60.

Table 7.59: Per 1 kg Impacts of Special Recyclables Disposal at NLR.

Impact Category	Transport Impact	Facility Impact	Facility Credit	Total	Unit
Global Warming	0.049	7.27	-2.84	4.48	kg CO2 eq
Acidification	0.014	8.07	-1.58	6.50	H+ moles eq
Eutrophication	0	0.0086	-0.0016	0.0070	kg N eq
Carcinogens	0	0.047	-0.0094	0.038	kg benzene eq
Non-Carcinogens	0.000014	15.68	-3.69	11.99	kg toluene eq
Respiratory Effects	0	0.038	-0.0076	0.030	kg PM2.5 eq

[145] Stephen Rorick. Employee at Northeast Lamp Recycling Facility. Personal Interview. 4 Apr 2012.

Table 7.60: Overall Environmental Impact of Special Recyclables Disposal at NLR.

Impact Category	Transport Impact	Facility Impact	Facility Credit	Total	Unit
Global Warming	94.90	10,983.96	- 10,983.96	94.90	kg CO2 eq
Acidification	27.80	6,123.68	- 6,123.68	27.80	H+ moles eq
Eutrophication	.030	6.12	- 6.12	.030	kg N eq
Carcinogens	-	36.51	- 36.51	-	kg benzene eq
Non-Carcinogens	-	14,263.49	- 14,263.49	-	kg toluene eq
Respiratory Effects	.028	29.32	- 29.32	.028	kg PM2.5 eq

The Per 1kg impacts of special recyclable disposal at IKon are summarized in Table 7.61. The overall environmental impacts of special recyclable disposal at Ikon Industries are summarized in Table 7.62.

Table 7.61: Per 1 kg Impact of Ink Cartridge Disposal at IKon Industries.

Impact Category	Transport Impact	Facility Impact	Facility Credit	Total	Unit
Global Warming	0.0045	7.30	-191.52	-184.21	kg CO2 eq
Acidification	.0013	65.056	-65.06	.0013	H+ moles eq
Eutrophication	.0000014	0.052	-0.052	.0000014	kg N eq
Carcinogens	-	0.244	-0.24	-	kg benzene eq
Non-Carcinogens	-	293.34	-293.34	-	kg toluene eq
Respiratory Effects	.0000013	0.33	-0.33	.0000013	kg PM2.5 eq

Table 7.62: Overall Environmental Impact of Special Recyclables Disposal at IKon Industries.

Impact Category	Transport Impact	Facility Impact	Facility Credit	Total	Unit
Global Warming	9.24	388,858.84	- 388,858.84	9.24	kg CO2 eq
Acidification	2.7	132,089.91	-132,089.91	2.7	H+ moles eq
Eutrophication	.0029	106.52	-106.52	.0029	kg N eq
Carcinogens	0	496.99	-496.99	0	kg benzene eq
Non-Carcinogens	0	595,600.73	-595,600.72	0	kg toluene eq
Respiratory Effects	.0027	677.32	-677.32	.0027	kg PM2.5 eq

SPECIAL RECYCLABLES DISPOSAL IMPACTS

A comparison of the per 1 kg special recyclables waste sent to trash and recycling is displayed in Table 7.63 and the comparison of overall special recyclables waste sent to trash and recycling is summarized in Table 7.64.

Table 7.63: Per 1 kg Comparison of Ecosystem Impacts of Special Recyclables Trash vs. Recycling.

Impact Category	Per 1 kg Trash Impact	Per 1 kg Recycling Impact	Unit
Global Warming	20.45	-179.73	kg CO2 eq
Acidification	12.13	6.50	H+ moles eq
Eutrophication	0.013	.0070	kg N eq
Carcinogens	0.071	.038	kg benzene eq
Non-Carcinogens	23.56	11.99	kg toluene eq
Respiratory Effects	0.057	.0304	kg PM2.5 eq

Table 7.64: Overall Comparison of Ecosystem Impacts of Special Recyclables Trash vs. Recycling.

Impact Category	Overall Trash Impact	Overall Recycling Impact	Unit
Global Warming	27,723.60	104.14	kg CO2 eq
Acidification	12,888.25	30.5	H+ moles eq
Eutrophication	10.33	.032	kg N eq
Carcinogens	79.92	0	kg benzene eq
Non-Carcinogens	46,428.08	0	kg toluene eq
Respiratory Effects	64.70	.03039	kg PM2.5 eq

Conclusions and Recommendations

Durable Goods

Durable goods encompass an extremely broad range of materials. They include books, clothing, electronics, personal appliances, institutional durable goods, batteries, printer cartridges, compact fluorescent light bulbs, and melamine dishware. While each material has its own unique recommendations to minimize environmental impacts, some broad generalizations can be made, succinctly put: reduce, reuse, recycle, and above all, do not throw them in the trash.

Books

The majority of books' impacts occur during the disposal phase. Changing the disposal method for books can influence whether books receive a net credit or cause net impacts. Choosing reuse and recycling over incineration changes book disposal from a debit to a credit for the college. We need to keep books away from the trash in order to fully benefit.

The current disposal breakdown of books is not ideal, but not as bad as it could be. Our first priority with books should be to keep them away from the trash. Despite the high heating value of paper in an incinerator, the incinerator energy credits per kilogram could not compensate for the debits involved with transportation and incineration. Recycling and Reuse both achieved net credits for the college. Encouraging further recycling and reuse should improve the College's overall waste impact profile. Even though recycling begets a larger credit than reuse, reuse should be encouraged. Current reuse practices impose no additional impacts, whereas recycling imposes additional impacts. If we want to eliminate disposal impacts altogether, reuse is the easiest way.

Melamine Dishware

The facility impact established by the incineration of the product poses the largest environmental impact. The major problem surrounding the disposal of dishware on Wellesley campus is not that individuals are neglecting to recycle or donate the products once they no longer serve a purpose to the students, but rather that students either intentionally or unintentionally discard of fully functional dishware the dinning halls still wish to utilize. The best approach to take in reducing the impacts of melamine dishware is to work with students by investing in dorm floor dish return infrastructure. This will achieve the ultimate goal of minimizing dishware that gets thrown out, and it will only impose a small increase in responsibility to the dining hall staff. Fiscally this would also be beneficial because the campus would be saving monetary funds by purchasing less dishware each semester and by not paying for the extra weight the dishware adds to the total MSW.

The best currently available option at Wellesley College for the disposal of melamine dishware would be reuse or donation. This method is preferred to disposal by trash because it avoids the impacts of the material being incinerated, ground up, or melted down. The durability of the product makes it ideal for reuse through donation. By adopting this method the only impact would be the transportation costs of relocating the material to an association such as Good Will.

Clothes

Given that production of textiles is anywhere from 10 to 15 times more damaging per kg in all categories (Global Warming Potential, Eutrophication potential, etc.) compared to paper and cardboard and disposal via incineration is negligible, reusing textiles as opposed to creating new would avoid tremendous amounts of damage.

The Best option for the disposal of clothing is reuse or donation. Currently, unwanted clothing can be donated to the Student Aid Society's Clothing Closet, where current students are free to take clothing and donate. Since donated clothing replaces clothing that someone might have bought, reducing demand for new textile production, the effects of production can be minimized.

Institutional Durable Goods

The overall recommendation for IDGs is that they should be reused as much as possible, then recycled. To maximize the lifetime of these materials, responsible care and good upkeep are necessary. The lifetimes of these products can also be extended by refurbishing the them instead of discarding them. For instance, when the fabric wears thin, couches can be stripped and recovered instead of being thrown in the trash or recycled. IDGs covers a range of materials, from refrigerators to furniture and carpets, but all have a credit when recycled. Large electronic materials like refrigerators and microwaves are covered by the waste ban in Massachusetts because of potentially harmful chemicals like Freon and rare earth metals, meaning that they are illegal to discard in this state. Wellesley College does currently recycle these goods at Conigliaro, where valuable materials can be reused and all components are redistributed.

Personal Appliances

The biggest problematic effects for a rice cooker or similar personal appliance are encountered after the appliance has been discarded into the MSW stream. The Facility Impact of incinerating the rice cooker at SEAMASS is particularly detrimental in terms of non-carcinogenic impacts. (table 8, part 3b) This impact is 662,596,221.88 kg toluene eq for the Facility, and 662,595,607.54 kg toluene eq for the total impact. In comparison, Non Carcinogenic impacts for the extraction and manufacturing stages together is much less, coming in at 13,543.5kg toluene eq.

Given currently available options (e.g. things Wellesley already does with its waste): There are currently no recycling options for personal appliances on campus. Therefore, the first option that should be considered is reuse of the appliance if it is in working order. This could mean putting the appliance in storage over the summer, or selling or donating it if it is no longer needed. However, if the appliance is not working, the next option that should be considered is repairing it. These two options do not require incinerating the product, and by reusing or repairing the appliance there is one fewer appliance that must be made and eventually incinerated (or land-filled if it ends up being discarded elsewhere. Throwing the appliance in the MSW stream should be the last option.

Students often do sell these products on the "For-Sale" Google group, or at the "Sustainable Move-Out." However, repairing personal appliances is rare. Once a fan or rice cooker or similar appliance stops working, students tend to throw them out and simply buy a replacement. This is because few students have the knowledge and skill to fix these appliances, and they also do not know where they can conveniently and inexpensively get someone else to fix the appliances. Mini Refrigerators are already recycled, which is required by law.

Students could be given the option to "donate" broken personal appliances to the college, and the college can then repair the items and sell them at Sustainable Move-Out. Another option to look into is if the college can set up an agreement with a recycling facility where these items can be recycled. Many recycling facilities simply fix broken appliances or use then for their materials.[146] Lastly, broken personal appliances can be collected in a bin in residence halls, and then they can be used for projects or art, (for example, a rice cooker could become a flower pot). It is also possible that the parts could be used at Olin for engineering materials.

In order to repair broken appliances the college would either need to hire new workers or add to the work that the current maintenance staff already has. Also, the location for the collection bins would have to be strategically placed. Also, if we were to implement the project/art idea, we would probably have to see if the art department has any interest in using these items, (potentially for sculpture or 3-D design). If these appliances go to Olin, we would have to transport and deliver them to the college. Donating these appliances could result in reuse of the appliance, or at least several of the materials in it, and costs could also be reduced.

Electronics

According to the calculations included in this report, recycling at NLR is the stage in the electronics' life cycle that has the largest impact. However, this could be attributed to the fact that this is the most specific data of any stage in the life cycle analysis. This information is based on the data in SimaPro7 under a model of a laptop computer. While it generates impact information, the nuances of the methods and sources are not included, making it difficult to determine details like where the raw materials are extracted, how they are processed and manufactured, and what the use phase assumptions are. Many of the raw materials in electronics have such lengthy supply chains that even the manufacturers themselves are not aware of how they were extracted and what the environmental impact was.[147] The environmental impacts of extraction and manufacture phases are most likely underestimated in these calculations. Likewise, the impacts of the recycling phase are also underestimated, because these calculations only include the impacts of the materials until they leave NLR's facilities. From there they are redistributed to domestic and international buyers.[148] The effects of transportation to their final destinations and reprocessing into their final products are also not included.

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[146] Customer Service Rep from Folica Products. Personal Interview. 10 Apr 2012.

[147] Murray, R. Perhaps a New App Is Not the Answer. *Wordpress.com*. 19 Apr 2011. Web. 29 Apr 2012. <http://iphoneproj2011.wordpress.com/2011/04/19/hi-steve/>.

[148] Stephen Rorick. Employee at Northeast Lamp Recycling Facility. Personal Interview. 4 Apr 2012.

The ideal option for electronic goods is to reuse them. Next is to de-manufacture and refurbish them. Recycling and disposal are the final two options. Of the electronic waste currently produced at Wellesley College, most of it is institutional waste that gets sent to NLR. Unless these goods are broken beyond repair, the College should look into reuse methods, such as donating. If the materials are broken, recycling at NLR is a good waste disposal method. The same can be said for personal electronics. Further efforts for reusing materials should be made. If reuse is not possible, recycling is ideal. Unless a brand-specific take-back program exists, on-campus recycling is a good option and efforts should be made to increase student and faculty members' awareness of the recycling options available.

Special Recyclables

For special recyclables, the most problematic parts of the life cycle are extraction of materials, manufacturing, and disposal. Due to the various precious metals in CFLs and household batteries, the extraction and processing of those materials are extremely taxing on the environment. Additionally, the improper disposal of all special recyclables through incineration results in the release of toxic chemicals and pollutants that harm both environmental and human health. The best currently available disposal option for all special recyclables on campus is recycling. Although recycling of all special recyclables is available at Wellesley College, increased visibility of collection bins in residence halls in particular is necessary to improve the proper disposal of special recyclables by students. Ink cartridges are successfully reused and recycled by administrative users on campus, and their disposal through recycling has minimal environmental impact. However, as with all special recyclables, efforts for proper disposal of ink cartridges must be emphasized for students in particular, as students are the main users that dispose of special recyclables as trash, and therefore have the greatest ecosystem and environmental impacts as a result of their special recyclables waste.

Overall Conclusions for Durable Goods

The first step to reducing impacts is monitoring consumption in the first place. Reduction in consumption is ideal because it means that extraction impacts are avoided, the lifespan of the item is extended, and disposal impacts are postponed. One way to address this is to encourage responsible care practices. For instance, if a microwave oven can be replaced every 5 years instead of every 4 years, then the waste and impacts associated with this product decrease. In some cases, reducing the amount of a product consumed is not possible. In those cases, the buyer should take environmental impacts into account when making purchasing decisions. For example, it may not be advisable to stop replacing light bulbs, but compact florescent bulbs minimize energy usage and create less waste because they last for a longer period of time. Oftentimes these choices affect impacts of other goods as well. For example, using efficient laundry machines reduces the use phase impact of clothing. Thus, environmental impacts are reduced exponentially.

The second best choice would be reuse. For goods like clothing, books, and personal appliances that are still in working order, reuse is not difficult. Similar to reducing consumption of the material, reusing the material extends its lifespan, postpones the impacts of disposal, and reuse leads to fewer items being produced, so extraction and manufacturing impacts are reduced if not avoided. The College would do well to increase opportunities for students and faculty to reuse or redistribute their unwanted goods through events like Sustainable Move-out.

In the case of many durable goods, these recommendations are not possible. If a piece of electronics is broken beyond repair, it must be disposed of. In that case, recycling is preferable to throwing the item in the trash.

However, many of these products have long, obscure recycling processes. Although this report has investigated the materials' and products' destinations, they have only been tracked to Conigliaro, NLR, and ACB. All of those facilities further distribute their materials, oftentimes overseas, meaning that transportation impacts are high and many environmental impacts associated with recycling are not included in our calculations.

The least advisable option is disposal into the MSW stream. Waste bans in Massachusetts cover many durable goods, including institutional durable goods, personal appliances, and electronics because they contain toxins that pose health threats when incinerated or land filled. Thus, it is not only environmentally harmful to throw them away, it is also against the law.

2.8 Impact Assessment Conclusions and Findings

Our material-based estimations of the amount, characterization and impacts, of Wellesley College's waste detailed in Chapters 3 through 7, gave us a sense of the material-specific life cycle impacts of our waste stream. This chapter will consolidate the material-specific findings in order to understand larger patterns surrounding the impacts of our waste.

First, this chapter will assess the current waste situation at Wellesley College by working with impacts calculated from Wellesley's total annual waste, as estimated by this report. An assessment of our total annual waste will give the best estimate of the annual impacts of Wellesley's waste stream as it currently functions. Then, we will examine the impacts of the waste stream per 1 kg of material to allow a one-to-one comparison across material impacts. A one-to-one comparison of material impacts will uncover the relative impacts of each material category without the influence of current use patterns. Together, these assessments will allow us to prioritize recommendations for how the college can alter its current waste habits, purchasing, and waste handling decisions in the future.

CURRENT WASTE PATTERNS AND IMPACTS OF WELLESLEY COLLEGE'S TOTAL ANNUAL WASTE

In total, we estimate that Wellesley College currently produces 1,074,977.49 kg of waste each year. Figure 8.1 displays the distribution of total annual waste by material category. Organic waste accounts for over half of the total waste stream, with food alone accounting for about 42% of all waste. A quarter of total waste comes from paper. It is important to note that total waste distribution is based on weight measures, and does not account for volumetric differences between materials; for instance, 1 kg of styrofoam is much larger than 1 kg of glass.

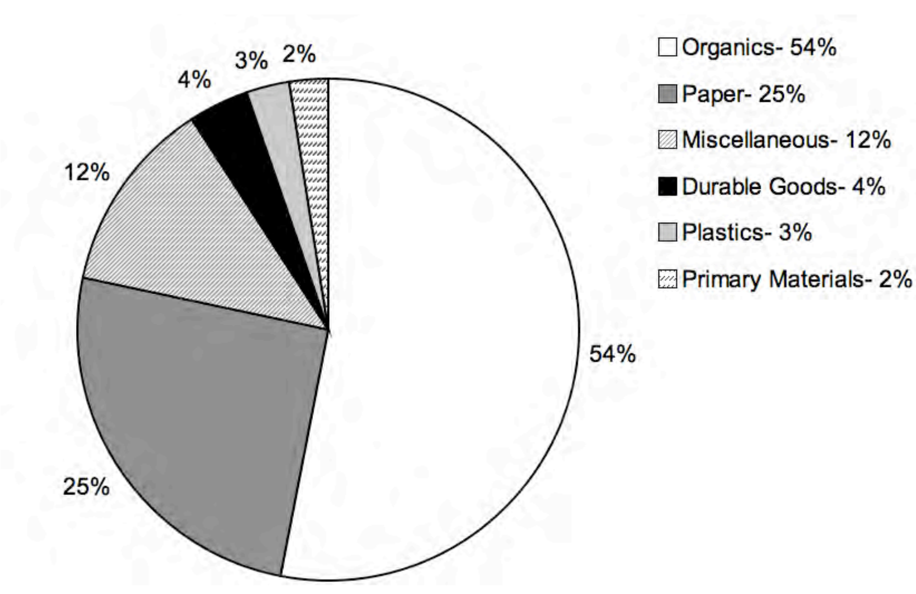

Figure 8.1: Distribution of Wellesley College Annual Waste by Material Category.

The proportions of Wellesley's waste treated as trash, recycling, special collections, and reuse is shown in Figure 8.2. A little over half the waste stream is thrown in the trash while nearly 40% is recycled. Significantly, 8.6% of our waste stream is reused-- yard waste reused as compost and mulch along with durable goods account for the entirety of the reuse category. A breakdown of the contribution to each handling option by material is shown in Table 8.1.

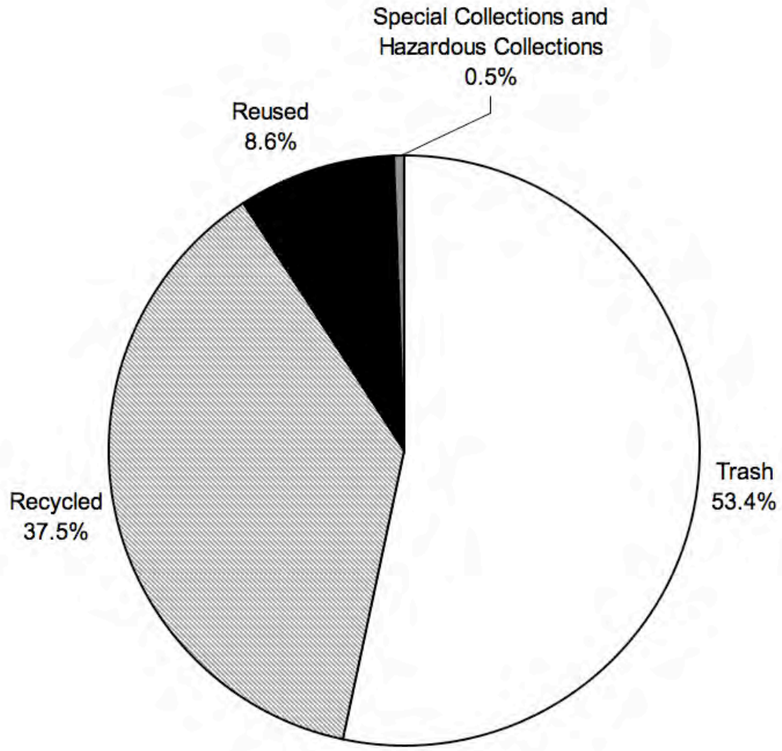

Figure 8.2: Distribution of Waste Handling for Wellesley College Annual Waste.

Table 8.1: Waste Handling By Material Category.

Material	Trash	Recycled	Reused	Special Collections and Hazardous Collections
Organics	66.51%	0.2%	33.28%	0%
Paper	60%	39%	0%	0%
Plastics	78%	19%	0%	3%
Primary Materials	66%	34%	0%	0%
Durable	49%	32%	18%	0%
Miscellaneous	0%	100%	0%	0%
Total	**53.4%**	**37.5%**	**8.6%**	**0.5%**

The distribution of waste by weight sent to primary-accepting facilities, is shown in Figure 8.3. Almost 78% of Wellesley's annual waste is sent to SEMASS for incineration. About 12% is reused and 9.4% is sent to Conigliaro Industries where it enters the recycling stream. The remaining 0.9% of waste by weight is distributed between Burke Bottle Distributor, IKon Industries, NLR and PSC for recycling, or is sent to the Regeneration Farm for composting.

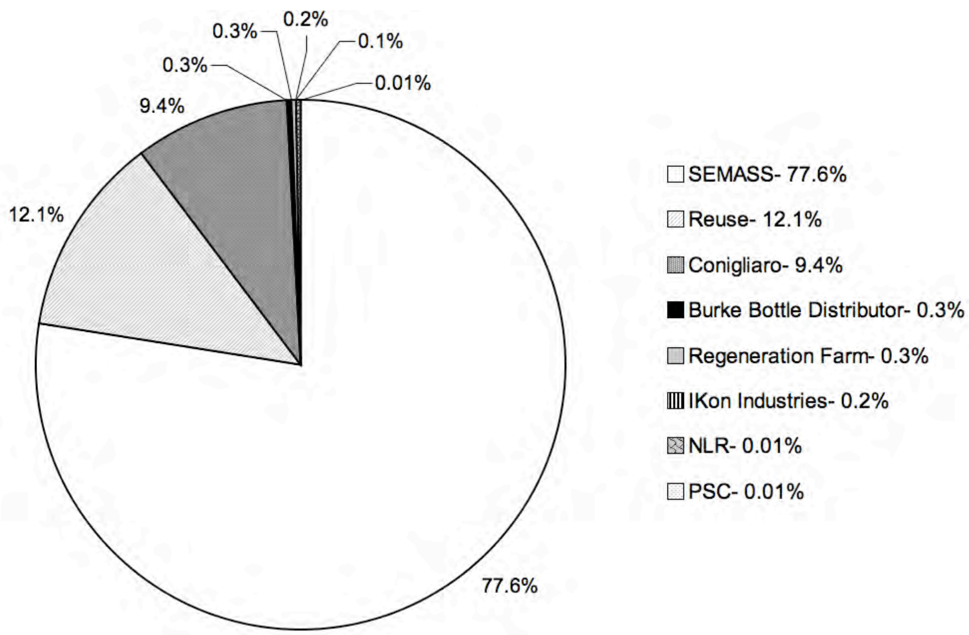

Figure 8.3: Distribution of Wellesley College Waste Sent to Primary Waste Handling Facilities. Percentages of waste sent to each facility were calculated by weight.

Incineration Impacts for Wellesley's Total Annual Waste

The cumulative impacts of Wellesley College waste sent to SEMASS as MSW were calculated for all impact factors to account for transport and facility impacts. Credit was given to account for the energy generated upon incinerating that material. Figures 8.4 through 8.9 present the relative contributions of each material according to transportation, facility impacts, and facility credit for each impact factor.

For global warming (Figure 8.4), incinerating small appliances has the largest impact, creating over 3 million kg of CO_2 equivalents. Burning food/compostable dishware creates the largest acidification impacts (Figure 8.5). Incineration of food/compostable dishware and paper result in the largest eutrophication impacts, creating about 160,000 and 130,000 kg N equivalents, respectively. Paper accounts for the majority of carcinogen impacts associated with burning Wellesley's trash, creating nearly 27,000,000 kg benzene equivalents each year. For non-carcinogen impacts, burning small appliances creates about 40 billion kg of toluene equivalence each year. Finally, the burning of miscellaneous waste accounts for the majority of the respiratory impacts of Wellesley's annual MSW.

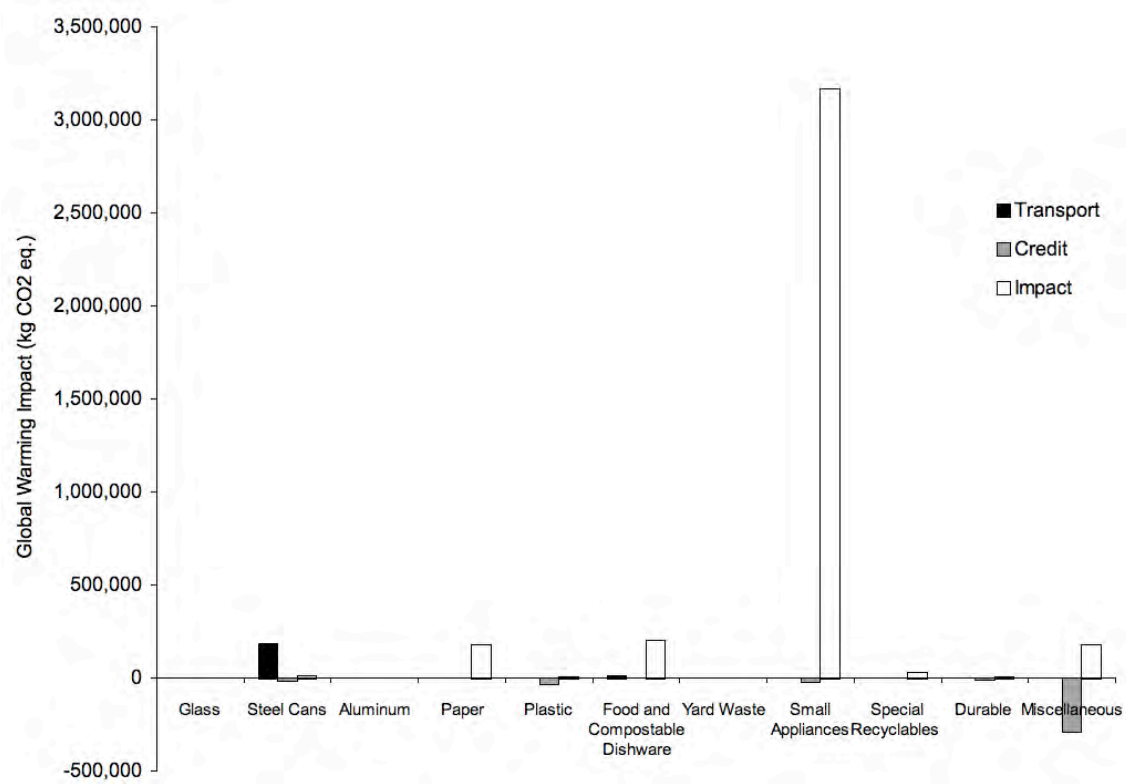

Figure 8.4: Global Warming Impacts for Total Annual Waste Sent to SEMASS by Material Category.

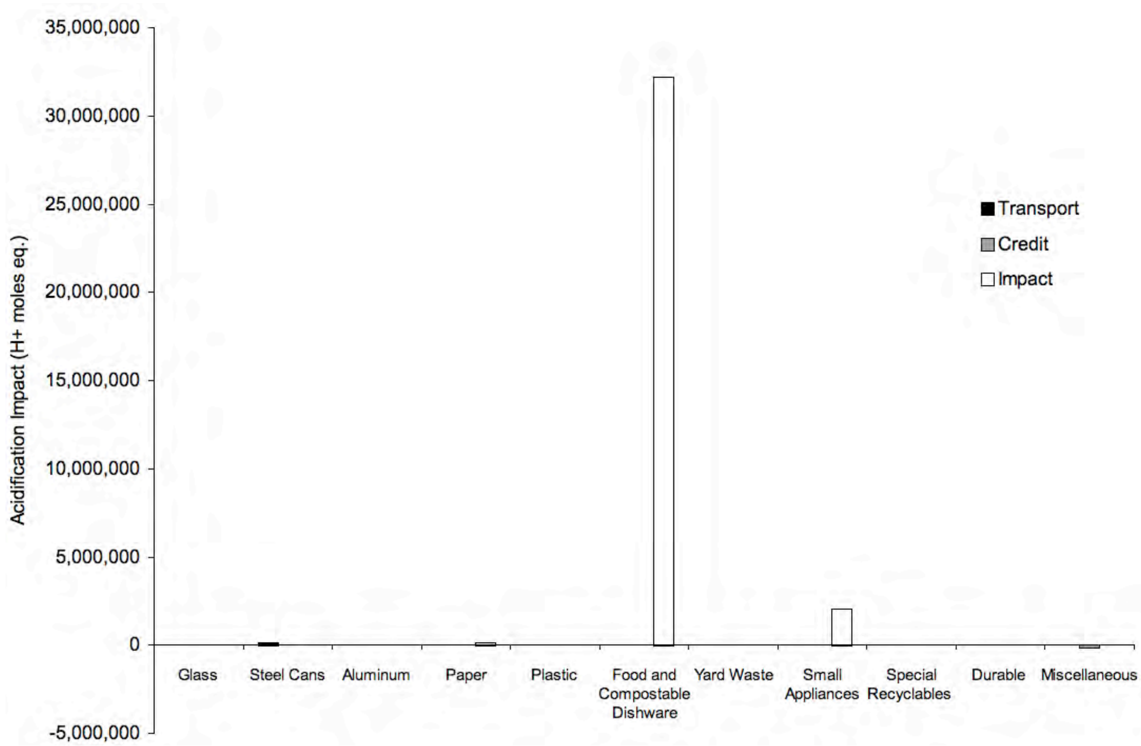

Figure 8.5: Acidification Impacts for Total Annual Waste Sent to SEMASS by Material Category.

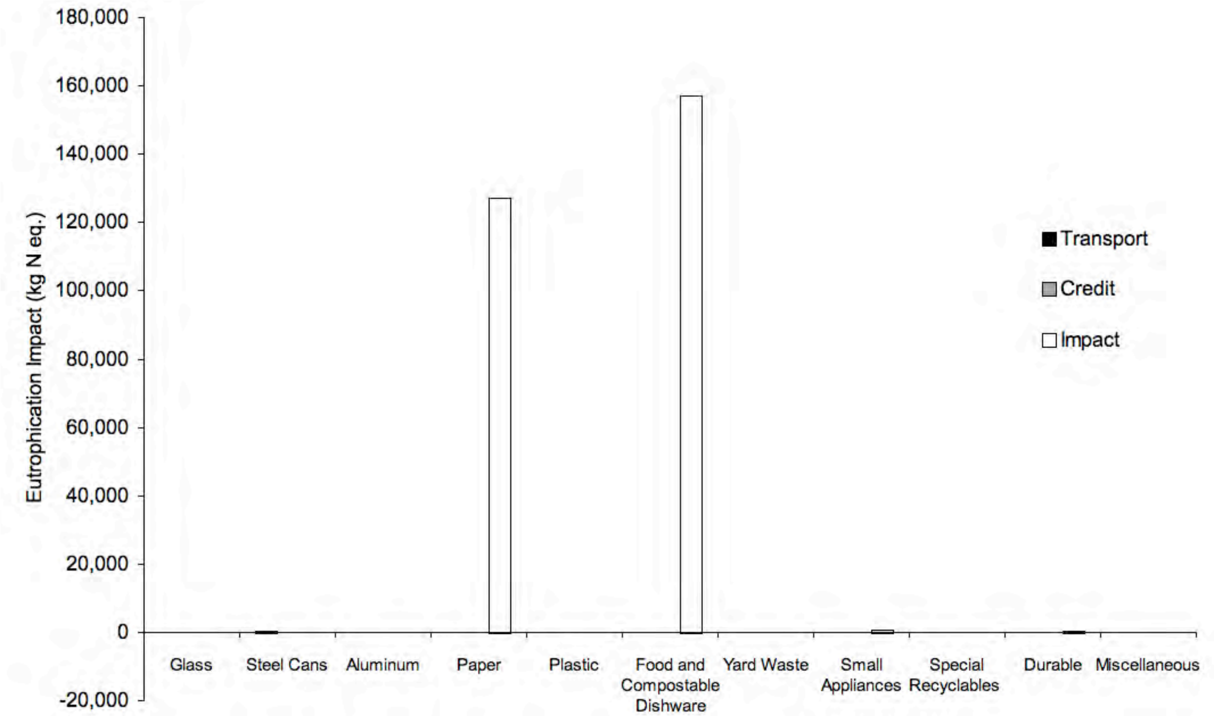

Figure 8.6: Eutrophication Impacts for Total Annual Waste Sent to SEMASS by Material Category.

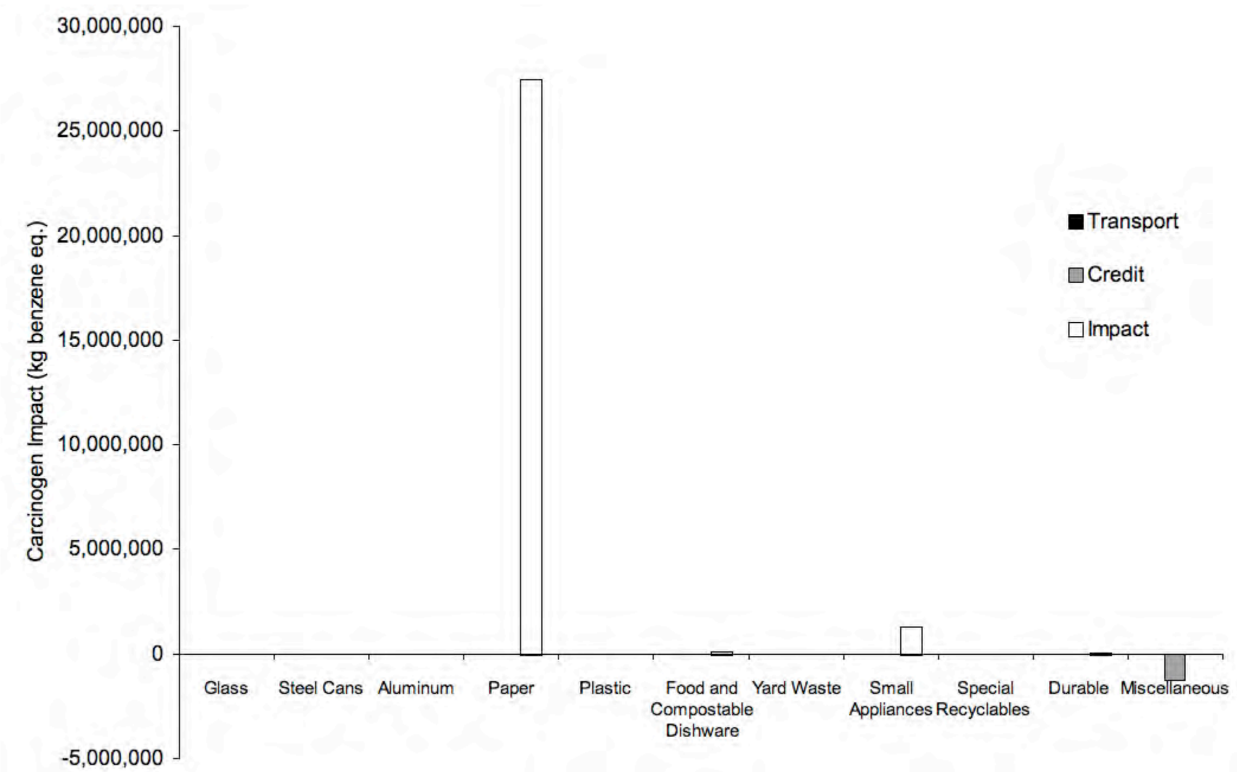

Figure 8.7: Carcinogen Impacts for Total Annual Waste Sent to SEMASS by Material Category.

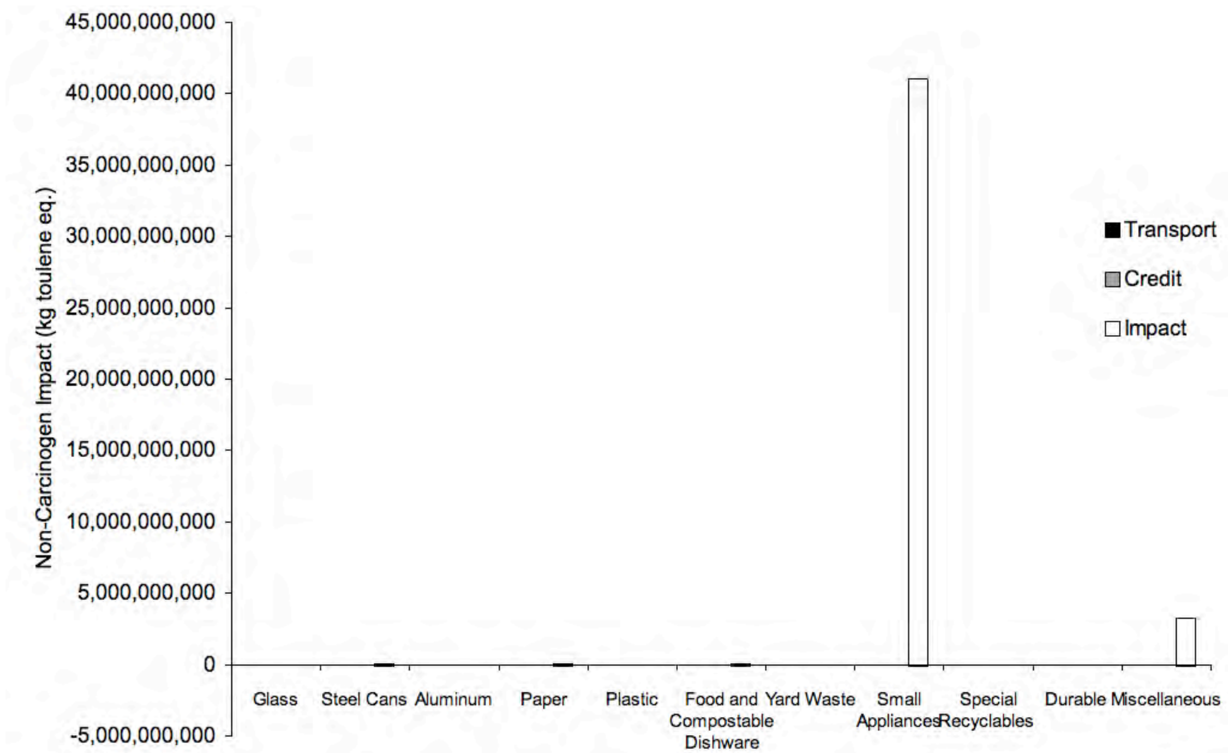

Figure 8.8: Non-Carcinogen Impacts for Total Annual Waste Sent to SEMASS by Material Category.

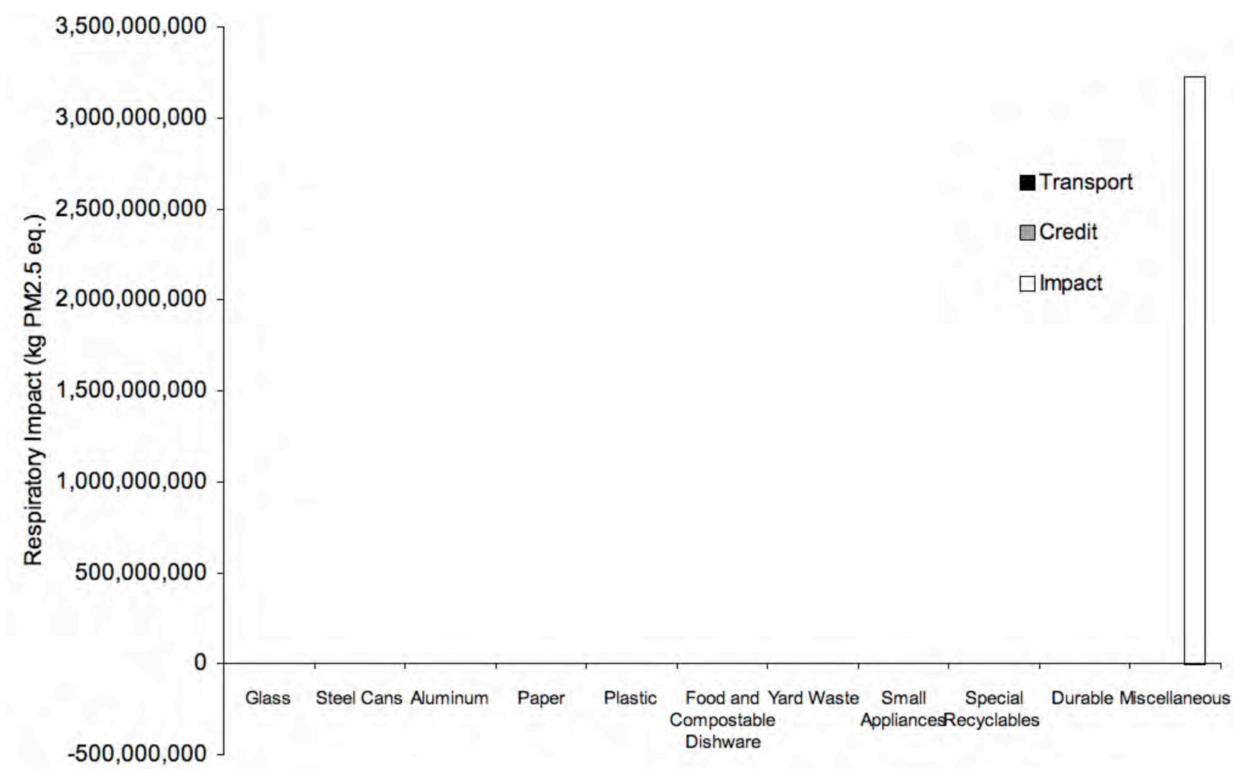

Figure 8.9: Respiratory Impacts for Total Annual Waste Sent to SEMASS by Material Category.

Recycling Impacts for Wellesley College's Total Annual Waste

About 40% of Wellesley's waste is sent to recycling facilities each year. The impacts of waste treated as recycling were calculated for all impact factors to account for transport and facility impacts for each facility involved in the recycling process. Many recycled materials are sent to a few processing locations for sorting before they reach their final processing destination, where the actual recycling takes place. For all waste treated as recycling, the recycled components are used in the creation of a secondary product. Credit was given for the impacts avoided as a result of making a secondary product instead of a new product from virgin materials. Figures 8.10 through 8.15 display the impacts for transport and processing, along with the recycling credit, by impact factor. Credit is shown as a negative value, indicating that those impacts are avoided for the particular product.

In examining the largest global warming impacts by material, transport associated with the recycling of heavy steel cans and the facility impact associated with paper recycling both produced the largest global warming impacts (Figure 8.10). However, the global warming impact of paper recycling is offset by the credit it receives for avoiding the creation of paper from virgin materials. Electronics recycling also results in a large negative global warming impact, suggesting that it is imperative for Wellesley College to recycle paper and electronics.

In terms of acidification, recycling paper produces the largest acidification impact, but this is again counteracted by the credit earned for avoiding the production of virgin paper (Figure 8.11). Recycling electronics and special recyclables also earns large credits since they contain extremely hazardous chemicals and toxins that have the potential to harm human health and the environment if improperly disposed of (through methods other than recycling). Steel cans also have a relatively large acidification impact as a result of transportation, compared to the other steps involved in their recycling process.

Glass recycling results in the largest eutrophication impacts, creating about 27,000 kg of N equivalents. (Figure 8.12). No other material has an eutrophication impact of this magnitude. Electronics and paper earn the largest eutrophication credits of all materials.

Paper recycling earns an enormous credit in avoided carcinogen impacts, diverting about 12 million kg of benzene equivalents (Figure 8.13). Recycling durable goods also earns a small carcinogen credit, and we were happy to find that there are no significant carcinogenic impacts from the recycling of any material.

Electronics recycling produces a small non-carcinogen impact during processing, but this is offset by the enormous non-carcinogen credit of nearly 55 million kg toluene equivalents (Figure 8.14). Steel can transport and paper recycling both earn relatively small non-carcinogen impacts.

Transporting steel cans for recycling produces about 150 kg PM2.5 eq., while the paper recycling process emits a little over 200 kg PM2.5 eq. (Figure 8.15). For paper, the respiratory impacts of the recycling process are offset by the enormous credit earned in offsetting virgin paper manufacture. Durable goods and electronics also earn large respiratory credits for recycling.

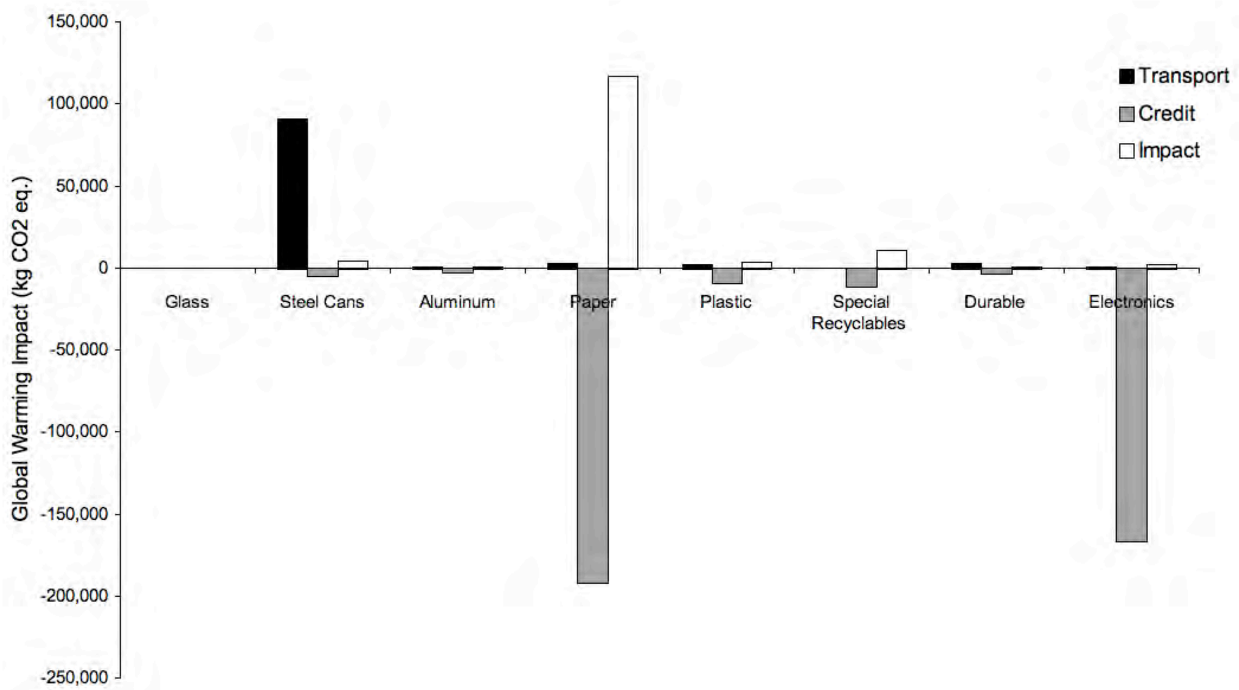

Figure 8.10: Global Warming Impacts for Total Annual Recycled Waste by Material Category.

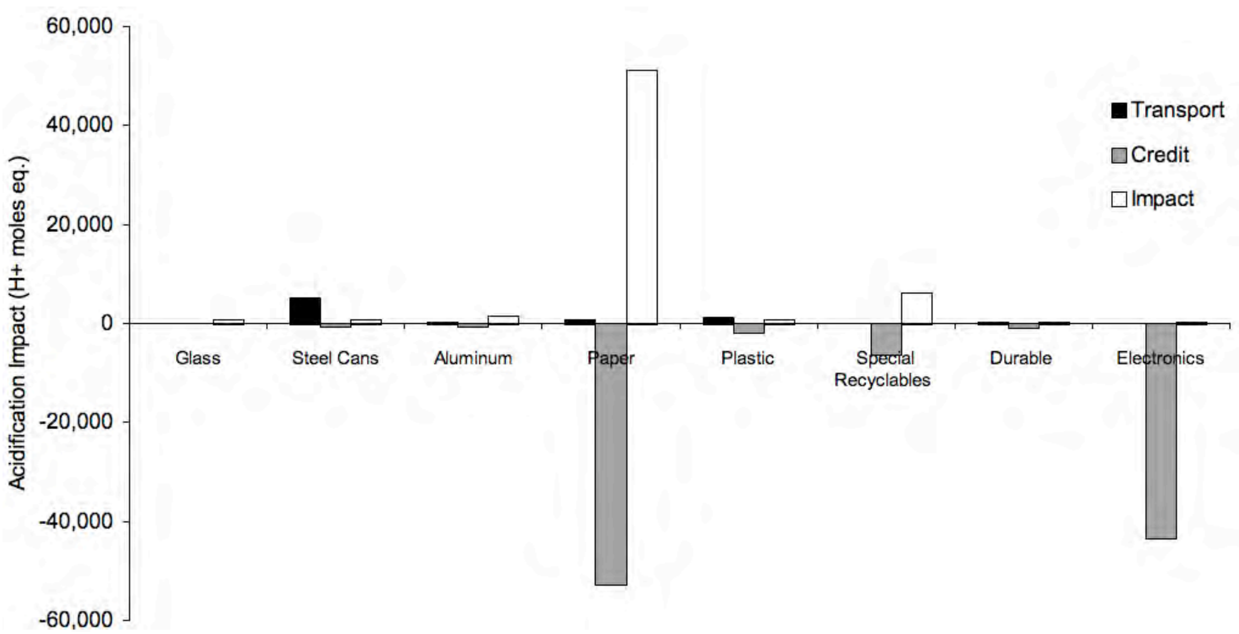

Figure 8.11: Acidification Impacts for Total Annual Recycled Waste by Material Category.

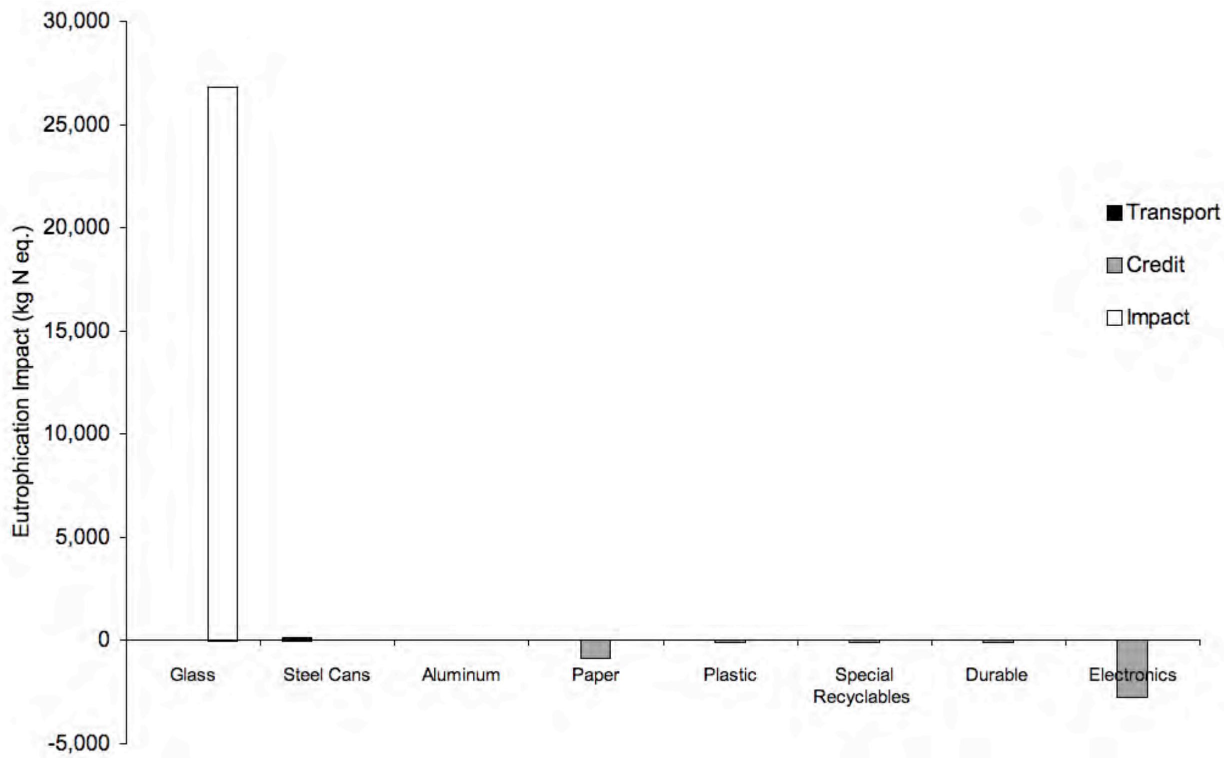

Figure 8.12: Eutrophication Impacts for Total Annual Recycled Waste by Material Category.

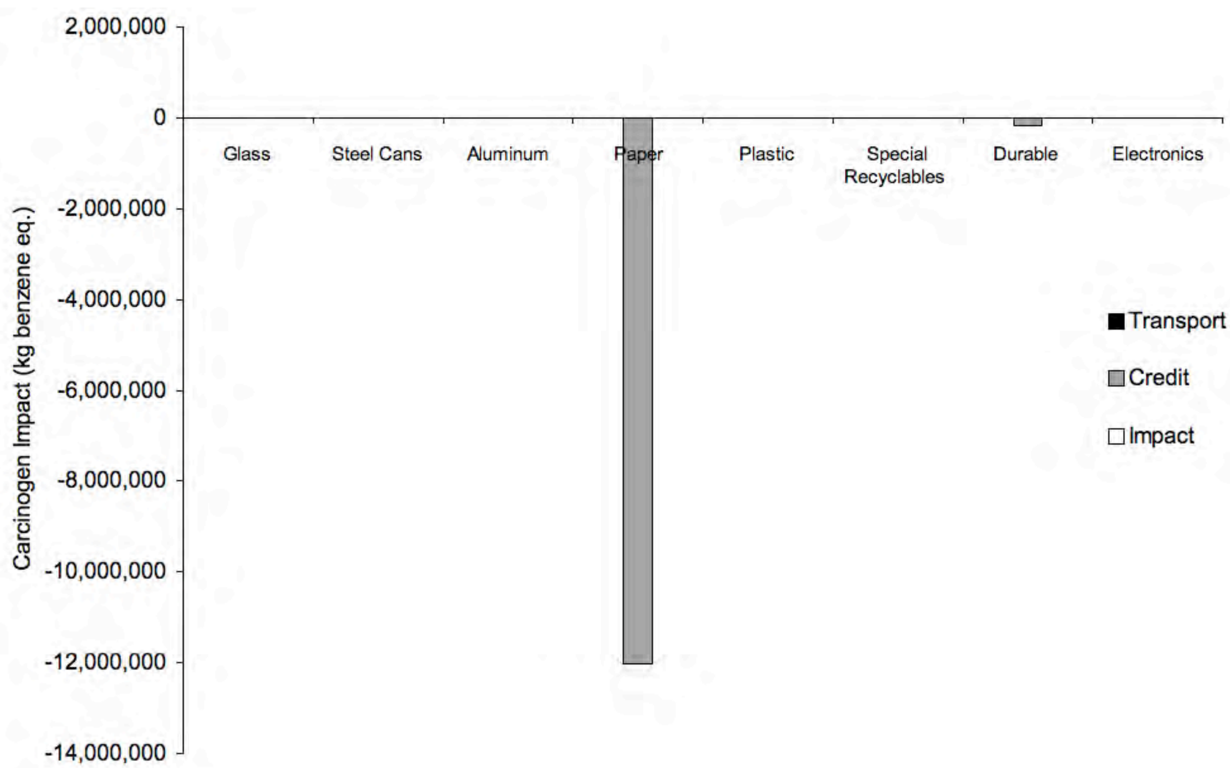

Figure 8.13: Carcinogen Impacts for Total Annual Recycled Waste by Material Category.

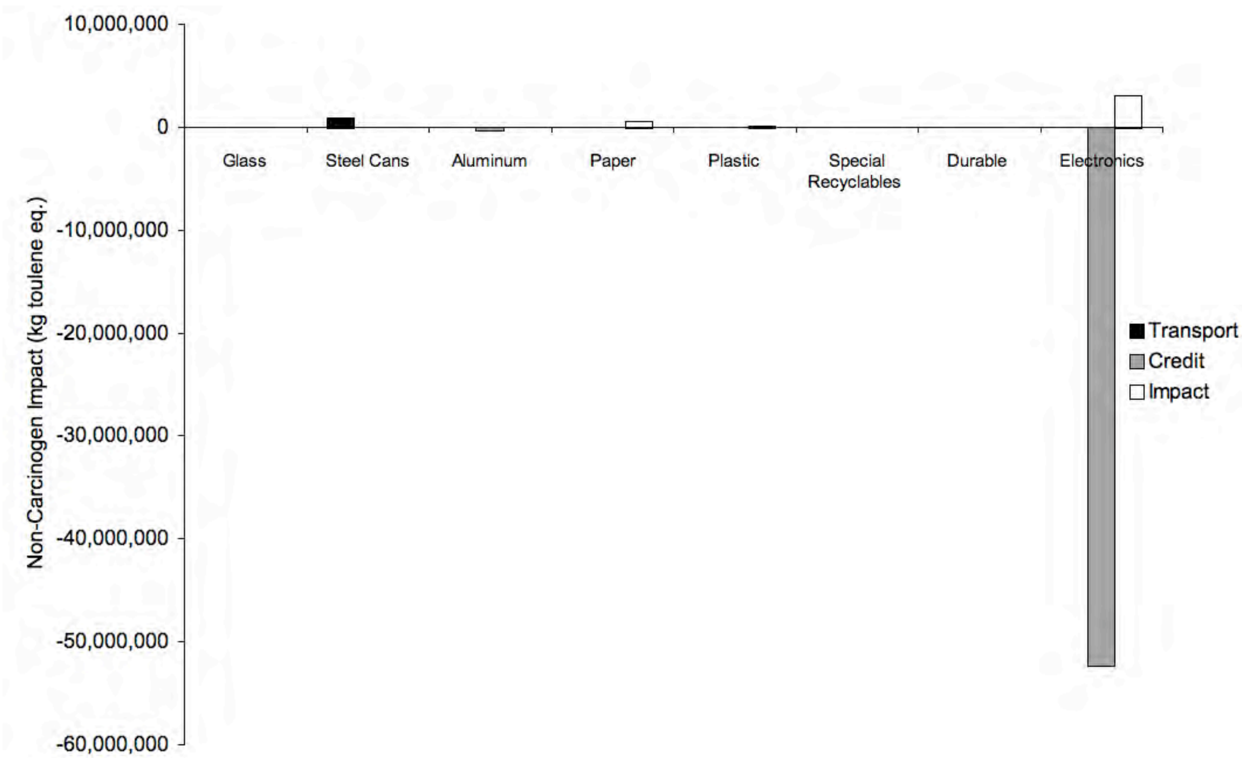

Figure 8.14: Non-Carcinogen Impacts for Total Annual Recycled Waste by Material Category.

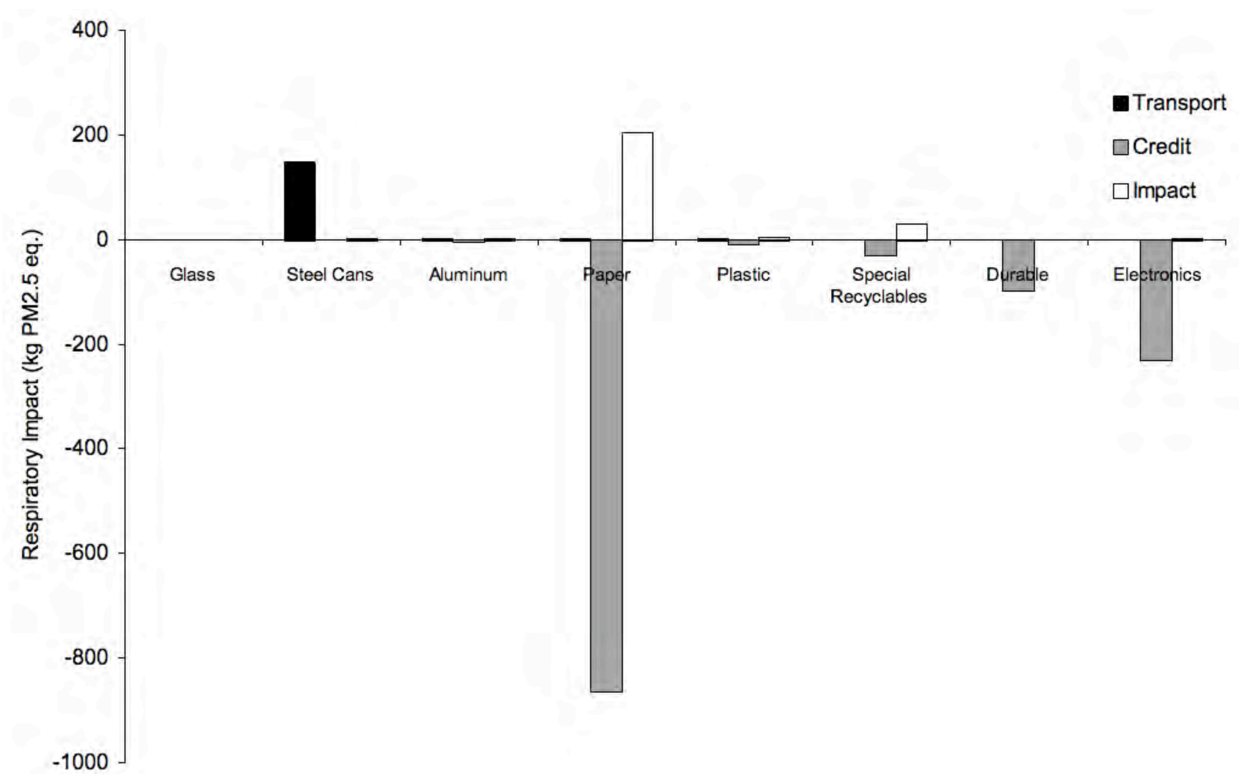

Figure 8.15: Respiratory Impacts for Total Annual Recycled Waste by Material Category.

Trash vs. Recycling Impacts for Wellesley's Total Annual Waste Stream

The cumulative impacts of Wellesley College's total annual waste (calculated by subtracting the credit from the sum of the transportation and processing impacts) for both trash and recycling are compared in Figures 8.16 through 8.21 by impact factor. These findings show the relative impacts and credits associated with the handling of a material as either trash or recycling. The following figures account for the total amount of annual waste treated as trash or recycling, and do not provide a one-to-one comparison of the two waste handling options (see section 8.2.4. for a one-to-one analysis).

Under the current system, disposal of electronics and small appliances in the trash results in the largest global warming impacts, creating over 3 million kg of CO2 equivalents each year (Figure 8.16). At a smaller magnitude, including steel cans, paper, and food/compostable dishware in the MSW stream results in relatively large global warming impacts. While recycling steel cans does result in some global warming impacts, the impacts of steel can recycling are about half of those created by the incineration of steel cans. Recycling paper and small appliances and electronics both have negative global warming impacts, making recycling the preferred waste handling option while considering global warming impact.

Incineration of food/compostable dishware carries enormous acidification impact, followed by the incineration of small appliances and electronics (Figure 8.17). Incineration of food/compostable dishware and paper creates the largest eutrophication impacts, while glass recycling also contributes to eutrophication (Figure 8.18). Burning paper has an enormous carcinogen impact, while recycling offsets carcinogen emissions (Figure 8.19). Throwing small appliances and electronics in the trash creates the largest non-carcinogen impacts of all of Wellesley's Waste (Figure 8.20). Finally, incinerating paper creates the largest respiratory impacts of all materials (Figure 8.21).

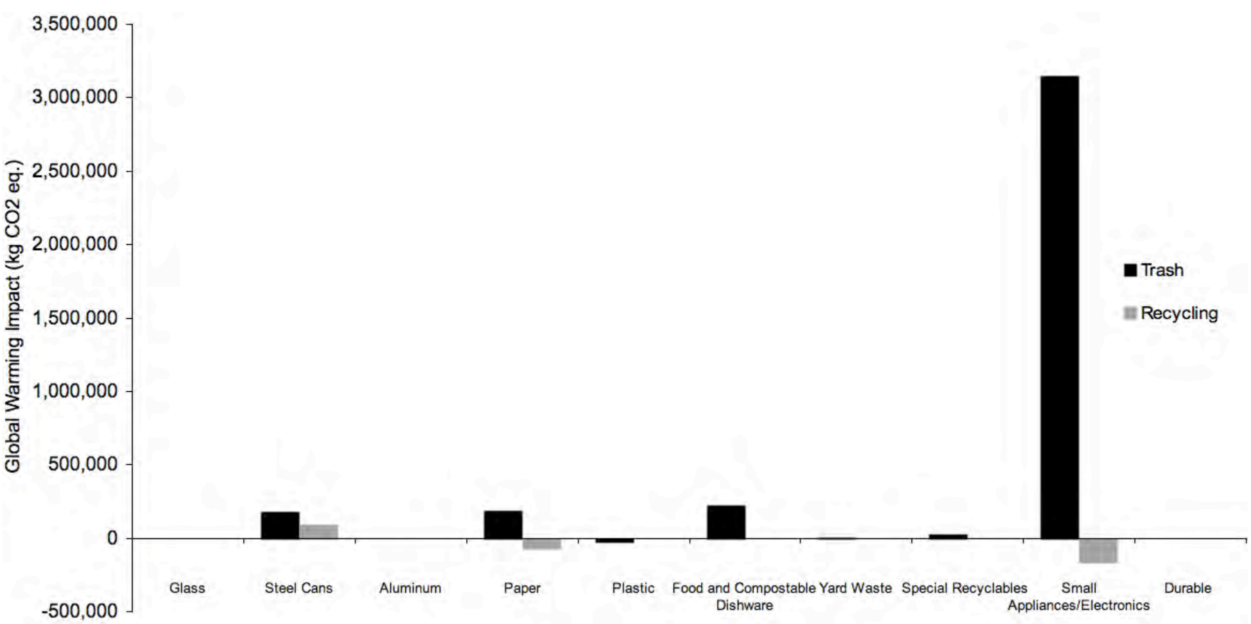

Figure 8.16: Comparative Global Warming Impacts for Total Annual Waste Handled as Trash or Recycling.

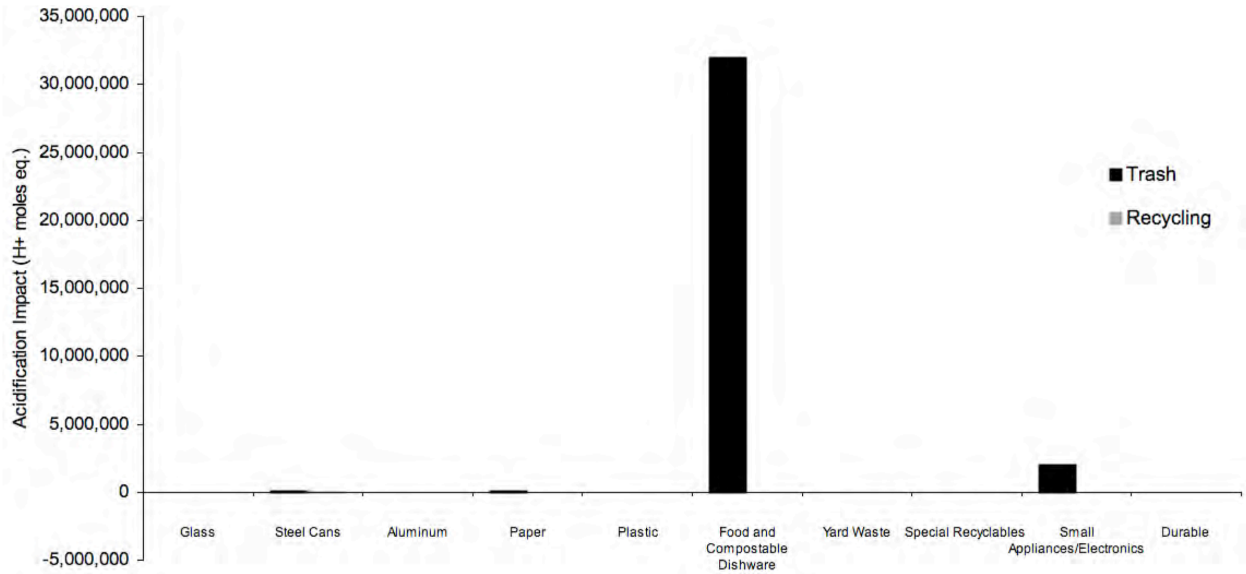

Figure 8.17: Comparative Acidification Impacts for Total Annual Waste Handled as Trash or Recycling.

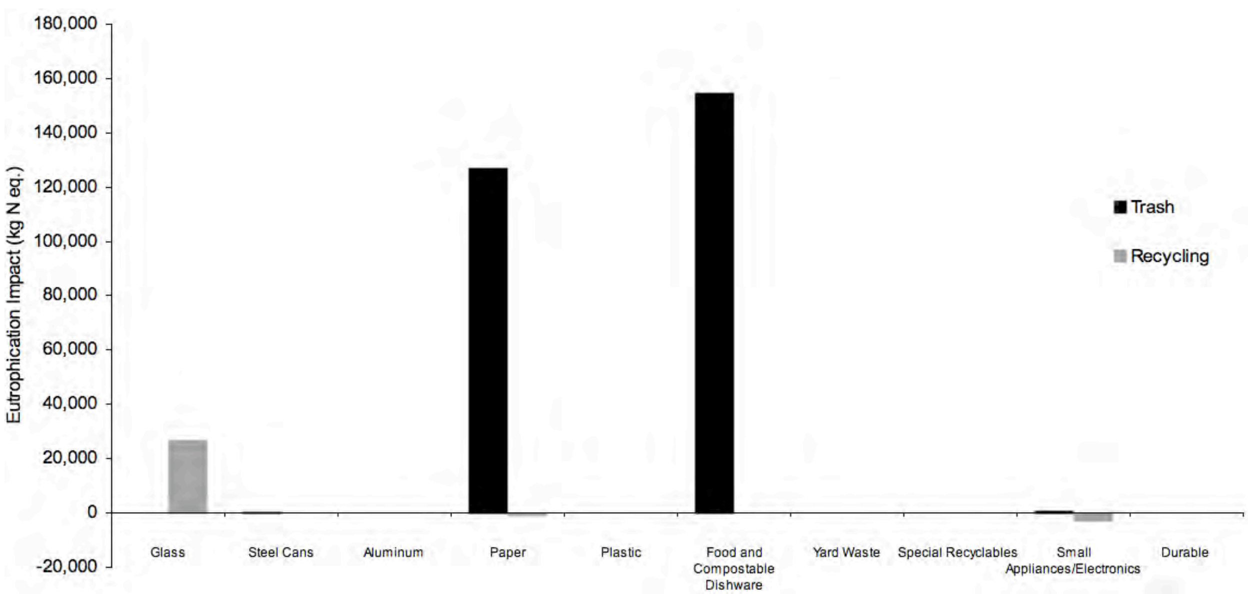

Figure 8.18: Comparative Eutrophication Impacts for Total Annual Waste Handled as Trash or Recycling.

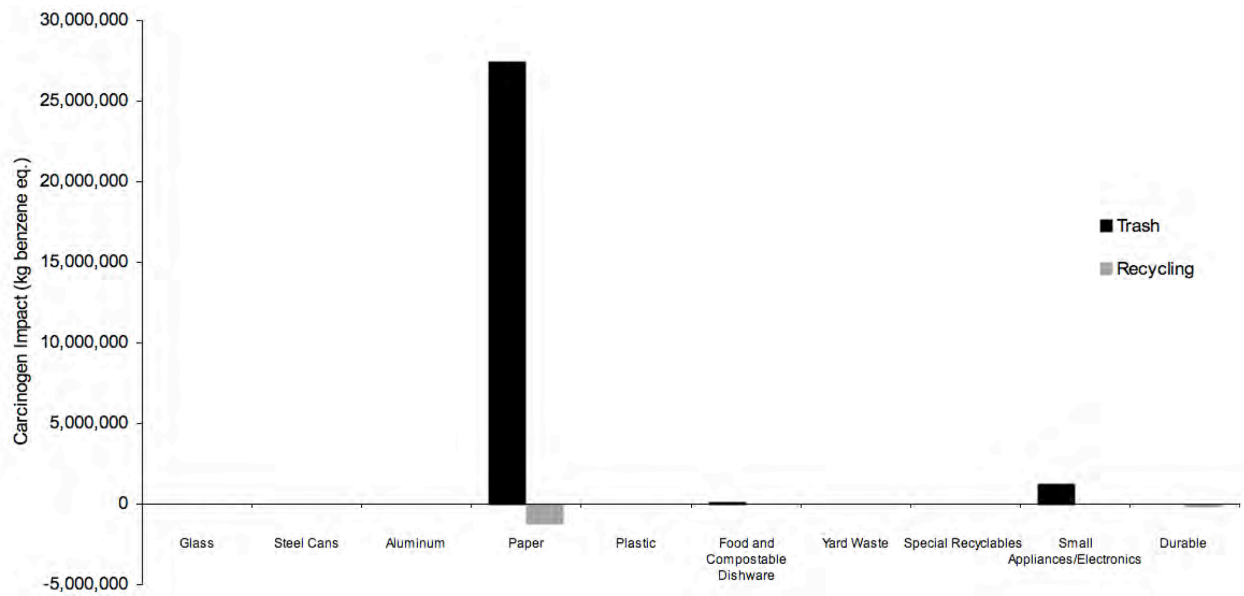

Figure 8.19: Comparative Carcinogen Impacts for Total Annual Waste Handled as Trash or Recycling.

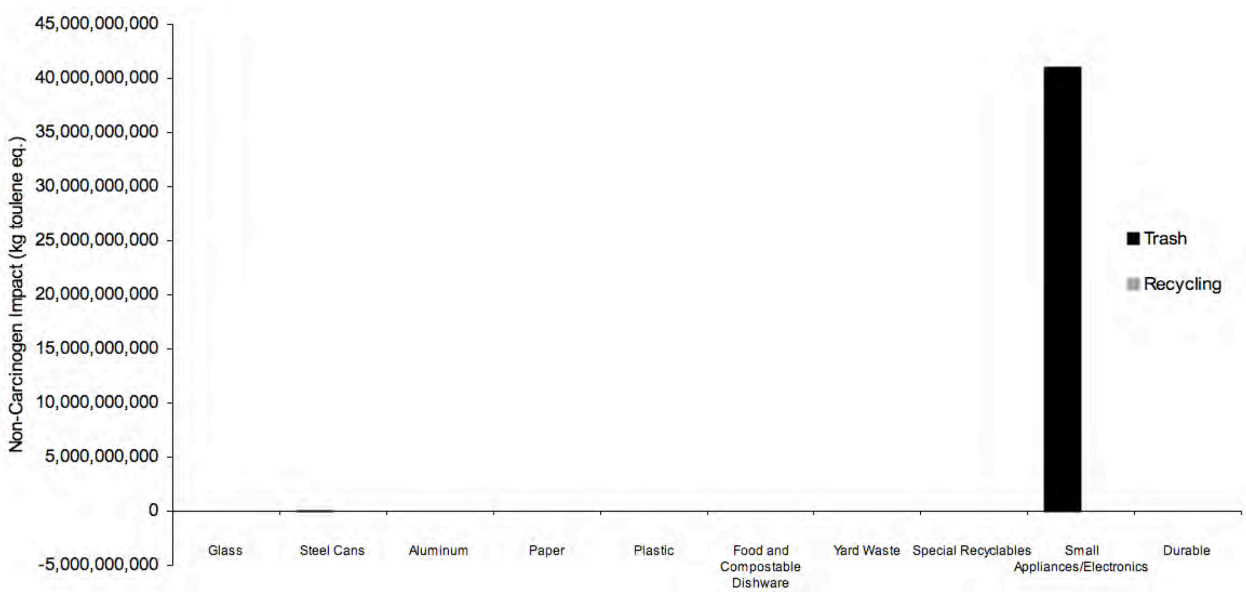

Figure 8.20: Comparative Non-Carcinogen Impacts for Total Annual Waste Handled as Trash or Recycling.

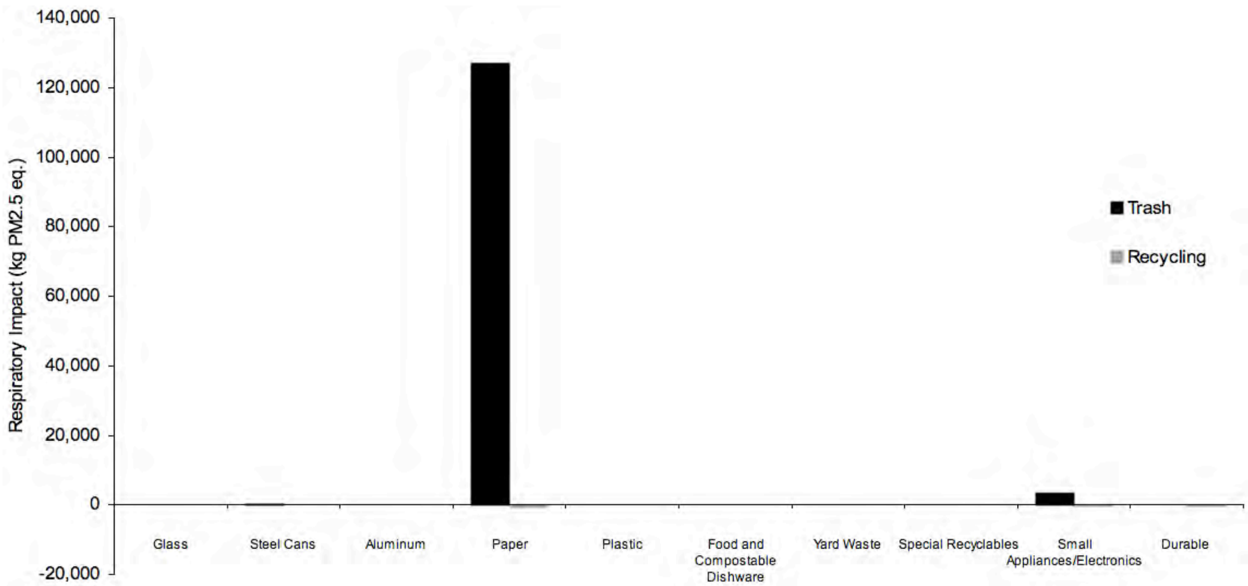

Figure 8.21: Comparative Respiratory Impacts for Total Annual Waste Handled as Trash or Recycling.

Conclusions for Wellesley College's Current Annual Waste Stream

This analysis examined the relative contributions of transportation, processing, and credit at each waste handling option, towards the overall impact of Wellesley College's waste stream. The cumulative impacts for trash and recycling were compared by material and impact factor to demonstrate the relative contributions of each waste handling option. These calculations present our best estimate of Wellesley College's current annual waste impacts.

From our assessment of the incineration impacts associated with the annual Wellesley College waste stream, we found that the college should work to limit the amount of small appliances, food and compostable dishware, and paper from entering the waste stream as trash. Of these materials, small appliances and paper are likely the easiest candidates to address, as recycling and special collection programs already exist on campus for these materials. Limiting food waste generation and reducing the amount of disposable dishware used on campus is a good way to limit the impacts of burning food waste. Reducing the amount of miscellaneous waste produced on campus is a large challenge that likely does not have a singular solution, but would require a campus-wide commitment to limiting personal waste habits.

Under the conditions of Wellesley College's current recycling stream, we found that it is most worthwhile to recycle electronics, paper, special recyclables and durable goods. Luckily, Wellesley already has recycling systems in place for these materials, but there is much room for improvement. Augmenting the College's existing recycling credits may only be a matter of increasing the recycling rates of these materials in particular.

COMPARING THE RELATIVE IMPACT CONTRIBUTIONS OF EACH MATERIAL: A PER-KILOGRAM ASSESSMENT

By comparing the relative impacts per 1 kg of each material through a life-cycle assessment, we gain a more complete understanding of the relative contributions of by material to the overall impacts of the waste stream. Through one-to-one material assessments, we can equally compare all aspects of a material's manufacturing, use, and waste handling lifecycle with other materials in the waste stream, in order to direct recommendations regarding consumption and disposal policies in the future.

Manufacturing Impacts Per 1 kg of Material

The average manufacturing impacts per 1 kg of each material category are displayed in Table 8.2 across impact categories. These values present the "cradle-to-gate" impacts associated with the manufacture of each material, including the raw material extraction impacts and processing, but not transportation to the consumer.

Table 8.2: Average Manufacturing Impacts per 1 kg from Material Categories.

Material	**Global Warming** (kg C02 eq.)	**Acidification** (H+ mole eq.)	**Eutrophication** (kg N eq.)	**Carcinogen** (kg benzene eq.)	**Non-Carcinogen** (kg toluene eq.)	**Respiratory** (kg PM2.5 eq.)
Primary Materials	1.39	0.28	0.00011	0.072	83.13	0.0010
Paper	0.87	0.21	0.071	0.0025	53.048	0.0016
Plastics	2.81	1.087	0.083	22.15	3.20	0.0025
Organics	2.34	0.53	0.013	0.0071	70.80	0.012
Durable Goods	5.49	1.44	0.029	10.52	126.10	0.0063

The additional ecosystem impacts associated with the manufacture of our materials are displayed in Figure 8.22. These values, which fall on a scale of 0-5, are a composite measure of the approximated erosion, permanent land disruption, water use, resource use, and biodiversity disruption impacts of the material manufacture, where a higher score indicates more severe impacts.

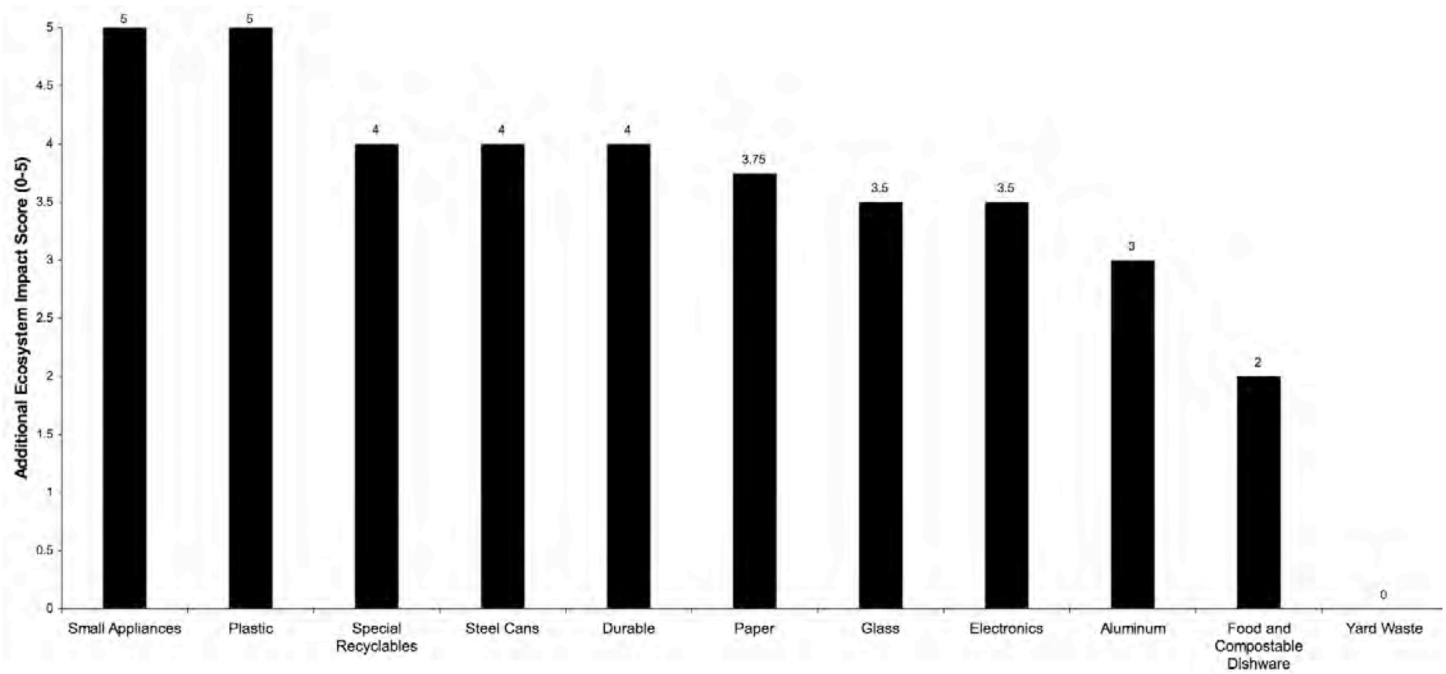

Figure 8.22: Average Additional Ecosystem Impacts for Manufacture of Materials.

Incineration Impacts per 1 kg of Material Waste

The impacts of incinerating 1 kg of each material are displayed in Figures 8.23 through 8.28 for all impact categories. In providing a one-to-one impact ratio, these values can be used to compare impacts across each material.

For global warming, incineration of small appliances, distantly followed by incineration of special recyclables and yard waste, produces the largest global warming impacts of all materials (Figure 8.23). Similarly, incinerating small appliances results in the largest acidification impacts, followed by food/compostable dishware, and special recyclables (Figure 8.24). Incinerating small appliances, paper, durable goods, and food/compostable dishware produce between 0.5-1 kg N eq. (Figure 8.25). Plastics incineration earns an eutrophication credit of over 2 kg N eq. per kg. Incinerating durable goods, paper, small appliances, and special recyclables is associated with the largest carcinogen impacts (Figure 8.26). Small appliances result in over 2.5 million kg of toluene eq. emissions per 1 kg incinerated (Figure 8.27). Finally, durable goods incineration is the largest contributor to respiratory impacts, followed by paper, small appliances, and special recyclables (Figure 8.28).

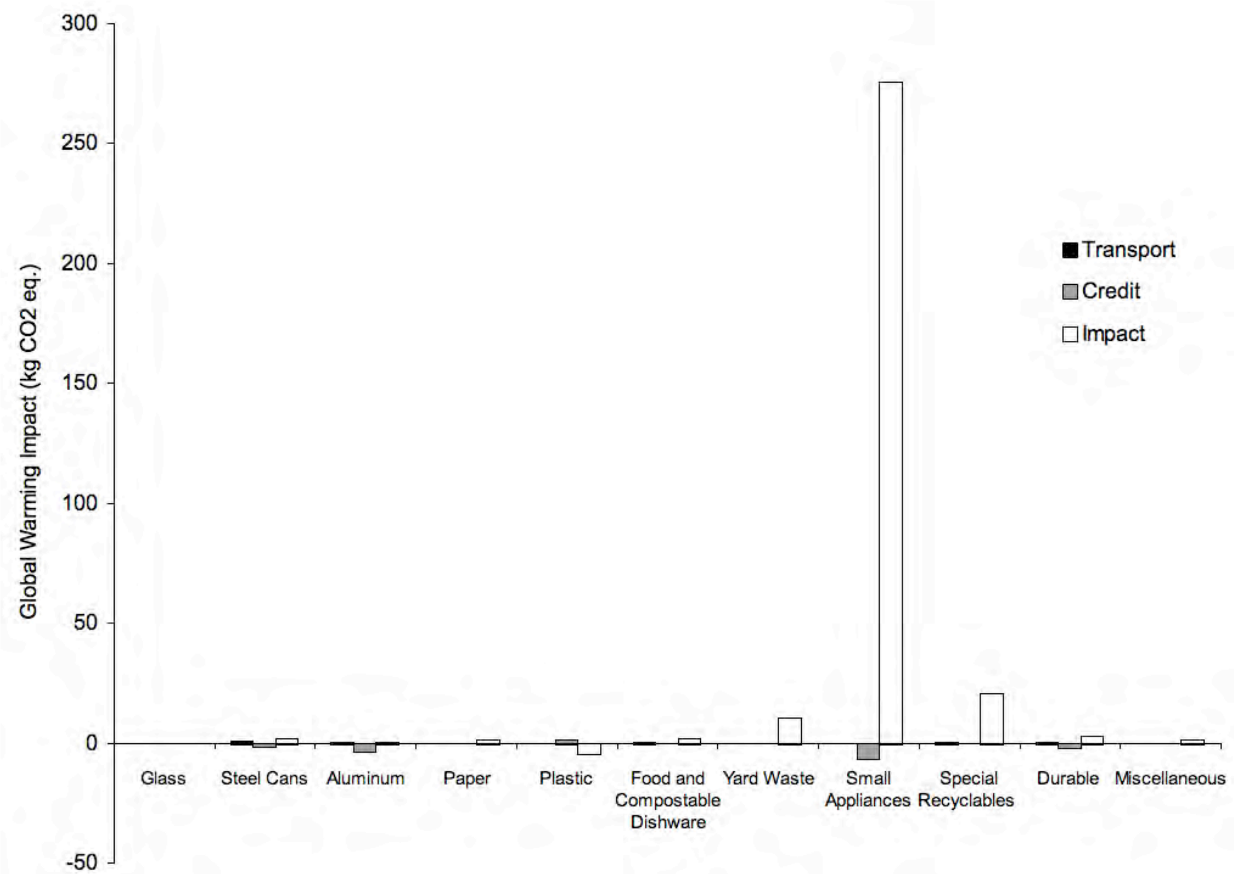

Figure 8.23: Global Warming Impacts Per 1 kg of Waste Sent to SEMASS by Material Category.

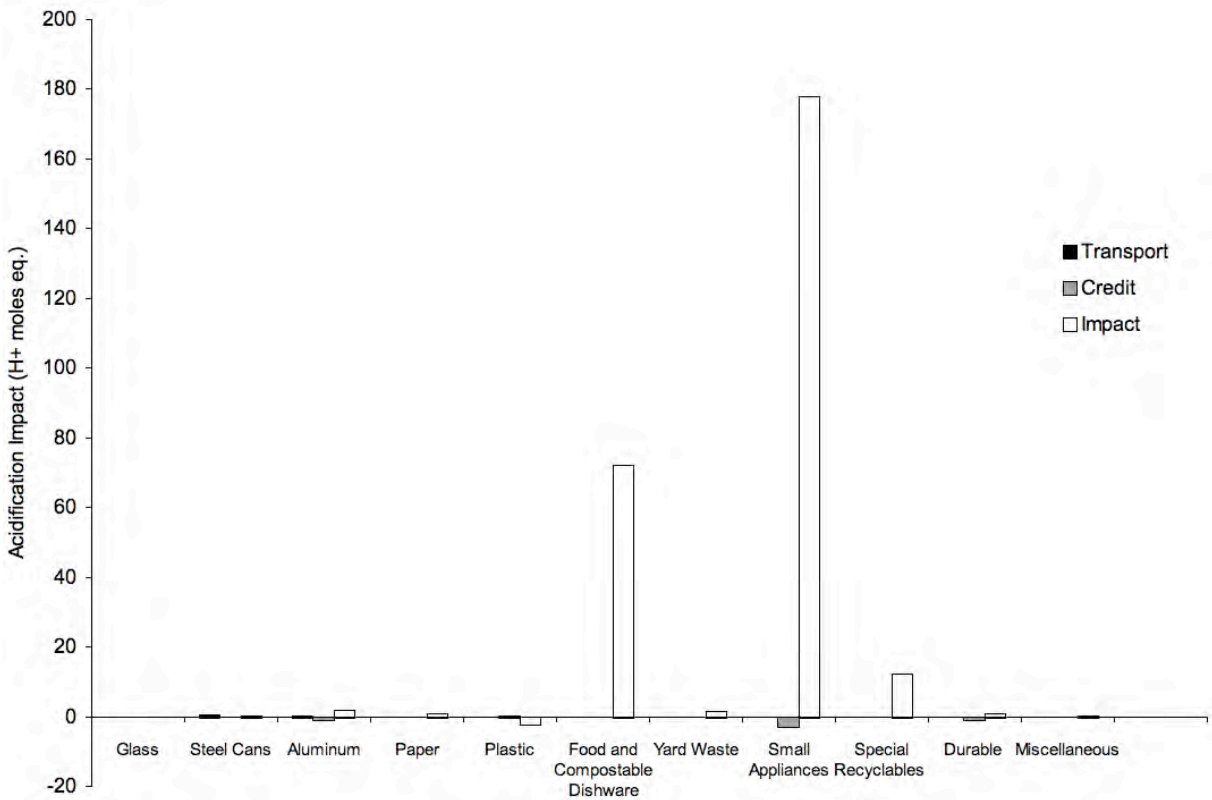

Figure 8.24: Acidification Impacts per 1 kg of Waste Sent to SEMASS by Material Category.

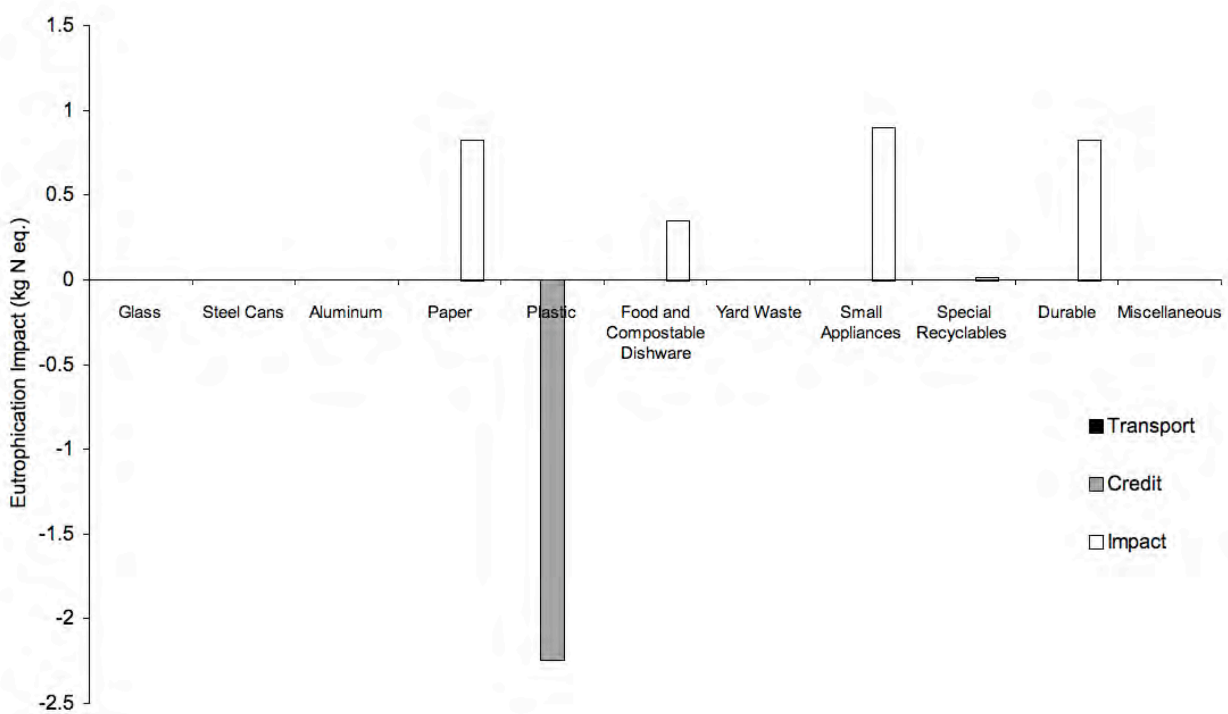

Figure 8.25: Eutrophication Impacts per 1 kg of Waste Sent to SEMASS by Material Category.

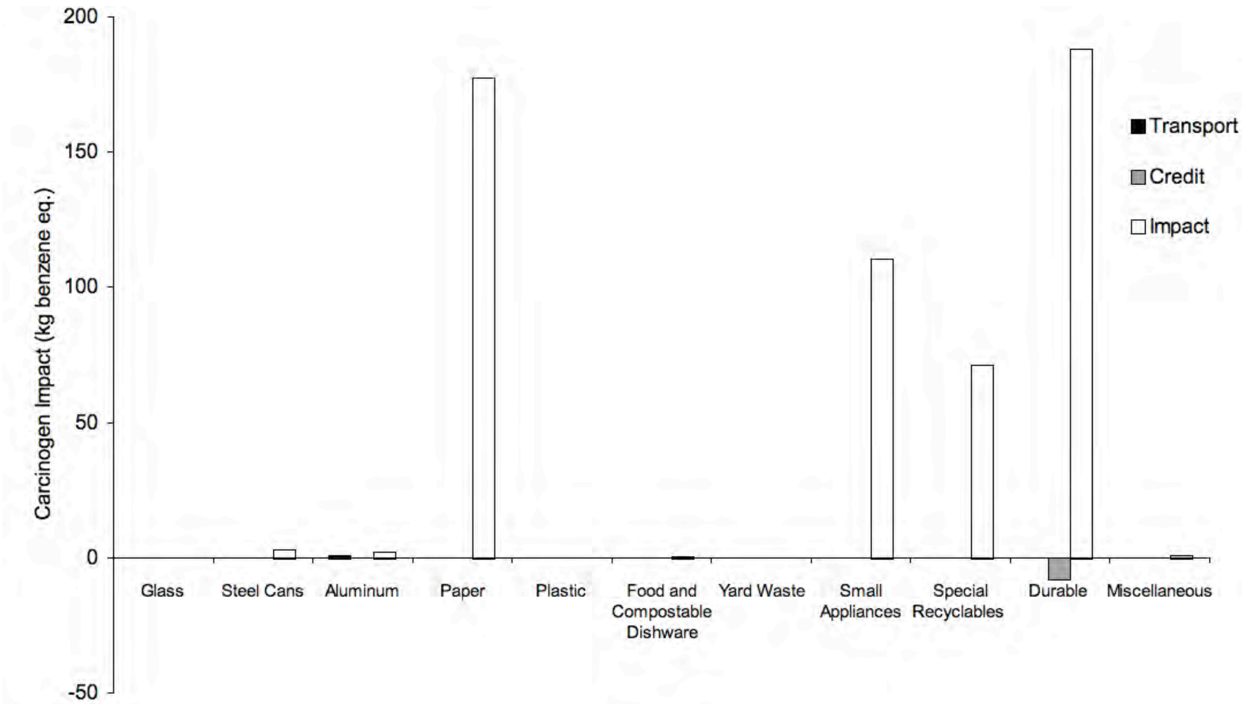

Figure 8.26: Carcinogen Impacts per 1 kg of Waste Sent to SEMASS by Material Category.

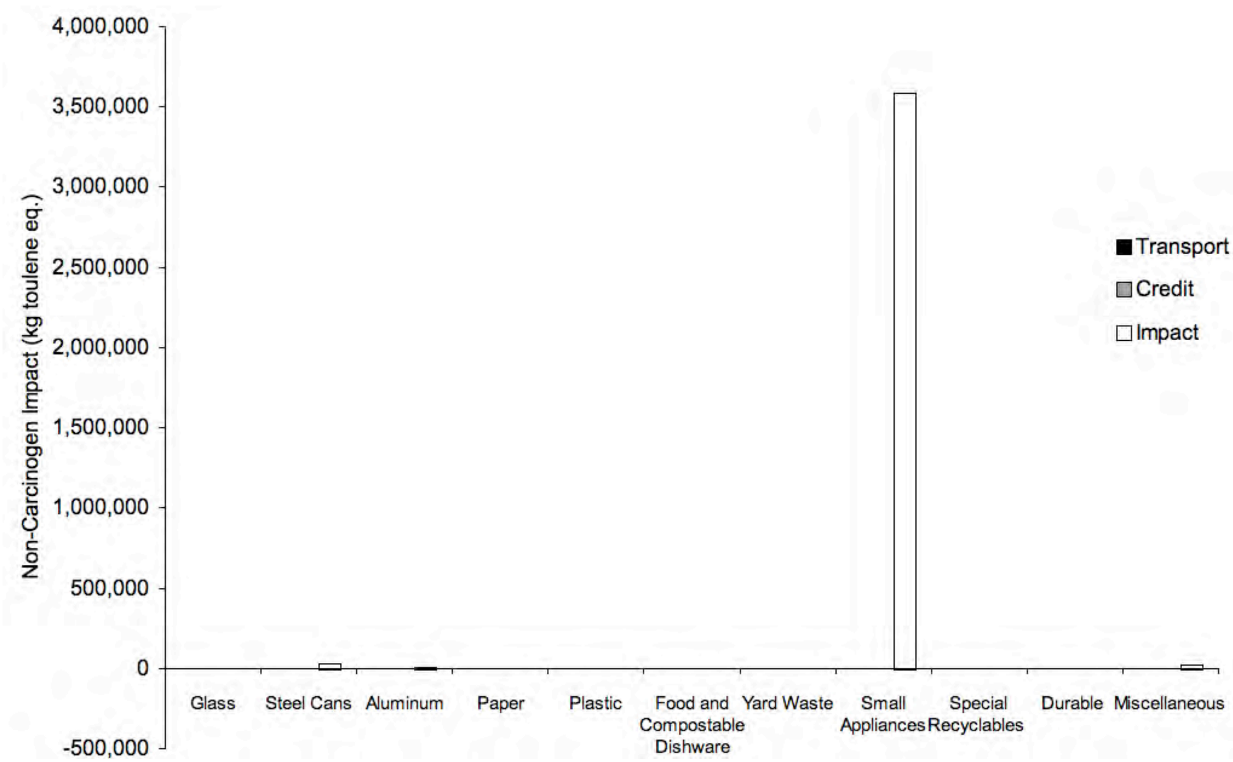

Figure 8.27: Non-Carcinogen Impacts per 1 kg of Waste Sent to SEMASS by Material Category.

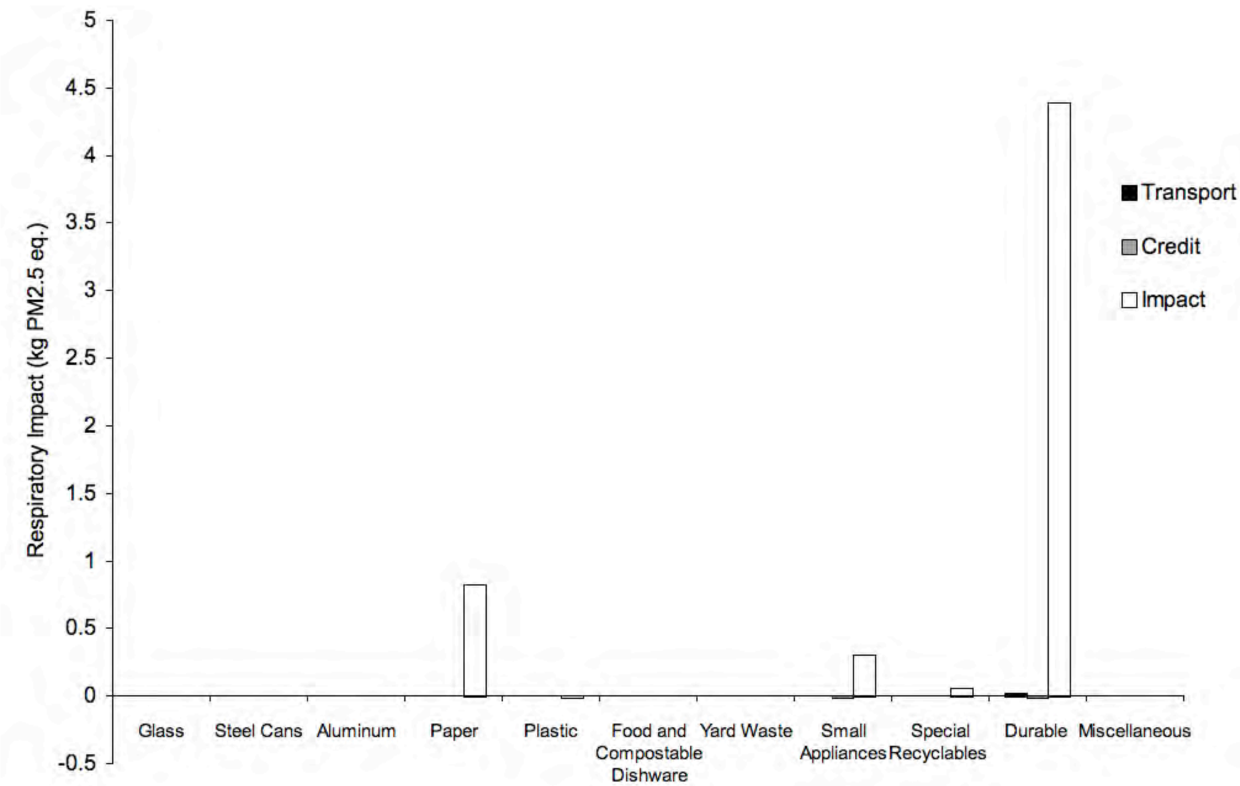

Figure 8.28: Respiratory Impacts per 1 kg of Waste Sent to SEMASS by Material Category.

Recycling Impacts Per 1 kg of Material

Comparing the impacts of recycling 1 kg of material across material categories allows us to understand the relative credit and debits associated with recycling certain products. If the credit is larger than the impacts or transportation and processing, then it is favorable to recycle the material. Figures 8.29 through 8.23 display the impacts and credits of recycling 1 kg of each material.

For global warming, there are small impacts for the transportation of steel cans, aluminum, plastic, and durable goods during the recycling process (Figure 8.29). Similarly, there are global warming processing impacts for steel cans, aluminum, paper, plastic, and special recyclables. Electronics recycling produces the largest credit, avoiding about 35 kg of CO_2 eq. per 1 kg.

There is a large acidification impact associated with processing 1 kg of special recyclables, while electronics recycling earns a large acidification credit per 1 kg (Figure 8.30). Glass recycling carries a large eutrophication impact, producing about 35 kg N eq. per kg (Figure 8.31). Recycling durable goods and paper avoids about 120 and 80 kg benzene eq., respectively, for carcinogen impact (Figure 8.32). Electronics are the largest player in avoiding non-carcinogenic impacts, gaining nearly 11,000 kg toluene eq. per kg (Figure 8.33). For respiratory effects, special recyclables processing carries the largest impact, while durable goods, electronics, paper, and aluminum earn respiratory credits (Figure 8.34).

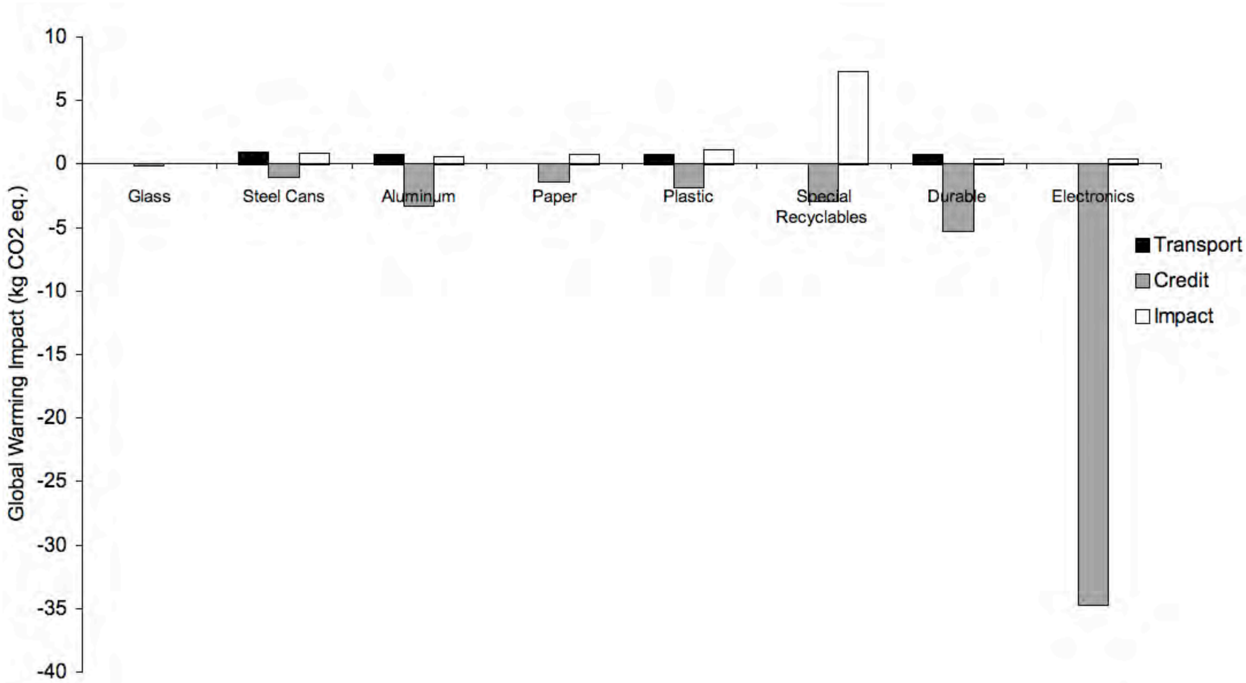

Figure 8.29: Global Warming Impacts per 1 kg of Recycled Waste by Material Category.

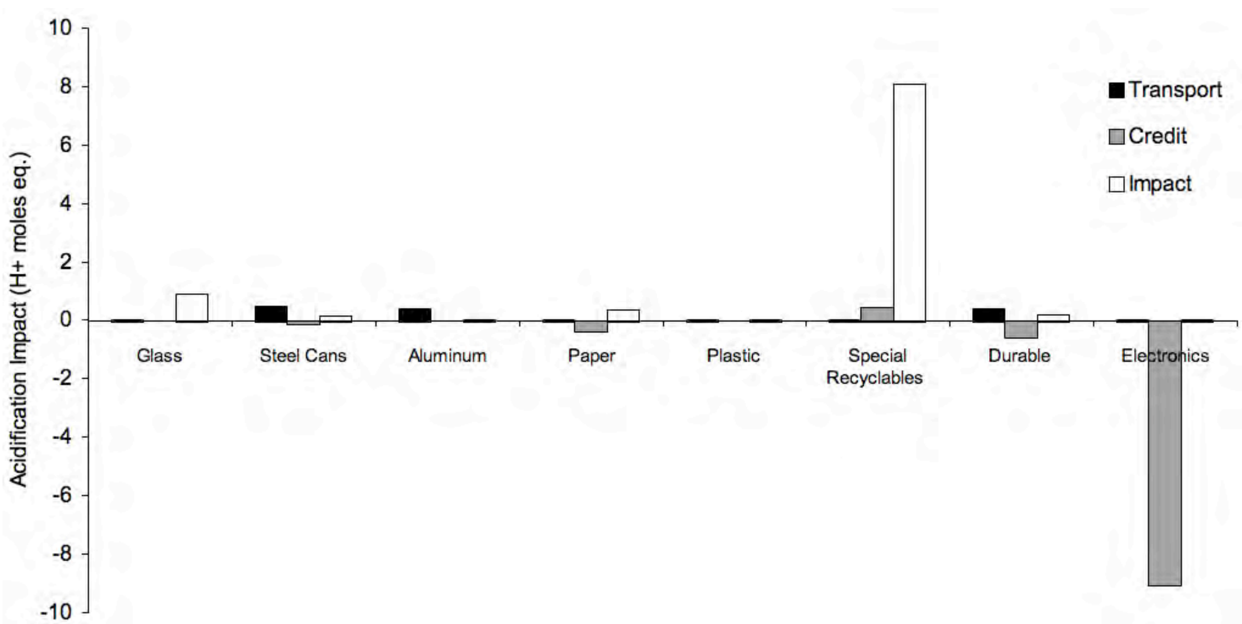

Figure 8.30: Acidification Impacts per 1 kg of Recycled Waste by Material Category.

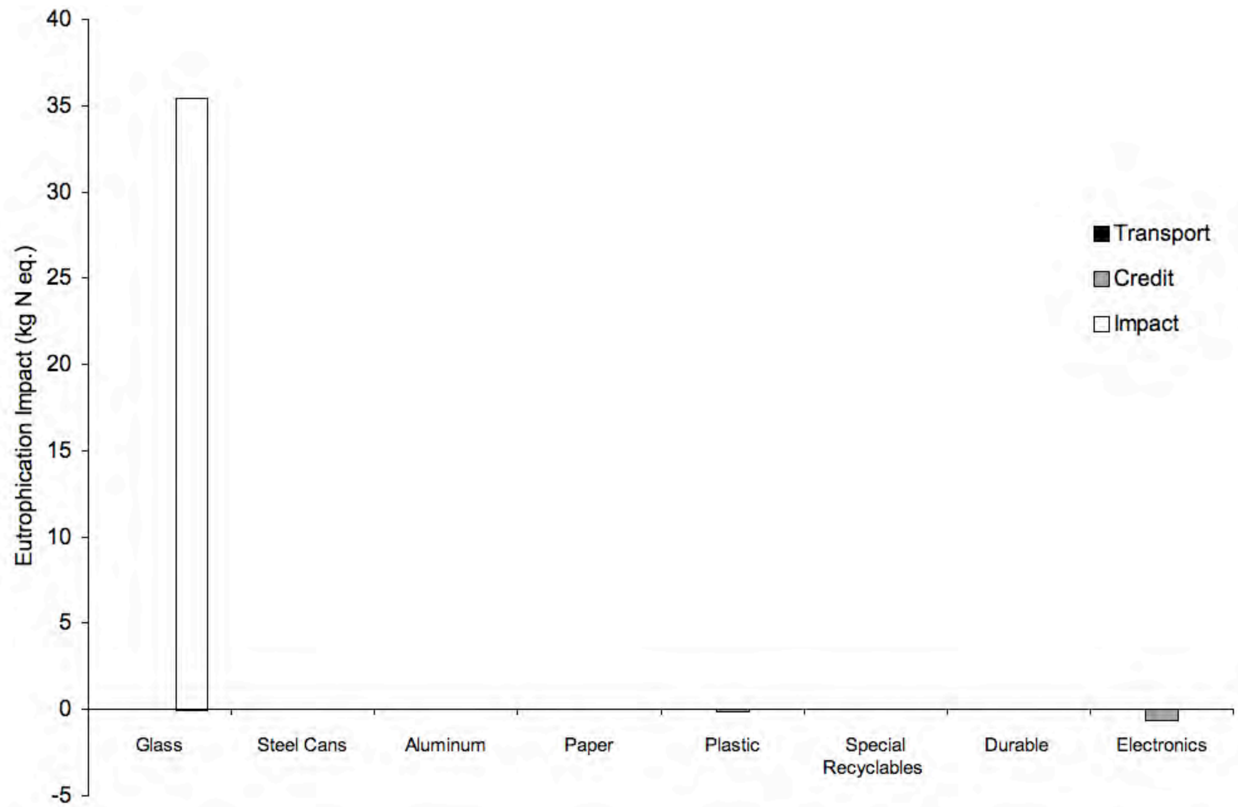

Figure 8.31: Eutrophication Impacts per 1 kg of Recycled Waste by Material Category.

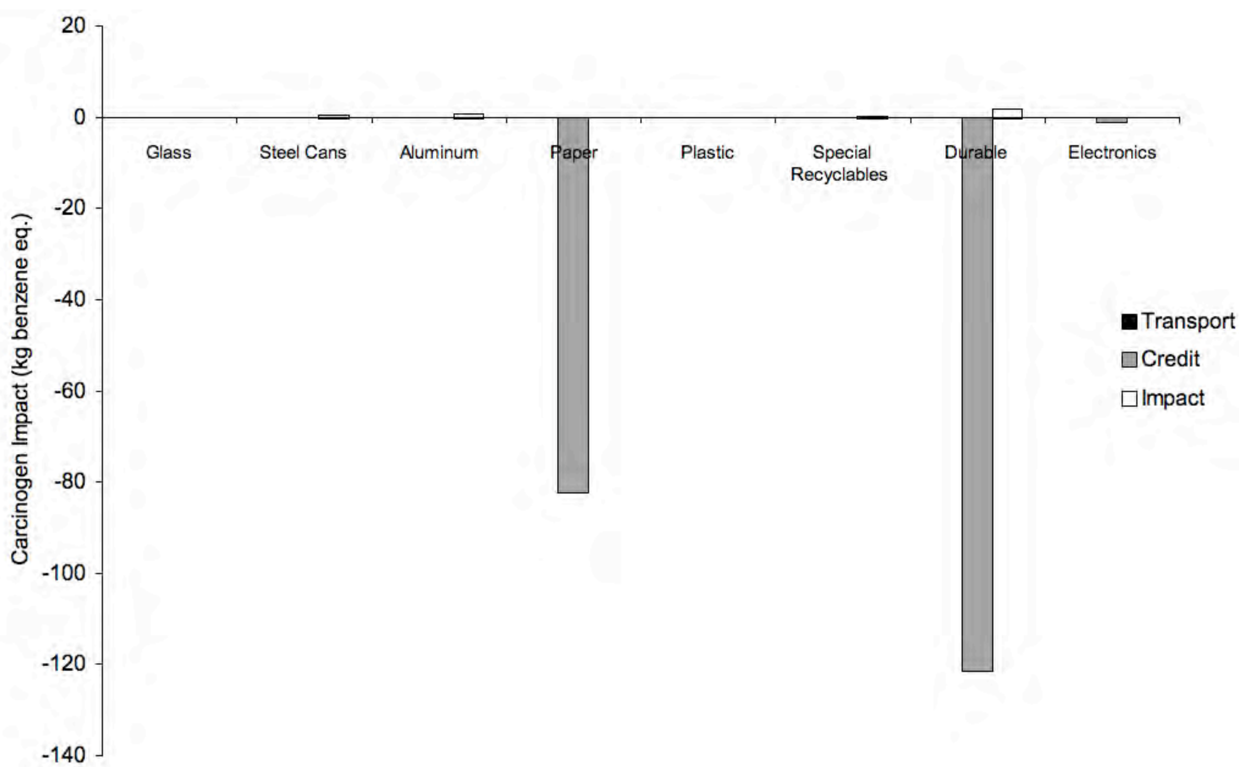

Figure 8.32: Carcinogen Impacts per 1 kg of Recycled Waste by Material Category.

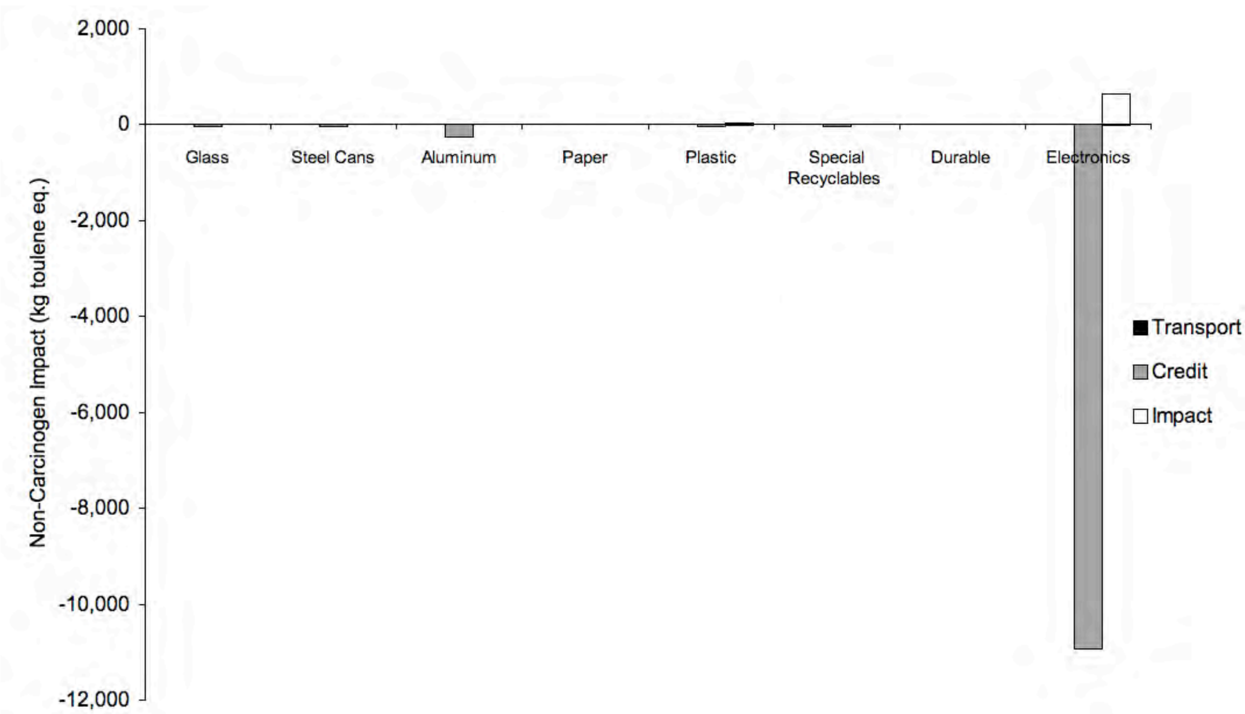

Figure 8.33: Non-Carcinogen Impacts per 1 kg of Recycled Waste by Material Category.

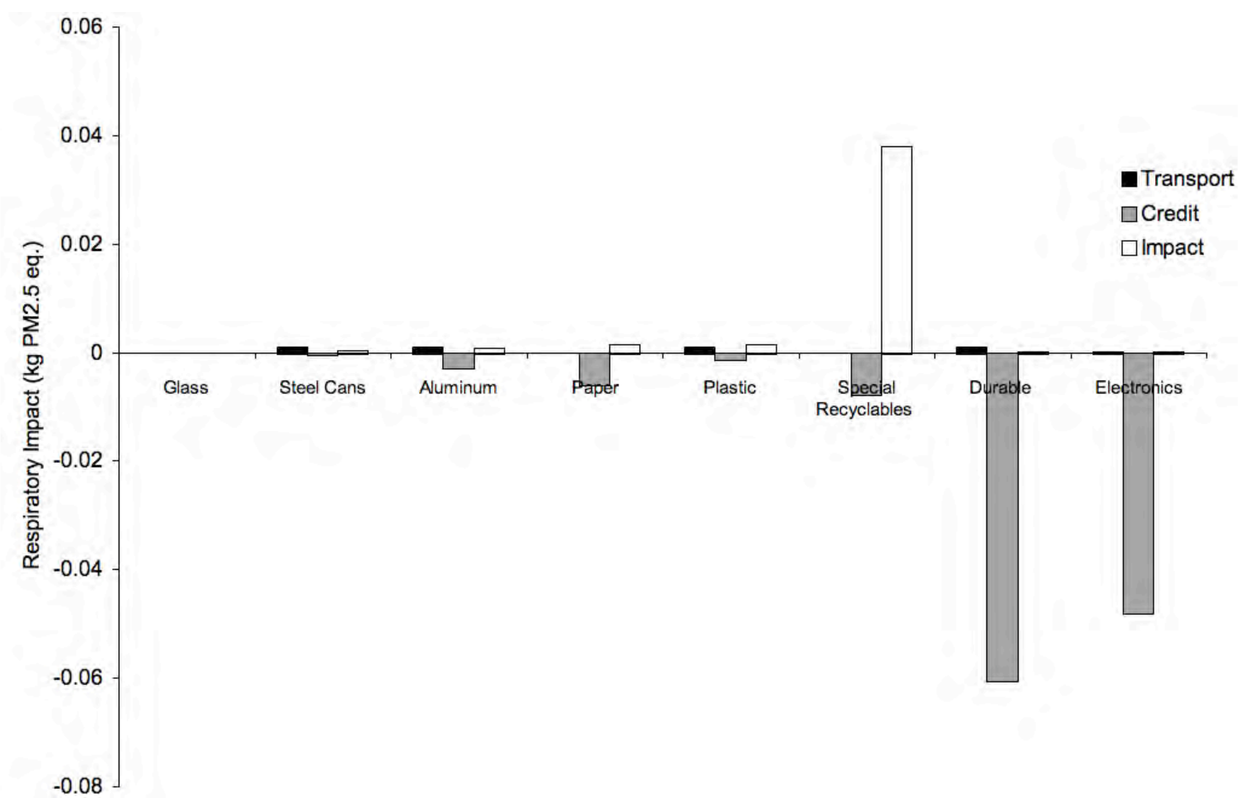

Figure 8.34: Respiratory Impacts per 1 kg of Recycled Waste by Material Category.

Trash vs. Recycling Impacts per 1 kg of Material Waste

In comparing the trash and recycling impacts per 1 kg of material waste, which account for transport impacts, processing impacts, and credits earned for each process, we may begin to understand which waste handling option is preferable for each material. It is important to note that these calculations do not account for the manufacturing (Table 8.2) or additional ecosystem impacts (Figure 8.22) associated with the early life cycle of each material, but rather give advice regarding the best disposal option by material. The trash and recycling impacts per 1 kg of material waste are compared in Figures 8.35 through 8.40.

The global warming impacts of throwing small appliances and electronics in the trash are far worse than when they are recycled (Figure 8.35). The global warming impacts of incinerating special recyclables, food/compostable dishware, steel cans, and durable goods are all worse than the alternative of recycling.

For acidification impacts, it is far worse to throw small appliances and electronics, food/compostable dishware, and special recyclables in the trash than all other materials (Figure 8.36). Recycling glass results in large eutrophication impacts, while incinerating small appliances, electronics, paper, durable goods and food/compostable dishware all carry eutrophication impacts (Figure 8.37). Interestingly, incinerating plastics avoids more eutrophication impacts than recycling.

Incinerating paper, durable goods, small appliances, electronics, special recyclables, and yard waste results in carcinogen emissions, while recycling paper and durable goods offsets carcinogen impacts (Figure 8.38). Throwing small appliances and electronics in the trash carries enormous non-carcinogen impacts, while recycling them offsets non-carcinogen impacts (Figure 8.39). Incinerating steel cans and aluminum also releases carcinogens. Treating durable goods, paper and small appliances and electronics as trash carries the largest respiratory impacts (Figure 8.40).

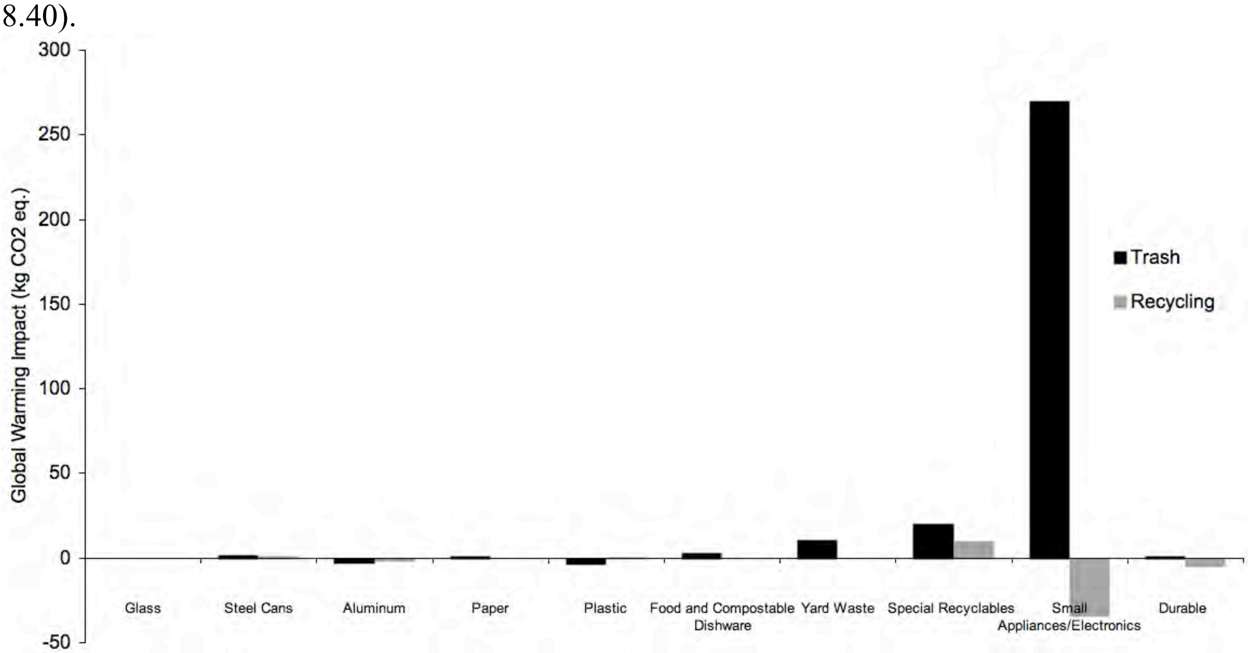

Figure 8.35: Comparative Global Warming Impacts per 1 kg of Waste Handled as Trash or Recycling.

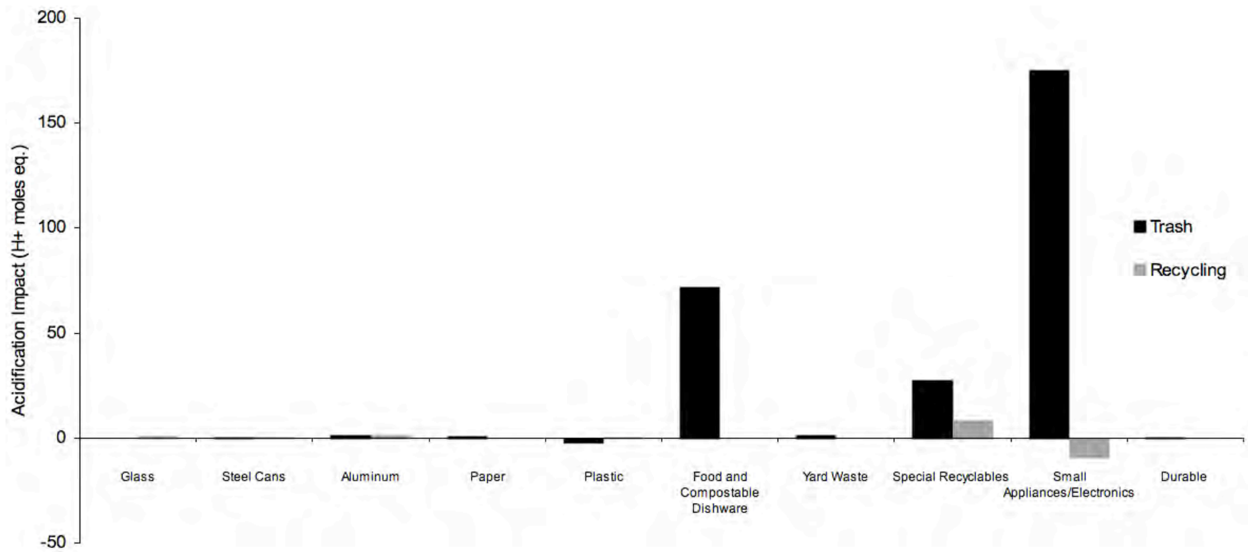

Figure 8.36: Comparative Acidification Impacts per 1 kg of Waste Handled as Trash or Recycling.

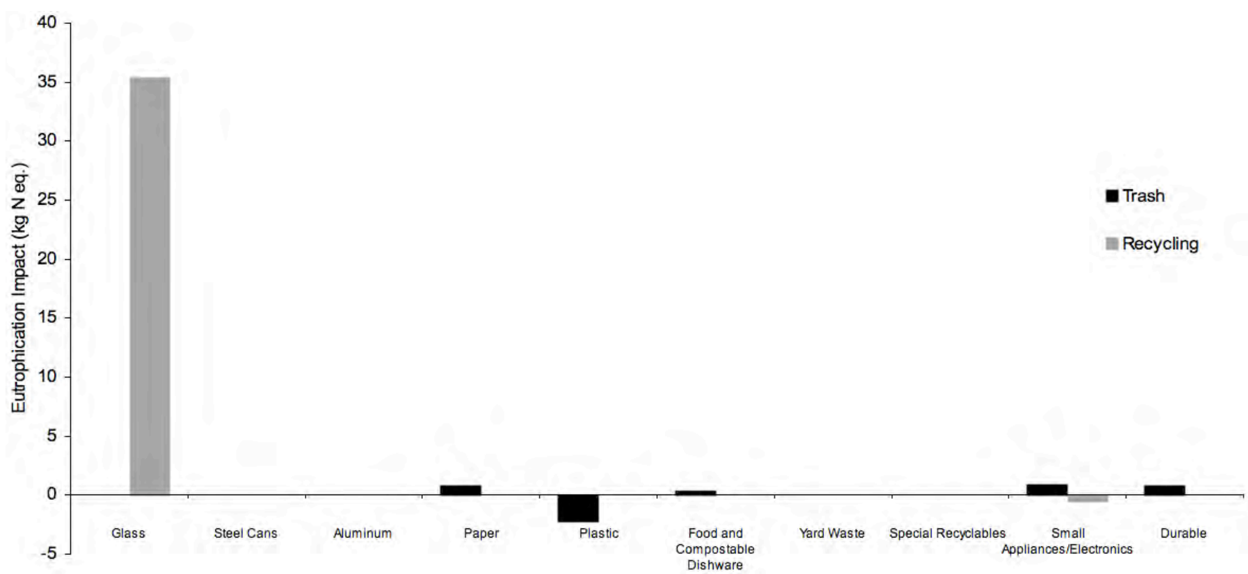

Figure 8.37: Comparative Eutrophication Impacts per 1 kg of Waste Handled as Trash or Recycling.

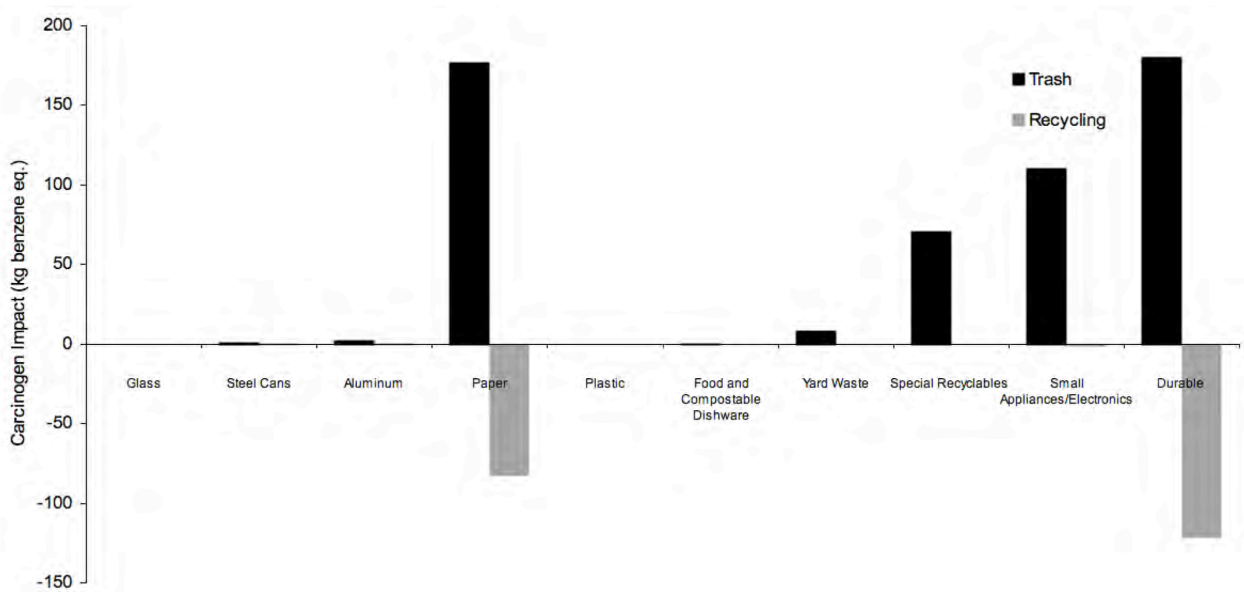

Figure 8.38: Comparative Carcinogen Impacts per 1 kg of Waste Handled as Trash or Recycling.

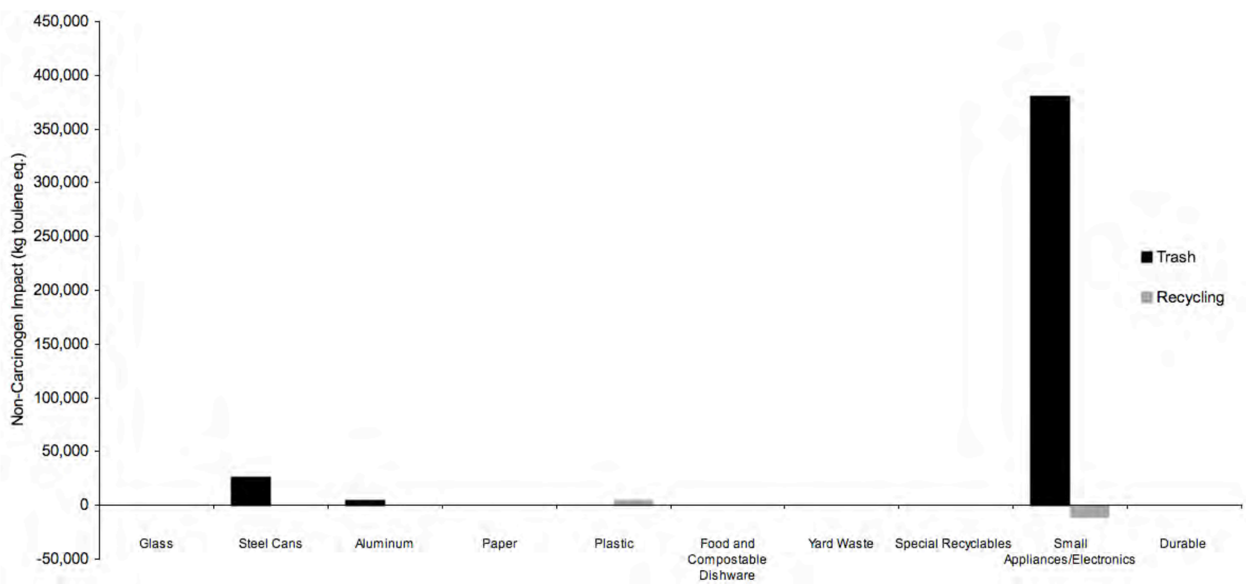

Figure 8.39: Comparative Non-Carcinogen Impacts per 1 kg of Waste Handled as Trash or Recycling.

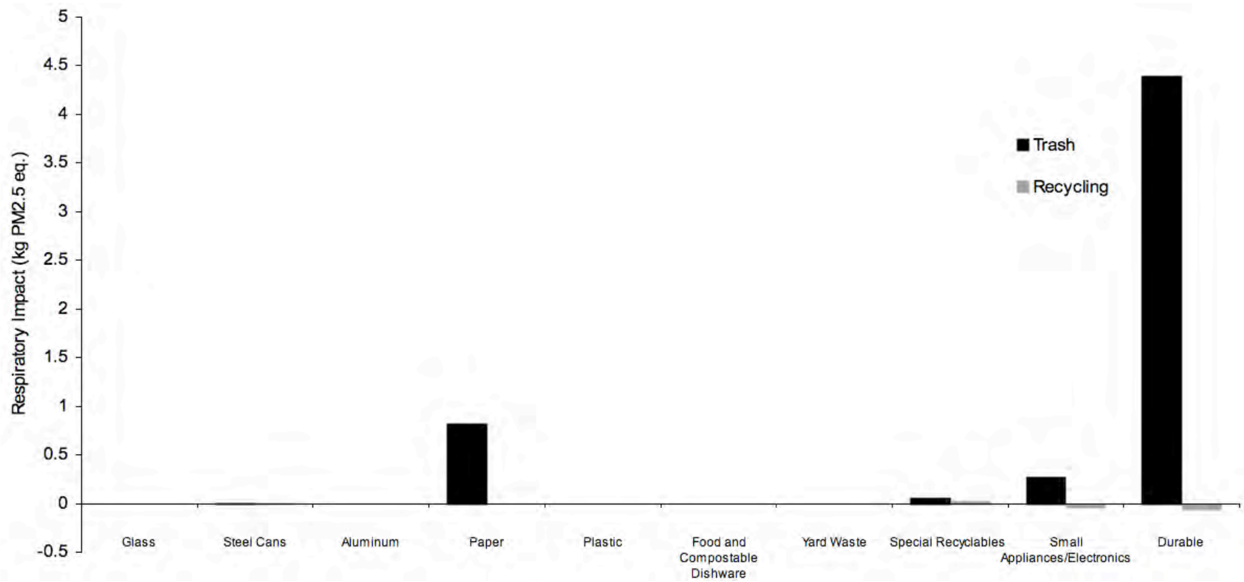

Figure 8.40: Comparative Respiratory Impacts per 1 kg of Waste Handled as Trash or Recycling.

Conclusions for 1 kg Impacts of Waste

Incinerating small appliances, special recyclables, durable goods, food/compostable dishware, yard waste, and paper must be avoided in order to reduce the impact of Wellesley College's waste. Recycling is the preferred option for paper, aluminum, steel cans, glass, small appliances, electronics, special recyclables, and durable goods, which results in a far smaller impact per kg of material than incineration. Because of their high heating value, plastics incineration often results in negative impacts, which makes incineration the preferred alternative to plastics recycling. However, this finding should not be taken in isolation, but should consider the manufacturing impacts and recycling legislation that make recycling the preferred option for plastics, as discussed in Chapter 5.

3.0 IMPROVING WASTE MANAGEMENT AT WELLESLEY COLLEGE

Our analysis of the Wellesley College waste stream suggests that there are a number of ways that the College can decrease the negative environmental effects created through its waste. These include changing how our trash and recycling are handled, reducing the amount of waste we generate, increasing the reuse of items that are prematurely disposed of as waste, and making it easier for people on campus to recycle things that can no longer be reused. In addition, given the extent to which food service on campus is responsible for the largest portion of our waste stream, some special consideration should be given to ways waste can be reduced and better disposed of from those operations. Finally, although there are many things that can be done to improve the way Wellesley College handles waste, we should remember that the College fits into a broader array of state, national, and international structures that we may not directly influence, but that have important effects on what happens with, or in many ways determines the effects of, our waste stream.

3.1 Improving Waste Handling

TRASH DISPOSAL

Although we do not pay by weight for our trash disposal, the recycling clause in our contract with Wellesley Trucking Service provides a small financial incentive for us to recycle a greater portion of our waste. If we did divert more of our waste to recycling, our recycling credit would increase.

Since we do not pay to dispose of waste by weight, a reduction in the amount of true waste (anything that cannot be recycled) that makes it to our dumpsters would not be reflected in our transactions with Wellesley Trucking Service. For 2011, the recycling credit was approximately \$0.03/kg, a small refund in comparison to the cost of \$3.49/kg for Wellesley Trucking Service. We suggest investigating a contract with Wellesley Trucking Service, or hauling waste in a different manner, that allows us to pay for disposal by weight. If the negotiated rate is less than \$3.49/kg, it would be a clear better option, but even if price were higher it might still result in an overall economic benefit, since it would give us a continued incentive to reduce the amount of our waste and in doing so, we would gain financially.

RECYCLING

We currently utilize a dual stream recycling system, which means that our paper and our commingled glass, plastic and metal are collected in separate loads, in addition to our scrap metal, mixed wood, and durable goods. We investigated through back-of-the-envelope calculations whether it would be more financially desirable to switch to a single stream system. Conigliaro Industries accepts single stream loads, and they charge us less for these loads than for commingled loads. We do, however, receive credit back from the paper they collect from us, which ultimately makes dual stream a better financial option. We save money from recycling dual stream rather than depending on single stream collection from Conigliaro, but if the paper market were ever to crash, single stream might become a more financially appealing option.

The other option is to pursue recycling that would require even more sorting. We have not been able to calculate the costs or savings of this option, but recycling that is better sorted can be less downcycled, and may, in some cases, bring in more money. On the other hand, increased sorting requires more labor, either at the point of discard by students, faculty, and staff on campus, or by other campus workers to sort post-discard. These costs and benefits would have to be calculated to determine whether such an option is realistic.

It is not enough to say that Wellesley College must simply recycle more of what it receives the highest credits for, since the rates that Conigliaro offers per material are determined by market forces. These fluctuating credits and charges make it difficult to suggest increasing our recycling of certain materials. Nevertheless, it likely that the market for recycling metals will remain relatively consistent because some metal supplies are becoming scarce.[1] Since we currently receive approximately $75 dollars per ton of scrap metal, and our steel recycling rates have room for improvement, this is the most appropriate step to recommend under our current approach to recycling.

Additionally, the contamination of recyclables should be avoided when possible. Custodians are instructed to throw contaminated loads into the trash, because we are charged $97/ton when recycled loads reach Conigliaro Industries and are deemed contaminated. In 2011, fines for contaminated loads at Conigliaro only amounted to a $30 charge, but that does not account for the contaminated loads that were discarded and incinerated. Avoiding the contamination of recyclable materials should be a priority at Wellesley College.

Alternative Recycling Facilities

Current recycling practices involve sending materials to Conigliaro Industries where they are either downcycled and reused on site, or shipped to domestic or international third parties to be further recycled. It would be useful for Wellesley to consider alternative recycling facilities that would address problems of downcycling and large transportation impacts created from international shipping.

When Wellesley College recycles its glass or its plastic waste at Conigliaro Industries, some percentage gets downcycled, or made into a product of lesser-quality,[2] and used as components of other products. For example, our glass waste is often downcycled into fiberglass or used as an additive in concrete or ceramic tiles, even though glass is an almost infinitely recyclable material.[3] In order to take full advantage of our recyclable materials, Wellesley should consider alternative recycling facility options that minimize downcycling and have a relatively larger environmental recycling credit, and therefore overall less impact, than Conigliaro Industries.

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[1] Is Scrap Metal Really a High Value Industry for Private Equity? Will it Impact Prices? *Metals Weekly*. 24 Sept. 2011. Web. 26 Apr. 2012, <http://www.metalsweekly.com/is-really-scrap-metal-a-high-value-industry-for-private-equity-will-it-impact-prices.html>.

[2] Granger, T. Truth About Glass Recycling. *Earth911.com*. June 2009. Web. April 2012. <http://earth911.com/news/2009/06/22/truth-about-glass-recycling/>.

[3] Granger, T. Truth About Glass Recycling. *Earth911.com*. June 2009. Web. April 2012. <http://earth911.com/news/2009/06/22/truth-about-glass-recycling/>.

When looking for alternatives, it is impossible to ignore the proximity of the Town of Wellesley's Recycling and Disposal Facility (RDF), which is often prized for its state-of-the-art sorting and collection program. The College would need a permit to send its recyclables there,[4] and making use of this facility would require some institutional changes enacted in the way we sort our waste. Our recyclable waste is not sorted to the extent that the RDF requires. As our waste audit can attest, the College already has difficulty adhering to our dual stream system, as demonstrated by the amount of recyclable materials found in the trash.[5] If the College could adopt a more specific system of sorting our recycles, it would be an option to send our recycling to the Wellesley RDF.

Thorough sorting of recyclables could also mean less downcycling, which would lessen the impact of our recycling waste stream. The College could pursue negotiations with the Wellesley RDF staff to accept our recyclables similar to other business clients, which would benefit our recycling stream in addition to allowing the Wellesley RDF to make a large profit from selling our recyclables. Diverting our recycling stream to a facility that is both so close by and so efficient at recycling a whole host of goods, could involve an overall beneficial trade off that Wellesley should consider.

Stricter sorting of recyclables would inevitably demand some changes to the way our recyclables are currently collected. Our current recycling program has already stretched Motor Pool's staff resources.[6] To realistically implement greater sorting would either have to be done by users (rather than staff) or would require hiring more staff.

Finally, one of the appeals of the Conigliaro Industries facility is that it has an on-site truck scale, which allows each load to be weighed and entered into a web-based system for information gathering and sustainability reports made by the College, which not all recycling facilities offer.[7] Ultimately, if Wellesley is going to consider shifting away from Conigliaro Industries it will first need to work out necessary institutional changes.

Another alternative location we considered is the Waste Management (WM) materials recycling facility in Lawrence, Massachusetts. Although the Lawrence WM facility is farther from the Wellesley College campus than Conigliaro Industries, its handling of recyclables may result in a relatively smaller environmental impact than our current recyclable waste stream. The WM recycling facility in Lawrence accepts single-stream recycling, and attempts to reuse and recycle the majority of materials received either on site or at another WM facility in the United States,[8] thereby eliminating the largest transportation impacts of sending recyclable goods to China for sale on the international market. Additionally, the WM company has demonstrated a commitment to the proper recycling and reprocessing of electronic waste and special recyclables, which are hazardous to the environment and human health if improperly disposed of. WM facilities accept electronic items like televisions, computers, microwave ovens, VCRs, DVDs, and the company has partnered with companies like LG Electronics to have WM facilities accept

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[4] Gordon, M. Recycling and Disposal Facility. *Town of Wellesley*. n.d. Web. Apr 30 2012. <http://www.ci.wellesley.ma.us/pages/FOV1-0001FDB3/rdf/index>.
[5] Interview with Patrick Willoughby, Sustainability Director at Wellesley College. May 1 2012.
[6] Interview with Patrick Willoughby, Sustainability Director at Wellesley College. May 1 2012.
[7] Interview with Patrick Willoughby, Sustainability Director at Wellesley College. May 1 2012.
[8] Interview with Jeff [could not disclose last name], Employee and Customer Service of Waste Management, Inc. Apr 30, 2012

LG e-waste products for free.[9] This approach encourages the proper reuse, recycling, and processing of e-waste materials, and would simplify our collection of e-waste on campus.

Additionally, innovative recycling programs provided by WM facilities, such as the "lamp tracker" program for CFLs, attempt to make recycling options more convenient for clients. Through their "lamp tracker" program, WM sends out prepaid UPS shipping boxes to their clients for the collection of CFLs. The UPS boxes are lined with a protective sealant that prevents leaching of mercury from CFLs, and each box can store anywhere from 140-160 CFL units, for up to a year at a time. Once a box is full, the WM client can ship the box to the nearest WM recycling facility (in our case, it would be the recycling facility in Lawrence), where CFLs are sorted, reused, and recycled on site.[10] As in the case of e-waste, sending our special recyclables such as CFLs to WM would eliminate the need for the separate shipment of special recyclables to the Northeast Lamp Recycling Facility. WM Inc. also has funded and partnered with several companies that could ultimately help lower the impact of our waste stream. For example, through the WM and Harvest Power partnership,[11] a company focused on the conversion of food and yard waste to compost, Wellesley College could increase its options for addressing the amount of food waste generated on campus, and could have the possibility of an industrial composting facility to handle Wellesley College's organic waste.

Even though Conigliaro Industries is not the most efficient recycling facility available for Wellesley College, structural components of our recycling system and market make it difficult to find nearby recycling facilities that do not downcycle their materials. First, Wellesley College's contract with Motor Pool trucking company involves balancing negotiations with several parties in the recycling process, meaning that finding a new recycling facility would require a solution that includes the College, a new facility, and contracted workers for Motor Pool trucking. Or, if necessary, the College could also consider contracting with another trucking company.

Second, alternative recycling facilities that don't involve eventual shipment and sales of recyclable material overseas are extremely difficult to find simply due to market dynamics. Although the WM facility in Lawrence is quite far from Wellesley College, it may prove to be a viable alternative as one of few facilities available to the College that does not ship goods overseas, and would thereby minimize our overall transportation impacts in the recycling process.

In addition, Wellesley College's recycling facility requirements are fairly specific, making it difficult to find an alternative to Conigliaro. As mentioned previously, since Conigliaro's truck scale feeds into a larger electronic database of waste data, the College can track our recyclable loads over time for the purpose of reports and grants; not all alternative sites have trucking scales or such detailed information regarding waste loads over time.

Finally, although Wellesley College has a vested interest in facilitating a more efficient and environmentally friendly recycling stream, it still must consider financial constraints in addition to environmental impact. Since electing to minimize our environmental impact with an alternative facility may involve an initial financial investment from the College, making changes to our recycling process may initially prove to be unappealing. An alternative recycling facility

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[9] LeCompte, C. LG and Waste Management to E-cycle LG Gear for Free. *earth2tech*. Aug 2008. Web. Apr 30 2012. <http://gigaom.com/cleantech/lg-and-waste-management-to-e-cycle-lg-gear-for-free/>.

[10] Interview with Jeff [could not disclose last name], Employee and Customer Service of Waste Management, Inc. Apr 30, 2012

[11] Waste Management Invests in Harvest Power. *Biomass Power and Thermal Magazine*. Jan 25 2010. Web. Apr 30 2012. <http://www.biomassmagazine.com/articles/3458/waste-management-invests-in-harvest-power/>.

to Conigliaro must be cost efficient in order for the College to reconsider our recycling process. Despite the initial cost of changing to an alternative recycling facility, however, Wellesley College could potentially benefit through a minimized environmental impact and perhaps a less costly recycling option in the long term, which is why we urge the College to reconsider its options.

The International Market for Recycling

Some of Wellesley College's recyclables are shipped abroad and sold on the international market. A major concern with shipping materials abroad for recycling is the inevitable environmental justice problems that arise with displacing our waste from where it was originally created to foreign countries, many of which are operating in a less-stringent regulatory environment. Another concern with international shipping involves large transportation impacts. The various recycling facilities that Wellesley College uses to recycle a variety of materials, often only serve as sorting stations. Due to stringent environmental regulations on recycling in the U.S, it is more economically efficient to ship recyclable materials abroad to be fully recycled. E-waste is one material that as a college we must ensure is properly recycled because when not disposed of or recycled properly it can have the most adverse environmental impacts out of any other material.

When proper disposal of electronic waste occurs, recycling electronics has many positive externalities. For example, recycling electronics saves energy, decreases greenhouse gas emissions, reduces toxic chemicals in the municipal waste stream (such as lead, mercury, arsenic), and ultimately preserves natural resources.[12] According to the United Nations Environmental Program, the U.S ships e-waste abroad to countries like China to take advantage of the lower labor costs and less stringent environmental regulations.[13] In places with little to no regulation of e-waste recycling, recycling techniques include stripping of metals in open-pit acid baths to recover gold and other metals, removing electronic components from printed circuit boards by heating over a grill using honeycombed coal blocks as fuel, chipping and melting plastics without proper ventilation, burning cables for recovering metals, burning materials in open air, and also disposing unsalvageable materials in fields and riverbanks.[14] The techniques described above contribute to the release of toxic metals (such as lead) and persistent organic pollutants (POPs) into the environment, which in turn can indirectly or directly affect human health.[15]

Studies conducted in Chinese traditional rice-growing communities that have been turned into intensive e-waste recycling centers, demonstrate the adverse environmental and health

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[12] Drayton, H.L. Economics of Electronic Waste Disposal Regulations. *Hofstra Law Review*. Vol. 36: 149. 2007. Web. April 2012. <http://lawarchive.hofstra.edu/pdf/academics/journals/lawreview/lrv_issues_v36n01_dd1_drayton_36_1.pdf>

[13] Wong, M.H., Wu, S.C., Deng, W.J., Yu, X.Z., Luo, Q., Leung, A.O.W., Wong, C.S.C., Luksemburg, W.J., Wong, A.S. Export of Toxic Chemicals - A Review of the Case of Uncontrolled Electronic-Waste Recycling. *Environmental Pollution*. Volume 149: 2. September 2007.Web. April 2012. <http://eprints.hkbu.edu.hk/345/1/MH_Wong_Export_of_toxic_chemicals.pdf>

[14] Wong, M.H. *et. al.* Export of Toxic Chemicals - A Review of the Case of Uncontrolled Electronic-Waste Recycling. *Environmental Pollution*. Vol. 149: 2. Sept. 2007.Web. April 2012. <http://eprints.hkbu.edu.hk/345/1/MH_Wong_Export_of_toxic_chemicals.pdf>.

[15] Wong, M.H. *et. al.* Export of Toxic Chemicals - A Review of the Case of Uncontrolled Electronic-Waste Recycling. *Environmental Pollution*. Vol. 149: 2. Sept. 2007.Web. April 2012. <http://eprints.hkbu.edu.hk/345/1/MH_Wong_Export_of_toxic_chemicals.pdf>.

effects of improper e-waste recycling. These centers dismantle and process e-waste using large-scale open burning sites distributed in the rice fields and along riverbanks.[16] It is the location of the recycling operations and the types of operations undertaken that cause environmental degradation which in turn affects human health. Communities in developing countries allow the introduction of these unregulated recycling centers since they view waste as a resource and an income-generating opportunity.[17] While a strong market for recycled materials already exists in China, along with extensive informal waste collection centers, policies to regulate recycling practices and facilities are still in the making and are currently playing catch-up. Wellesley College as an institution committed to environmentally just and sustainable practices should strongly consider avoiding recycling facilities that export our recyclables abroad.

3.2 Improving Waste Behaviors on Campus

IMPORTANCE OF REDUCTION

The key to reducing environmental impacts from waste generation is to follow the universal doctrine of, in order of importance, reducing the amount of waste created, reusing materials when possible, and recycling materials after their use phase. We heard this universal doctrine at both Conigliaro Industries and Covanta SEMASS, where employees stressed the importance of waste reduction as the first steps to combating negative environmental impacts. Wellesley College should prioritize waste reduction by targeting activities that generate the most waste on campus, and instituting sustainable initiatives following the model of other universities.

Approximately 42% of Wellesley College's total waste comes from food waste. There are many ways to reduce food waste. Among the most dramatic, implementing a meal plan in which students pay for a certain number of meals per week would drastically influence the amount of food waste produced on campus. This kind of meal plan would better inform dining service staff in their meal preparation amounts, and would also reduce the amount of food discarded.[18] Regardless of the overall approach taken, it is important for dining services staff to collectively review trends in pre-consumer food waste and post-consumer food waste to better inform their food preparation.[19]

Plastics usage that is not associated with durable goods, accounts for only 3% of our total waste stream by weight and includes some materials that are unnecessary to use in the first place. In order to reduce the amount of plastics discarded, the College could reduce plastics use in the form of beverage containers, specifically plastic water bottles. Reducing plastic water bottle waste should be relatively easy because water can be obtained from the tap. At least 20 colleges in the United States have adopted partial or complete plastic water bottle bans including Harvard

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[16] Wong, M.H. *et. al.* Export of Toxic Chemicals - A Review of the Case of Uncontrolled Electronic-Waste Recycling. *Environmental Pollution*. Vol. 149: 2. Sept. 2007.Web. April 2012. <http://eprints.hkbu.edu.hk/345/1/MH_Wong_Export_of_toxic_chemicals.pdf>.

[17] Hicks, C. *et al.* The Recycling and Disposal of Electrical and Electronic Waste in China --Legislative and Market Responses. *Environmental Impact Assessment Review*. Vol. 25. April 2005. Web. April 2012. <http://www.bvsde.paho.org/bvsacd/cd43/diet.pdf>.

[18] Food for Thought: Restaurant Guide to Waste Reduction and Recycling. *California Environmental Protection Agency.* City and County of San Francisco, 1992. Web. 30 April 2012. <http://www.calrecycle.ca.gov/publications/BizWaste/44198016.pdf>.

[19] A Short Guide to Food Waste Management Best Practices. *LeanPath,* 2008. Web. 30 April 2012. <http://www.leanpath.com/docs/Waste_Guide_o.pdf>.

University, The University of Vermont, and Vassar College.[20] Wellesley College could also potentially save money by banning purchasing and provision of plastic water bottles at on-campus events and in cafés.

A large quantity of plastic waste, in addition to compostable dishware and cutlery, is generated by Dining Services. Students often take reusable dishware and cutlery from the dining halls without returning them, or returning them days later, leading to a shortage of supplies. Dining services responds to this problem by providing disposable dishware and cutlery until the missing dishware can be replaced. Although we have not looked in depth at ways to prevent loss of dining hall dishware, there are many options, from monitoring dining hall exits, to providing reusable containers for students to use when taking food out of the dining hall. McGill University[21] and Stanford University[22] have reuse initiatives present in their dining halls, and have found that students successfully use their Tupperware in dining halls.

Paper, which makes up 25% of the total waste stream at Wellesley College, is another source of waste to target for reduction. Our on-campus policy of free printing certainly encourages paper waste and does not reward reduction in use. One option is for the College to revise our on-campus printing policies. Printing policies could be implemented through a system that keeps computer records of student printing, which could involve either charging per page or allowing a quota of free printing beyond which students would have to pay. This approach has been undertaken in many other colleges and universities, such as Temple University, which successfully implemented and used a quota system to limit unnecessary paper waste.[23]

Another area where paper waste can be reduced is in Mail Services, particularly through the junk mail that students receive. More specifically, an area that could be realistically addressed is the unwanted mail from student organizations. Many organizations on campus send out campus-wide mailings to advertise events and activities. These mailings could be emailed to students, unless the organization had a request from each individual student for paper mailings, rather than all students automatically getting mail. More important (but harder to control) is unwanted junk mail from sources from outside the college such as credit card advertisements, catalogues, surveys, etc. Anyone can go to http://www.privacyrights.org/fs/fs4-junk.htm[24] for more information about reducing or eliminating their junk mail, but few actually know about this option or take advantage of it. Public campaigns, including computer stations that would enable

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[20] Banning Bottles. *University of Vermont,* 2012. Web. 30 April 2012. <http://www.uvm.edu/vq/?Page=news&storyID=13332&category=vq-green>; Student Push for Ban on Plastic Water Bottles Irks Industry. *Environment360.* Yale University, 2012. Web. 30 April 2012. <http://e360.yale.edu/digest/student_push_for_ban_on__plastic_water_bottles_irks_industry/3330/>.

[21] Waste Reduction. *Food and Dining Services McGill University*, 2012. Web. 30 April 2012. <http://www.mcgill.ca/foodservices/responsible-food/stories>.

[22] Towards Zero Waste. *Stanford Dining of Residential & Dining Enterprises,. Stanford University*. n.d. Web. 30 April 2012. <https://www.stanford.edu/dept/rde/cgi-bin/drupal/dining/node/217>.

[23] Student Printing in Temple University Computer Labs. *Temple University Computer Services*. Temple University. Web. 10 April 2012. <http://www.temple.edu/cs/policies/printingpolicy.pdf>.
Printing policy. *University of Michigan Law School*, 2012. Web. 10 April 2012. <http://www.law.umich.edu/currentstudents/informationtechnology/printing/Pages/printingpolicy.aspx>; Freeman Network Printing Policies. *Freeman School of Business.* Tulane University, 2012. Web. 10 April 2012. <http://www.freeman.tulane.edu/lib-tech/computing/printing.php>.

[24] Fact Sheet 4: Junk Mail: How Did They All Get My Address? *Junk Mail: How Did They All Get My Address?* Web. 30 Apr. 2012. <http://www.privacyrights.org/fs/fs4-junk.htm>.

students or others to opt out of junk mail in person, along with information about the benefits of doing so, may be helpful.

Increase the Ease of Reuse

An informal network on campus already exists to encourage the reuse of items that could otherwise end up in the waste stream. There are Google groups and Facebook groups dedicated to the resale and reuse of items, and these are used often. The Wellesley College Students' Aid Society offers a Clothes Closet where donations are welcomed and students receiving financial aid are welcome to reuse the clothing.

If the location and operation of these programs could broadened to be available to students, faculty and staff in a centralized location, they might be more effective. One suggestion to increase the convenience of donation to the Clothes Closet is campus-wide dorm collection. If a box could be placed in each dorm and emptied once a month, students could have a go-to location for their durable waste. An institutional clothing donation system could minimize the amount of clothing thrown in the trash during the school.

A big program that encourages the reuse of on-campus items is the Office of Sustainability's Sustainable Move-Out at the end of the spring semester and the Rummage Sale at the start of the fall. It is free for students (and faculty and staff) to donate items, and there are collection bins in every dorm across campus. The Sustainability Office hires student workers to help with the organization of the materials, which encourages student investment in the program and helps the collection process run more smoothly. Increasing the frequency of events like Sustainable Move-out could increase the amount reused within the current resource limitations. At the end of the fall semester many students move out of their current rooms to study abroad or simply move to another room. If Sustainable move-out could be implemented at the end of the fall semester with a sale at the beginning of spring, we could increase the amount of reused items and reduce the amount disposed of during this high waste time.

The Google and Facebook groups, the Rummage Sale, and the Clothes Closet all face a publicity problem, especially amongst first-years. Many of the goods collected during the Sustainable Move-out are durable and composite goods donated from graduating seniors. If incoming first-years could defer the purchase of new durables until the end Rummage Sale, we could increase the volume sold and the revenue of those goods we do sell. An important step in incorporating reuse and sustainable behavior on-campus would be to include information about the Google and Facebook resale groups and the Rummage Sale in the information packets sent to incoming first-years. In addition, the collection bins for the Clothes Closet should be advertised periodically to encourage donation instead of disposal. If we can get students in the habit of reuse and donation, we can minimize the volume of durables that end up in waste stream.

The most convenient way to increase reuse rates amongst students as well as the broader campus community would be a free give-and-take store available all year round in a central location. People could donate items in working order for others to take for reuse at their discretion. There are logistical hurdles to creating such a "store." An ideal location would need to be identified, and someone would need to be in charge of organizing it, which would be an increased workload for whomever took it on. Many institutions (as well as the town recycling facility) have nevertheless found a way to make this option work, and we think that it is therefore worth further investigation.

MAKING RECYCLING EASIER ON CAMPUS

One of the easiest ways for Wellesley College to reduce the environmental impact of its waste stream is to increase recycling rates on campus. The recycling system is already in place, so increasing rates would require no major new resources. Increasing recycling rates is a multifaceted issue, and requires both specific changes and broad, overarching shifts of a community's values. On a small scale, the best way to increase recycling rates is to make it as simple as possible for the recycler. The best ways for Wellesley to address recycling would be to adjust recycling stations and focus on target materials.

Several concrete strategies can be used to increase recycling rates, many of which focus on slight changes in recycling station design. First, there must be recycling bins available everywhere there are trash bins. Dual collection systems would both increase recycling rates and decrease the rate of contaminated recycling loads. In many instances where only a recycling bin is available, people on campus simply throw their garbage in the first bin they see, thereby contaminating the recycling stream. If every trash bin were paired with a recycling bin on campus, then we could expect an increase in proper disposal of waste across campus.

Secondly, studies show that well-designed waste receptacles with specialized lids increase recycling rates. Lids with shapes that mimic the materials recycled there reduces the cognitive and motor demands for recycling.[25] For instance, bins for cans and bottles should have small, round openings while bins for paper should have long, thin slits.

Finally, it is imperative that each bin be adequately labeled in a way that is clear at a glance to any person. In addition to signage, a color-coding system could be implemented to increase the ease of recycling. In Belgium for example, all recycling bins and bags are color-coded, depending on what material is being recycled. Their system is so successful that the Belgian national recycling rate of post-consumer household packaging is over 93 percent.[26]

While we should focus on raising overall recycling rates on campus, the most efficient way to reduce Wellesley's environmental impact would be to focus on certain target materials that give the greatest environmental or economic benefit when recycled. Among the materials we analyzed, metals, paper and glass yield the highest environmental credit when recycled because the impacts of manufacturing, production, and incineration of these materials is significantly greater than recycling them.[27] Wellesley College should aim for higher recycling rates for all materials, but especially these target materials to most efficiently improve current recycling systems.

Another key area to address is special recyclables, like batteries, compact fluorescents, and ink cartridges, because these items contain some of the most hazardous environmental impacts as a result of their toxic chemical content. For example, compact fluorescent light bulbs contain mercury, household batteries contain mercury and cadmium, and ink cartridges contain toxic chemicals like ammonium nitrate. Currently, the receptacles for special recyclables on campus are not all located in centralized or easily accessible locations. Wellesley can increase recycling rates of these materials by improving the accessibility and visibility of special recyclable receptacles on campus. Furthermore, Wellesley can increase special recycling rates by hosting special recyclable drives. Von Borgstede and Biel concluded that individuals are more

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[25] Duffy, S., Verges, M. It Matters a Hole Lot : Perceptual Affordances of Waste Containers Influence Recycling Compliance. *Environment and Behavior*. 41 (2009): 741-749. Print.

[26] Recycling the Belgian Way. *Apeal Newsletter*. n.d. Web. 28 Apr 2012. <http://www.apeal.org/newsletter/?p=67>.

[27] Ackerman, F. The Price of Pollution. *Why Do We Recycle: Markets, Values, and Public Policy*. Washington, D.C.: Island, 1997. Print.

likely to engage in pro- environmental behavior when there are fewer obstacles to overcome, when conditions are not *difficult,* and when situations require less sacrifice.[28] Some individuals may find sorting and recycling special recyclables difficult, since it is not always easy to identify which items should be recycled. For example, some alkaline batteries are advertised as safe enough to throw away in the trash, while other types of batteries like button batteries are extremely hazardous if thrown away. Individuals may be easily confused about what types of batteries should actually be recycled or thrown in the trash, and need help choosing the proper disposal option. Special recyclable events held in central locations on campus would allow people at Wellesley to drop off their recyclables while avoiding the burden of sorting, subsequently increasing recycling rates.

WELLESLEY'S ENVIRONMENTAL FUTURE: THE REALISTIC OUTLOOK

Enacting these solutions can potentially decrease the impact of Wellesley's waste stream significantly. But these action points are not the panacea for "greening" Wellesley waste stream. Results of our recycling audit show that even when recycling bins are adjacent to trash receptacles, recyclable materials are still discarded in the trash. In order for the improper discarding of recyclables in the trash to end, a large-scale cultural shift, where recycling becomes a part of the Wellesley identity, must take place. More importantly, to truly "green" Wellesley College's waste stream, the stream itself must become significantly smaller. In order to become most effective, the College not only must move towards a recycling culture, but it also must establish an identity of generating as little waste as possible.

The Special Case of Food Service

The extent of waste, especially trash, generated by dining services on campus suggests that a focus on management of the food service waste stream must be pursued. AVI Fresh employees are charged with keeping dining halls open seven days a week during the academic year, providing three meals a day, and keeping the dining halls clean and safe for students; we have no wish to make the jobs of these employees more difficult.

There are nevertheless small changes that can be made in the dining halls that will significantly reduce the amount of materials unnecessarily thrown in the trash. The four main materials AVI Fresh staff currently places in the trash are corrugated cardboard, steel cans, food waste, and disposable dishware.

The majority of the corrugated cardboard and steel cans found during our waste audit were clearly used to store food products purchased by AVI Fresh. We estimate that AVI Fresh throws 44,090 kg of cardboard and 9,702.26 kg of steel cans annually in the trash. Recycling both cardboard and steel cans produces fewer environmental impacts than incinerating these materials. If all the corrugated cardboard and steel cans thrown in the trash by AVI Fresh annually were placed in the recycling instead, then 250,347.14 kg of CO_2 equivalents could be avoided. Cardboard and steel cans are easily recyclable materials. As long as the cardboard is not contaminated with food and the steel cans are rinsed quickly before being recycled, the materials can be effectively recycled. AVI Fresh should conduct an audit to determine which dining halls

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[28] Von Borgstede, C and Biell, A. Pro-Environmental Behaviour: Situational Barriers and Concern for the Good at Stake. *University of Göteborg*. n.d. Web. 28 Apr 2012. <http://130.241.147.3/download/gpr021.pdf>.

need recycling bins in the kitchens and subsequently contact the Office of Sustainability to request recycling bins for dining halls that do not possess an adequate number.

Ensuring recycling bins are in each kitchen, both paper bins and steel/aluminum/plastic/glass recycling bins, will most likely increase AVI Fresh's recycling rate. AVI Fresh should require every dining hall to have at least two recycling bins. The bins should be visible, easy to access, and the metal recycling should be placed next to a sink that allows easy rinsing of large steel cans. Based on the amount of cardboard produced by AVI Fresh in one week, 326.59 kg of cardboard, the college should consider investing in a vertical paper baler for all dining halls. Vertical paper balers compress a large volume of paper waste into a compact bale and take up less space than horizontal balers that are typically used at recycling centers.[29] A vertical baler would reduce the space required for recycling cardboard waste, and increase the ease of recycling large amounts of waste.

AVI Fresh should also either commit to requiring employees to recycle materials such as cardboard and steel cans, and rewards could be given to employees practicing good recycling behavior. Simply placing recycling bins in dining halls will not completely eliminate unnecessary waste; employee behavior also needs to change. Additionally, including mandated recycling both in the college's contract with our food service provider, and in the employment contract with workers, will reduce the improper disposal of materials. The college should require that food service employees separate, rinse (if necessary), and recycle all materials including: cardboard, paper, steel, aluminum, and glass, and if this process requires additional effort beyond what is currently undertaken, then other duties should be adjusted accordingly.

Although changing recycling behavior is essential, it is important to recognize that the largest portion of our total waste stream is food waste. AVI Fresh produces 449.007.26 kg of food waste annually. The possibility of institutionally composting food waste should be investigated. This report did not compare the impacts of institutional composting with incinerating food waste. The overall impacts of incinerating food waste are large, however; the acidification impacts of incinerating the food waste produced by AVI Fresh each year are particularly disturbing, totaling 10,789,018.08 H+ moles eq, equal to releasing 33,094 bathtubs of hydrochloric acid into the environment annually.

Additionally, programs should be initiated to minimize the amount of food waste produced. Requiring swipe card access to enter dining halls simultaneously produces records of how many students enter the dining hall throughout the day and reduces the number of people who eat in the dining halls that are not on the meal plan. Introducing swipe card access would allow AVI Fresh to determine how many students enter each dining hall at meal times and consequently how much food a certain number of students eat at each meal. Understanding the number of students that typically enter a dining hall throughout the day could reduce food waste because AVI Fresh would have increased knowledge of how much food to prepare. AVI Fresh could also consider closing most dining halls during off-hours, between meal times. The amount of post-consumer food waste would decrease substantially since students cannot enter the dining halls outside of meal times.

We understand that AVI Fresh already has efforts in place to reduce the amount of melamine dishware that students remove from the dining halls, which, if successful, would also reduce the amount of disposable dishware used. We suggest continued efforts to change student behavior regarding the disposal of melamine dishware. The effects of incinerating both

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[29] Equipment Balers: Paper Balers. *American Recycler*. Oct. 2002. Web. 5 May 2012. <http://www.americanrecycler.com/10spotlight02.html>.

melamine and disposable dishware could be posted outside of dining halls to encourage students to return dishware to dining halls promptly. But many will be unmoved by the environmental effects, especially because students often have good short-term reasons for believing their removal of dishware in the moment is the right choice for them (even if it is collectively problematic), and do not experience the aggregate effects of dishes lost. Consideration of other, more intrusive approaches may therefore be necessary.

If the initiatives described above are implemented, AVI Fresh would significantly reduce the amount of waste produced by dining halls on Wellesley's campus. Most of the efforts are relatively easy to employ and AVI Fresh will no longer be responsible for such a large proportion of the waste produced by Wellesley College annually.

Consider Composting Organics More Broadly

While we did not research the possibility of composting food waste in our impact assessment, we saw how great of a positive effect composting yard waste produced. Thus, we would strongly urge Wellesley College to investigate the feasibility of incorporating composting into our dining hall system.

Composting food rather than sending it to our general waste stream would have many strong, environmental advantages. It would avert the environmental degradation to air, water, and soil caused by incineration, especially given the low energy content of food. Instead, food waste could be converted to useful nutrients that would improve the soil.[30] Depending on where composting takes place, it could also reduce economic costs of paying for waste disposal and the economic and environmental impacts of transportation. Our dining halls and campus-wide catered events have largely shifted to compostable disposable dishware and utensils. While these materials represent an improvement over plastic or styrofoam disposables, compostable dishware will have a much greater benefit if they are actually composted rather than sent to the general waste stream.

In order to investigate the potential of a composting program, we would suggest that the College conduct LCAs for both on-site and off campus industrial composting programs. These programs would likely have different environmental effects, and we did not address the effects of industrial composting in this audit. Similarly, these programs would likely have different costs and levels of labor required. We also have observed that Pomeroy Dining Hall is already well set up for composting, as it is small and only produces vegetarian waste. If the College wishes to experiment with a dining hall composting trial run, we think that Pomeroy would be a wise location to start.

A growing number of colleges and universities are composting food waste. These peer institutions include Smith College,[31] Amherst College,[32] Oberlin College,[33] Yale University,[34]

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[30] Newhouse, R. A Lot to Digest with Composting on Campus. *ClimateEdu.* 31 March 2009. Web. 8 May 2012. <http://www.nwf.org/campusecology/climateedu/articleView.cfm?iArticleID=64>.

[31] Recycling & Composting. *Smith College*. n.d. Web. 8 May 2012. <http://www.smith.edu/green/operations_recycling.php>.

[32] Composting at Amherst College. *Amherst College*. n.d. Web. 8 May 2012. <https://www.amherst.edu/campuslife/greenamherst/recycling/composting>.

[33] Farkas, K. Oberlin College Pulper turns Food Scraps into Compost. *Cleveland*. 27 Nov 2011. Web. 8 May 2012. <http://blog.cleveland.com/metro/2011/11/oberlin_college_pulper_turns_f.html>.

[34] Welcome to Yale: Food and Dining. *Yale Office of Sustainability*. 2012. Web. 8 May 2012. <http://sustainability.yale.edu/welcome-undergrad-dining>.

and Harvard University.[35] These institutions have received attention and praise for beginning composting programs.[36] If it is proven to be logistically and financially feasible, composting food waste could be a newsworthy environmental and financial success for Wellesley.

Make Environmentalism and Recycling a Bigger Part of the Campus Culture

Wellesley College is not only a place where roughly 2,300 motivated women come to learn about life and the world around them, but it is also a home to the majority of these women for two thirds of the year. As with any home, there are responsibilities associated with its upkeep and each individual plays a role in its overall success. Part of what makes Wellesley College special is our honor code. It enables certain privileges, yet requires certain behavior and dedication to honor in return. Part of living an honorable life is reducing the harm one causes onto others. Wellesley students are indirectly harming others through their waste disposal methods. Our campus's waste, although a small portion of the overall waste of the world, does make a difference to the health of the planet and the health of the human population. By not disposing of our waste materials in the proper manner, we are perpetuating the global impact factors, such as global warming and ecotoxicity, discussed in the above chapters.

Each student at Wellesley College signs the Honor Code book during First-Year orientation. This undertaking is done with contemplation and a sense of commitment. Through this report, we hope to incorporate proper waste disposal into the honor code commitment. Wellesley women will make a difference in the world and by incorporating a sense of environmental responsibility into their time on campus, the college helps to assure that difference isn't negative through waste. Wellesley College thrives on trust, respect, and learning. A transition to conscientious waste disposal is a logical step for Wellesley College to make moving forward. The current entitlement to negligent waste must end; Wellesley College must recognize that its current waste disposal methods are unsustainable, and redesign and implement changes to reignite Blue Pride around the waste habits of the campus community.

In order to raise awareness around waste disposal when students first arrive on campus, introductions to recycling systems should be mandatory when moving into a new dormitory. These introductions could be informal, yet informative, and administered by the student's Resident Advisor (RA). Part of RA training would therefore need to include recycling awareness. Recycling guidebooks specific to the Wellesley College recycling system should also be available in each residence hall on every floor. They could be kept in the floor kitchen, or above recycling centers, and placed in a binder or laminated. If physical recycling guidebooks are not preferred, an online version should be available to students via the college website. An increase in recycling information will help to lessen recycling contamination and reduce the rate of recyclable materials being thrown in the trash. By incorporating this information into orientation and move-in settings, students would become more familiar with proper waste disposal practices, and see that lessening our waste impact is important to Wellesley College. The home metaphor can be extended here in that pro-environmental behavior, such as recycling,

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[35] Harvard Strives to Set Standards in Green Catering. *Food Service Director*. 11 Jan 2012. Web. 8 May 2012. <http://www.foodservicedirector.com/trends/going-green/articles/harvard-strives-set-standards-green-catering>.

[36] Harvard Strives to Set Standards in Green Catering. *Food Service Director*. 11 Jan. 2012. Web. 8 May 2012. <http://www.foodservicedirector.com/trends/going-green/articles/harvard-strives-set-standards-green-catering>.

can be seen as house rules and expectations. Just as a family, our community here on campus can be strengthened when trust is extended and people uphold our shared values and exhibit appropriate behavior.

Wellesley could further help to change the campus' current acceptance of wasteful behavior by discontinuing the use of disposable plastic cups and dishware at events and meetings on campus. In utilizing reusable cups and dishware, and instilling a "bring your own cup" mentality, Wellesley College could drastically reduce its plastic waste annually. This is a critical step because plastics make up the second largest percentage of our waste stream, only surpassed by organic waste. These types of changes are happening at similar highly selective, small, liberal arts colleges, such as Vassar College, where resolutions are currently being passed to ban plastic water bottles from dining services.[37] Wellesley College has been a leader in many arenas and should not fall behind its peer institutions in making necessary environmental changes. It is also important that these changes are embraced and implemented with positivity and hope. Unfortunately, many people anticipate negative emotions surrounding pro-environmental behavior, which then leads to lower participation or lack of appropriate action,[38] but the use of campus pride in the face of waste habits at Wellesley College could yield a dramatic change in our actions and overall environmental impact. Through a cultural shift in waste habits and environmentalism on campus, the environmental impact of our waste stream could be minimized, along with an increase in campus community and pride.

3.3 Wellesley's Waste and the World

While Wellesley College is taking an initiative to reflect on and change its own personal waste practices in order to reduce the impact of its waste, waste practices on campus are only a small piece to a much larger problem. There is an expansive world outside of the "Wellesley bubble", and in cases of widespread environmental issues, broader structural reforms are needed in addition to individualized clean up efforts. These are generally enacted through the federal or state legislature as a way to quickly target and enforce behavior that is deemed hazardous or unsatisfactory.

Wellesley College has no control over the transportation or disposal methods its waste facilities utilize or what materials citizens will be required to recycle or dispose of in a certain manner. Thus, uniting as a community to focus on enacting laws to mitigate these issues will yield much faster and extensive results. Whether or not we support or work for these types of programs, we will be affected by them if they are implemented locally, at the state level, or nationally.

MASSACHUSETTS WASTE DISPOSAL BAN

In 1990, Massachusetts enacted the Massachusetts Waste Disposal Ban, which prohibits institutions from sending recyclables and hazardous materials to landfills or incineration.[39] The

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[37] Bosque, T. Vassar College's Tap That Campaign Gains Momentum. *Ban the Bottle*. 10 Apr 2012. Web. 28 Apr 2012. <http://www.banthebottle.net/>.

[38] Carrus, G., Passafaro, P., and Bonnes, M. Emotions, Habits and Rational Choices in Ecological Behaviours: The Case of Recycling and Use of Public Transportation. *Journal of Environmental Psychology*. 28. (2008): 51–62. Web. 28 Apr. 2012. <http://psycnet.apa.org/psycinfo/2008-02176-006>.

[39] Waste and Recycling: Massachusetts Waste Disposal Ban. *Massachusetts Department of Environmental Protection.* n.d. Web. 18 Apr. 2012. < http://www.mass.gov/dep/recycle/solid/wastebans.htm>.

goal of the ban was to strengthen the recycling industry by providing a dependable stream of recyclable materials, and to minimize the adverse environmental and human health effects associated with current disposal methods. [40]

Through the waste ban, the Massachusetts Department of Environmental Protection (DEP) initiated a set of material-specific disposal regulations in order to reduce adverse impacts to human and environmental health.[41] The DEP banned the disposal of several hazardous materials in the municipal solid waste stream, causing the recycling of these materials to be their only legal disposal option.

The following items are banned from disposal or transfer of disposal within the Massachusetts State border:

- Asphalt pavement, brick & concrete
- Cathode ray tubes
- Clean gypsum wallboard
- Ferrous & non-ferrous metals
- Glass & metal containers
- Lead acid batteries
- Leaves & yard waste
- Recyclable paper, cardboard & paperboard
- Single resin narrow-necked plastics
- Treated & untreated wood & wood waste
- White goods (large appliances)
- Whole tires (banned from landfills only; shredded tires acceptable)[42]

Legal responsibility for these restrictions is placed on the disposal facilities themselves, not on their clients. Therefore, an institution like Wellesley College does not have a legal obligation to recycle what the Massachusetts DEP defines as a restricted material. Wellesley can be affected by the requirements its waste facilities impose in order to implement the regulation.

The following facilities must legally comply with the waste ban and are subject to enforcement and penalties:

- Solid waste landfills
- Solid waste combustors
- Solid waste transfer stations
- Construction and demolition handling facilities (including both construction and demolition processing facilities and construction and demolition transfer stations)[43]

Wellesley's MSW handling facility SEMASS falls under the category of "solid waste combustor," and is therefore subject to the legal restrictions and penalties of the Massachusetts State Waste Ban.

[40] Waste and Recycling: Massachusetts Waste Disposal Ban. *Massachusetts Department of Environmental Protection.* n.d. Web. 18 Apr. 2012. < http://www.mass.gov/dep/recycle/solid/wastebans.htm>.
[41] 310 CMR 19.017: Waste Disposal Ban Regulation. *Massachusetts Department of Environmental Protection.* n.d. Web. 18 Apr. 2012. <http://www.mass.gov/dep/recycle/laws/bansreg.htm>.
[42] Waste and Recycling: Massachusetts Waste Disposal Ban. *Massachusetts Department of Environmental Protection.* n.d. Web. 18 Apr. 2012. < http://www.mass.gov/dep/recycle/solid/wastebans.htm>.
[43] Waste and Recycling: Massachusetts Waste Disposal Ban. *Massachusetts Department of Environmental Protection.* n.d. Web. 18 Apr. 2012. < http://www.mass.gov/dep/recycle/solid/wastebans.htm>.

Since the establishment of the 1990 Waste Ban, Massachusetts waste handling facilities must draft and submit a compliance plan for approval by the DEP. This document requires a site-specific plan for monitoring and inspection of loads for banned materials. Action points established in compliance plans can include posting signs at the facility to raise awareness regarding banned materials, record-keeping culminating in an annual report, waste ban-oriented training of facility personnel, and the agreement to regular inspections by the DEP.[44] SEMASS undergoes several unannounced inspections a month to ensure it is complying with DEP regulations.

In accordance with MassDEP's Enforcement Response Guidance, facilities that fail to comply with the Waste Ban will receive written notices of non-compliance, consent orders, unilateral orders, administrative penalties, or referral to the Attorney General. Serious violations and repeat facility offenders may result in daily penalties of up to $25,000 for each violation. MassDEP may also require a modified compliance plan to be submitted by the facility if it determines that banned materials are not being removed effectively.[45]

Due to the allocation of legal responsibility on waste handling facilities rather than producers, Wellesley College's disposal habits remain relatively unaffected by the restrictions and threat of enforcement set in place by the Massachusetts State Waste Disposal Ban.

In the worst-case scenario, Wellesley College's waste can be – and has been – turned away by the facility if it is does not meet standards. However, Wellesley College as an institution will not suffer fines as a result of improper disposal behavior. In order to maintain good relations with our disposal facility and to uphold the honor code, Wellesley College must adhere to the legal restrictions set in place by the waste ban, and take serious action in the pursuit of ethical and sustainable waste disposal of its hazardous and special recyclable waste.

TAKE-BACK POLICIES

Take-back legislation, particularly within the category of electronics, is another useful policy that encourages proper disposal habits. The goal of this type of legislation is to place the responsibility of the full life-cycle of products on the manufactures themselves, in the hopes that this will create incentives to internalize waste costs in corporate bottom lines. Increased manufacturer responsibility also can result in updated product design to phase out the use of hazardous substances, and make products more easily recyclable rather than disposable as trash.[46]

So far, 25 states have passed legislation mandating statewide e-waste recycling. Several more states introduced legislation in 2011, including Massachusetts. All laws except those in California and Utah use the Producer Responsibility approach, where the manufacturers must pay for recycling. This means that 65% of the population of the U.S. is now covered by a state e-waste recycling law.[47]

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[44] 310 CMR 19.017: Waste Disposal Ban Regulation. *Massachusetts Department of Environmental Protection.* n.d. Web. 18 Apr. 2012. <http://www.mass.gov/dep/recycle/laws/bansreg.htm>.

[45] 310 CMR 19.017: Waste Disposal Ban Regulation. *Massachusetts Department of Environmental Protection.* n.d. Web. 18 Apr. 2012. <http://www.mass.gov/dep/recycle/laws/bansreg.htm>.

[46] States are Passing E-Waste Legislation. *Electronics Take Back Coalition.* n.d. 18 Apr 2012. <http://www.electronicstakeback.com/promote-good-laws/state-legislation/>.

[47] Electronics Take Back Coalition. *State Legislation*. n.d. Web. 1 May. 2012 < http://www.electronicstakeback.com/about-us/>

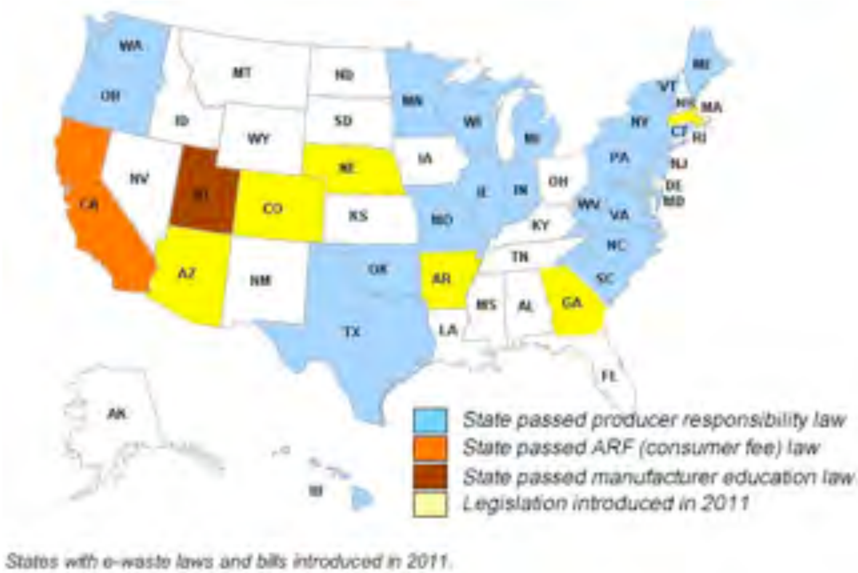
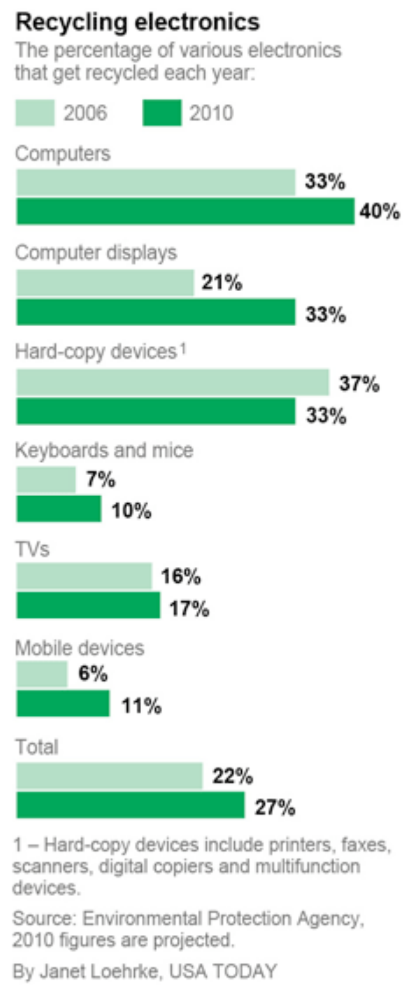


Figure 9.1: States with Passed E-Waste Laws and Legislation Introduced in 2011



There are several organizations, such as the Electronics Take Back Coalition, that have made promoting take-back legislation within the U.S. their goal. On the ETBC website, citizens can become better informed on the activity surrounding electronics disposal and have the opportunity to engage in political dialogue as well as research the best recycling options in their area.[48]

Another policy that creates similar incentives to take-back legislation would be the adoption of a leasing model in which companies lease out products to customers rather than sell them. In 1995, Interface spearheaded this idea by developing the Evergreen Lease program for floor covering and carpeting.[49] Through this program consumers enjoyed a service of carpet installation complete with repairs and upkeep for a monthly lease fee rather than a large, one-time purchase, and once the carpet became overused, it was the company's responsibility to remove and recycle it. This model can

[48] Electronics Take Back Coalition. *State Legislation*. n.d. Web. 1 May. 2012 <http://www.electronicstakeback.com/promote-good-laws/state-legislation/>

[49] Leonard, A. The Story of Stuff: How Our Obsession with Stuff Is Trashing The Planet, Our Communities, And out Health- And a Vision For Change. *Free Press*. 2010. Print.

be applied to any product, but it can prove to be difficult for companies to adopt leasing models, due to current accounting procedures, tax laws, institutional barriers and subsides for virgin materials (especially oil).[50] However, structural changes in legislation could improve incentives for leasing models in the future.

CARBON RULES AND PRICING THAT MAKE TRANSPORT MORE EXPENSIVE

By putting a carbon tax or a cap on carbon emissions, governments can protect communities from the threats of global warming and air pollutants, while incentivizing more efficient and sustainable disposal systems. A carbon tax system charges entities (be they individuals or companies) based on their emissions. A cap system is one in which a maximum amount of emissions is allowed; this allowance could be tradable or not, depending on how the system is constructed. If disposal industries were taxed according to carbon emissions, it would no longer be financially viable for them to ship recyclables to China since the cost of transport would outweigh the benefit of low wages of labor and low recycling regulation abroad.

The negative public perception often associated with higher cost as a result of carbon tax policies can be offset with a revenue neutral tax shift policy: meaning that the total amount of tax dollars citizens pay to the government is unchanged as a result of increasing taxes on pollution while simultaneously decreasing taxes by an equal amount in another sector like social security.[51] Some of the tax revenues could then provide economic relief for low-income citizens to offset high-energy costs. Additionally, if carbon tax policies were designed to affect companies, businesses, and industry, then the average American taxpayer would not be significantly affected. Hopefully, such carbon tax policies could in turn shift the status quo of disposal and recycling methods to become more sustainable in the future.

RECYCLING MANDATES

Four methods of government-mandated recycling legislation exist: minimum recycled content mandates, utilization rates, procurement policies, and recycled product labeling.[52]

Both minimum recycled content mandates and utilization rates increase demand for recyclable materials by forcing manufacturers to make products that are more easily recyclable and contain more recycled content. Content mandates require specific percentages of recycled content in new products, while utilization rates can help industries transition towards the manufacture of more recyclable and recycled products, by allowing them to either purchase tradable credits in exchange for product reform, or to meet government standards at any point of the production process.[53]

Procurement policies involve government funding of the purchase of recycled items. The Office of Federal Procurement Policy (OFPP) in the Office of Management and Budget plays a central role in shaping the policies and practices federal agencies use to acquire the goods and

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[50] State Legislation. *Electronics Take Back Coalition*. n.d. Web. 1 May. 2012 <http://www.electronicstakeback.com/promote-good-laws/state-legislation/>

[51] Carbon Pricing. *David Suzuki Foundation*. n.d.. Web. 31st April. 2012. <http://www.davidsuzuki.org/issues/climate-change/science/climate-solutions/carbon-pricing/>.

[52] The Garbage Primer. *The League of Women Voters* (1993). New York: Lyons & Burford. pp. 35–72. Print.

[53] The Garbage Primer. *The League of Women Voters* (1993). New York: Lyons & Burford. pp. 35–72. Print.

services they need to carry out these responsibilities.[54] The laws specified in Section 6002 of the Resource Conservation and Recovery Act (RCRA), Pub. 1. 94-580, and Section 9001 of the Food, Conservation, and Energy Act of2008, Pub. 1. 110-246, for fiscal years 2008 and 2009, require that the Office of Federal Procurement Policy (OFPP) report to Congress biennially on agency compliance with requirements to buy recycled and biobased products.[55] The Federal Acquisition Regulation (FAR) is also under revision in order to require that 95% of new products contracted be energy-efficient, water-efficient, non-ozone depleting, contain recycled content, and non-toxic or less toxic alternatives to older products, provided that new products and services meet agency performance standards.[56]

Government mandated demand for recyclables can also be seen in legislation like the Massachusetts beverage container law or "Bottle Bill" enacted in 1981, which provided an economic incentive for consumers to return recyclable items and receive a financial reward for recycling, and ultimately encouraged more sustainable disposal habits.[57] The "Bottle Bill" created a deposit- refund system in which each citizen must pay an extra five cents per purchase of a recyclable beverage container, under the assumption that they will get that five cents back once the container is returned to a recycling facility.[58]

The recyclable materials that fall under the "Bottle Bill" law include glass, plastic, metal, and aluminum or bi-metal beverage containers. Legally, all of the materials listed in the Bottle Bill law must carry a deposit label before they are sold.[59]

Retailers must redeem empty containers during all of their business hours and are required to accept 120 containers in one day from any one person, but may choose to accept more.[60] If additional regulations were set in place to mandate a minimum acceptance of 200 recyclable containers per day by retailers, then recycling could be encouraged even further.

Any person who violates the Bottle Bill law may be subject to a civil penalty up to one thousand dollars for each violation. In addition, any person who attempts to redeem empty beverage containers that they know were not originally sold in Massachusetts is subject to a civil penalty of one hundred dollars per container or up to twenty-five thousand dollars for each tender of containers. The Attorney General and local district attorneys are responsible for enforcing the provisions of the Bottle Bill law.[61]

Finally, product labeling allows for increased transparency in the production process of materials that consumers are purchasing. Labeling mandates require companies to label the amount of recycled material that has gone into their products, including the packaging, which allows citizens to make more informed decisions about the environmental impact of products

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[54] Report to Congress on the Implementation of the Resource Conservation and Recovery Act (RCRA), Farm Security and Rural Investment Act of 2002 and the Food Conservation, and Energy Act of 2008. *Office of Federal Procurement Policy, Office of Management and Budget.* Nov 2011. Report.

[55] The Garbage Primer. *The League of Women Voters* (1993). New York: Lyons & Burford. pp. 35–72. Print.

[56] The Garbage Primer. *The League of Women Voters* (1993). New York: Lyons & Burford. pp. 35–72. Print.

[57] What is a Bottle Bill? *Bottle Bill Resource Guide*. n.d. Web. 31 Apr 2012. <http://www.bottlebill.org/legislation/usa/massachusetts.htm>.

[58] What is a Bottle Bill? *Bottle Bill Resource Guide*. n.d. Web. 31 Apr 2012. <http://www.bottlebill.org/legislation/usa/massachusetts.htm>.

[59] Guide for Consumers to the Bottle Bill. *Massachusetts Department of Environmental Protection.* n.d. Web. 31 Apr 2012. < http://www.mass.gov/dep/recycle/reduce/bbillcon.htm>.

[60] Guide for Consumers to the Bottle Bill. *Massachusetts Department of Environmental Protection.* n.d. Web. 31 Apr 2012. < http://www.mass.gov/dep/recycle/reduce/bbillcon.htm>.

[61] Guide for Consumers to the Bottle Bill. *Massachusetts Department of Environmental Protection.* n.d. Web. 31 Apr 2012. < http://www.mass.gov/dep/recycle/reduce/bbillcon.htm>.

they are purchasing. Improved product labeling also empowers the public through informed consumer demand to influence the inclusion of environmental issues in corporate decision-making.[62]

Broad structural reforms are a necessary to implement alongside individual mitigation efforts. They can be addressed through legislation ranging from direct laws that target the recycling practices themselves, to more indirect laws such as a carbon tax price setting that makes it more costly to unsustainable dispose of waste. Being a small piece of a much larger system, Wellesley College cannot only look inward for a shift in waste habits, but must also reflect outward and support policies such as the ones described above when considering its role in future waste-related sustainability initiatives.

3.4 Conclusions

Although the current functioning of Wellesley College's waste stream leaves a lot to be desired, there is also a good deal of room for improvement in the sustainability and environmental impact of our waste stream. While some recommendations may prove to be more difficult than others, a targeting of the largest components of our waste stream and largest impact areas, such as food service and plastic waste, is crucial for improving the sustainability of our waste practices. Additionally, in reviewing overall recommendations for waste handling in the future, some options for improvement could positively influence several aspects of our waste stream at once, and therefore might be more desirable to implement. For example, a focus on minimized food waste sent to incineration could both increase the likelihood of composting food waste in the future as well as save the college money from unnecessary and excessive food provision that goes uneaten. Above all, establishing a dialogue with all parties involved in waste handling and production on campus is essential for improvements in our waste stream and waste handling at Wellesley College. Without holding students, faculty, and staff accountable for the impacts of their waste at Wellesley, our unsustainable waste practices will only continue.

[62] The Garbage Primer. *The League of Women Voters* (1993). New York: Lyons & Burford. pp. 35–72. Print.

3.5 Future Work

Our analysis of the Wellesley College waste stream has been an enormous undertaking. Unfortunately, we have not been able to address everything we would find useful in making recommendations to improve the environmental impacts of Wellesley's waste, especially in light of the new questions that arose from our findings. We therefore highlight here our hopes for future work to be pursued in order to augment the work that we have already done.

The first, and perhaps most obvious, avenue for further research is doing an environmental impact analysis of some of the recommendations made that we have not had the opportunity to conduct ourselves. In particular, we need an environmental impact analysis of the composting options we could use for composting food in addition to yard waste. One of the most important lessons from our life-cycle assessments is that there are a variety of environmental benefits and problems from any kind of waste disposal, and it is important to assess all of them (along with costs and logistics) before making a specific recommendation.

In particular, there are many different approaches to composting, from on-site versions to off-site industrial composting facility options; each has different implications for environmental effects and costs, and a thorough analysis needs to be done in order to decide which option is the most environmentally and financially sustainable. It is especially important to pursue this analysis given the likelihood that Massachusetts will soon require diversion of organic material from institutional waste streams.[1]

It is also important to investigate alternative disposal options for our on-campus waste. It is possible, for example, that we can cause less environmental harm by switching our recycling facility from Conigliaro Industries to the Town of Wellesley's Recycling and Disposal Facility (RDF). However, the relative impacts of the RDF would depend on where recycling is sent and how it is processed there. The comparison of economic costs is also unclear until someone performs a complete financial analysis, because pricing Wellesley College's waste is not as simple as comparing the fees (or payments) for recycling; instead a comparison of the sorting requirements, transportation options, and labor costs that would go into disposal processes would lead to a more reliable conclusion regarding which recycling facility has less of an environmental and financial impact.

In discussing alternative disposal options, it also would be helpful if future research could focus on what the costs of disposing of waste in one facility over the others really are, along with the full variety of options that could be considered. The way Wellesley College currently pays for waste disposal is not typical, and it would be helpful to know what the costs and benefits would be if existing waste contracts were re-negotiated.

Additionally, it is important to do further research into the policies that affect disposal of waste on-campus. In our research, we found some cases in which the most responsible way to dispose of a material waste, such as recycling electronics,

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1 Organic Waste Recycling. *Center for EcoTechnology*. n.d. Web. 14 May 2012. <http://www.cetonline.org/FarmBusiness/farm_composting.php>.

occasionally clashed with college policy in other areas, such as the college information security policy, which avoids computer recycling due to potential data theft.[2] Due to time constraints, we were not able to look at these policies thoroughly, but further research could help Wellesley formulate a waste disposal policy that takes into account concerns about security, economics, and convenience for the college as a whole.

Finally, we think that any future work needs to involve more research on how to implement best-disposal practices across the campus. The general message of our work is that beyond reduction in consumption, there is not any single practice that will efficiently reduce waste across the board; among our most potentially effective recommendations, better management of free printing for students only addresses about 10% of Wellesley's total waste stream. Moreover, even if we adjusted the way that food is disposed of in the dining halls, dining hall waste is about 18% of our total waste stream. In some cases, improvement involves figuring out how to efficiently expand existing programs. For example, one of the problems with our current electronics recycling program is that many students don't know that it exists. Other programs, such as the proposed switch from handing out water bottles to using cups and pitchers at department-sponsored events, will need to be built from scratch, and integrated with other programs.

While Wellesley College still has much to consider in the ways of waste management, there are some recently adopted practices, such as yard composting, that have been extremely successful at reducing the impact of our waste. When working on other programs in the future, it will be helpful to consider how successful waste practices were implemented in the past, and how current practices can aid future implementation of more sustainable waste management at Wellesley College.

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[2] Wellesley College Written Information Security Program. *Wellesley College*. n.d. Web. 14 May 2012. <http://www.wellesley.edu/Policy/WISPFeb2010.pdf>.

Appendix A: Common Assumptions

1. Number of Students= 2300[1]
2. Number of Faculty/Staff= 1200
3. Number of Custodial Staff= 65[2]
4. Number of Residence Halls= 20[3]
    a. New Dorms (Residential Use)
        i. 12 Months of Use (Academic and Summer)
        ii. 400 Students
    b. Tower Complex (Residential Use)
        i. 8 Months of use (Academic Only)
        ii. 605 Students
    c. Residential Quad (Residential Use)
        i. 11 Months of use (Academic + Explo (June, July, August))
        ii. 757 Students
    d. Stone Davis (Residential Use)
        i. 8 Months (Academic Only)
        ii. 245 Students
5. Number of Academic and Administrative Buildings = 20
        i. Observatory, Distribution Center, Pendleton, Jewett, Green, Founders, Clapp Library, Science Center, Weaver House, Cheever House, Campus Police, Facilities, Schneider/Billings, Sports Center, Health Services/Stone Center, Davis Museum, Power Plant, Wellesley Centers for Women
6. Number of Dining Halls = 5
    a. Months Bates Dining Hall Open = 9 months (Everything except June, July, and August)
    b. Months Pomeroy Dining Hall Open = 8 Months (No Wintersession or Summer)
    c. Months Stone Davis Dining Hall Open (no weekends) = 8 Months (No Wintersession or Summer)
    d. Months Lulu Dining Hall Open = 12 months
    e. Months Tower Dining Hall Open = 8 months (No Wintersession or Summer)
    f. Months Auxiliary Food Services Open
        i. El Table= 8 Months
        ii. The Hoop= 8 Months
        iii. The Pub= 8 Months
        iv. Collins= 12 Months
        v. Emporium= 12 Months

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[1] Wellesley Facts. *Wellesley College*. n.d. Web. 16 Apr 2012. <http://web.wellesley.edu/web/AboutWellesley/wellesleyfacts.psml>.
[2] Kevin Kesterson. Personal Interview. 16 Apr 2012.
[3] Residence Halls. *Wellesley College*. n.d. Web. 16 Apr 2012. <http://web.wellesley.edu/web/StudentLife/ResidenceLife/residencehalls.psml>.

vi. Leaky Beaker= 12 Months
vii.College Club= 12 Months

7. Number of Auxiliary "Special Events" Annually
    a. September: Orientation, Move-in Day, Flower Sunday, and Lake Day
    b. October: Homecoming, Tanner Conference, Fall Break
    c. November: Fall Frenzy, student org events (Mamaland, Shruti Laya), Thanksgiving Break
    d. December: Move-out (for graduating seniors)
    e. January: Wintersession (new dorms)
    f. February: student org events, Alumnae Achievement Awards
    g. March: student events (Yuki Matsuri, Nightmarket, CSA/KSA culture show), Spring Break
    h. April: Ruhlman Conference, Marathon Monday
    i. May: Commencement, Sustainable Moveout (for the general student body)
    j. June: Upward Bound (Munger), Explo Move-In
    k. July: Explo , Summer Session
    l. August: Explo Move-Out (quad area), Upward Bound Move-out, Summer Session II
8. Metals are sent to Schnitzer's Metal Processing where they are shredded and shipped overseas for processing[4] (http://www.schnitzersteel.com/)
9. About 40% of glass received (including bottles and windows) is ground for inclusion in the cement blocks. 60% of glass received (generally commingled bottles) is sent to Casella Recycling (to one of two facilities in Charlestown or Auburn, MA). [5](http://www.casella.com/)
10. Only about 1% of plastics received are ground for inclusion in the cement blocks. The other 99% of plastics received is sent to Casella Recycling (to one of two facilities in Charlestown or Auburn, MA).[6] (http://www.casella.com/)
11. Aseptic containers sent to Conigliaro for recycling are sent to Casella Recycling.[7] (http://www.casella.com/)
12. Transportation Distances
    a. Distance to Conigliaro= 10.78 km
    b. Distance to Casella= 39.91 km
    c. Distance to Schnizer Metal Processing= 42 km
    d. Distance to Conigliaro and then to Casella (whole trip)= 50.69 km
    e. Distance to Conigliaro then to Schnizer Metal Processing= 52.78 km
    f. Distance to Northeast Lamp Recycling= 141.44 km
    g. Distance to SEMASS (including transfer at Holliston)= 98.16 km

[4] Interview. Richard Garrison, VP of Operations at Conigliaro Industries. 30 Mar 2012.
[5] Interview. Richard Garrison, VP of Operations at Conigliaro Industries. 30 Mar 2012.
[6] Interview. Richard Garrison, VP of Operations at Conigliaro Industries. 30 Mar 2012.
[7] Richard Garrison. Personal Interview. 14 Mar 2012.

h. Distance to Overseas Processing (assumed common location is Shanghai, China)= 17,080 km

13. SEMASS Waste-To-Energy Efficiency = 76.7%[8]

[8] Themelis, K.J., Kim, Y.H., Brady, M.H. "Energy Recovery from New York City Solid Wastes." *ISWA Journal: Waste Management and Research*, 2002: 20, 223-233.

Appendix B: Primary Materials

Glass

Table B.1: Substance Contributions to Impact Values for Glass Bottle Material Extraction and Manufacture Per 1 kg of Material.

Impact Category	Substance	Total	Unit	% of Category Emissions	Emission Medium
Global Warming	Carbon dioxide, fossil	0.03	kg CO2 eq	96	Air
	Methane, fossil	8.98E-4	kg CO2 eq	3	Air
	Dinitrogen monoxide	2.47E-4	kg CO2 eq	1	Air
	Carbon monoxide, fossil	1.18E-4	kg CO2 eq	0	Air
	Ethane, 1,1,1,2-tertaflroro-, HFC-134a	6.1E-5	kg CO2 eq	0	Air
	Methane, biogenic	2.77E-5	kg CO2 eq	0	Air
Acidification	Nitrogen oxides	8.65E-3	H+ moles eq	82	Air
	Sulfur dioxide	1.88E-3	H+ moles eq	18	Air
	Ammonia	3.99E-5	H+ moles eq	0	Air
	Hydrogen chloride	1.71E-5	H+ moles eq	0	Air
	Hydrogen fluoride	6.38E-6	H+ moles eq	0	Air
Eutrophication	Phosphate	3.86E-5	kg N eq	68	Water
	Nitrogen oxides	9.57E-6	kg N eq	17	Air
	COD, Chemical Oxygen Demand	3.72E-6	kg N eq	7	Water
	BOD5, Biological Oxygen Demand	3.44E-6	kg N eq	6	Water

	Nitrate	1.08E-6	kg N eq	2	Water
	Ammonia	4.95E-8	kg N eq	0	Air
Carcinogens	Arsenic	1.81E-5	kg bensen eq	42	Air
	Arsenic, ion	1.09E-5	kg bensen eq	25	Water
	Lead	8.93E-6	kg bensen eq	21	Water
	Dioxin, 2,3,7,8 Tetrachlorodibenzo - p-	3.08E-6	kg bensen eq	7	Air
	Chromium	1.1E-6	kg bensen eq	3	Air
	Lead	7.67E-7	kg bensen eq	2	Air
Non-Carcinogens	Lead	0.29	kg toluene eq	83	Water
	Lead	0.03	kg toluene eq	9	Air
	Cadmium, ion	0.02	kg toluene eq	6	Water
	Aluminium	5.08E-3	kg toluene eq	1	Air
	Dioxin, 2,3,7,8 Tetrachlorodibenzo - p-	3.41E-3	kg toluene eq	1	Air
	Lead	2.68E-3	kg toluene eq	1	Soil
Respiratory	Particulates, <2.5 um	9.31E-6	kg PM2.5 eq	27	Air
	Nitrogen oxides	8.96E-6	kg PM2.5 eq	26	Air
	Sulfur dioxide	8.92E-6	kg PM2.5 eq	26	Air
	Particulates, <10 um	7.11E-6	kg PM2.5 eq	21	Air

Aluminum

Table B.2: Substance Contributions to Impact Values for Aluminum Cans Material Extraction and Manufacture Per 1kg of Material.

Impact Category	Substance	Total	Unit	% of Category Emissions	Emissions Medium
Global Warming	Carbon dioxide, land transformation	2.21	kg CO2 eq	91.32	Air
	Methane	0.10	kg CO2 eq	3.98	Air
	Methane, tetrafluoro-, CFC-14	0.08	kg CO2 eq	3.38	Air
	Ethane, hexafluoro-, HFC-116	0.02	kg CO2 eq	0.64	Air
	Dinitrogen monoxide	0.01	kg CO2 eq	0.52	Air
Acidification	Sulfur dioxide	0.38	H+ moles eq	69.56	Air
	Nitrogen oxides	0.15	H+ moles eq	28.21	Air
	Hydrogen fluoride	6.70E-03	H+ moles eq	1.24	Air
	Hydrogen chloride	4.37E-03	H+ moles eq	0.81	Air
	Ammonia	9.89E-04	H+ moles eq	0.18	Air
Eutrophication	Nitrogen oxides	1.69E-04	kg N eq	81.30	Air
	COD, Chemical Oxygen Demand	2.05E-05	kg N eq	9.88	Water
	Nitrate	8.60E-06	kg N eq	4.14	Water
	Phosphate	3.81E-06	kg N eq	1.83	Water
	Nitrogen	3.71E-06	kg N eq	1.78	Water
	Ammonia	1.23E-06	kg N eq	0.59	Air
	BOD5, Biological Oxygen Demand	9.49E-07	kg N eq	0.46	Water
	Nitric oxide	2.33E-08	kg N eq	0.01	Air
Carcinogens	Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-	0.12	kg benzene eq	98.73	Air
	Arsenic	1.10E-03	kg benzene eq	0.90	Air
	Benzo(a)pyrene	2.83E-04	kg benzene	0.23	Air

			eq		
	Lead	1.34E-04	kg benzene eq	0.11	Water
Non-Carcinogens	Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-	134.211838	kg toluene eq	96.16	Air
	Lead	4.34E+00	kg toluene eq	3.11	Water
	Lead	5.33E-01	kg toluene eq	0.38	Air
	Vanadium	0.25	kg toluene eq	0.18	Air
	Arsenic	0.06	kg toluene eq	0.04	Air
	Antimony	0.05	kg toluene eq	0.03	Air
Respiratory Effects	Sulfur dioxide	1.79E-03	kg PM2.5 eq	84.63	Air
	Particulates, < 2.5 um	1.66E-04	kg PM2.5 eq	7.87	Air
	Nitrogen oxides	1.58E-04	kg PM2.5 eq	7.50	Air

Steel

Table B.3: Substance Contributions to Impact Values for Steel Cans Material Extraction and Manufacture Per 1kg of Material.

Impact Category	Substance	Total	Unit	% of Category Emissions	Emissions Medium
Global Warming	Carbon dioxide, land transformation	0.90	kg CO2 eq	94.65	Air
	Carbon monoxide, fossil	0.02	kg CO2 eq	2.14	Air
	Methane	0.02	kg CO2 eq	1.71	Air
	Dinitrogen monoxide	0.01	kg CO2 eq	1.5	Air
Acidification	Nitrogen oxides	0.05	H+ moles eq	49.41	Air
	Sulfur dioxide	0.05	H+ moles eq	49.21	Air
	Hydrogen chloride	1.52E-03	H+ moles eq	1.38	Air
Eutrophication	Nitrogen oxides	6.02E-05	kg N eq	54.06	Air
	Phosphate	3.67E-05	kg N eq	32.96	Water
	COD, Chemical Oxygen Demand	1.05E-05	kg N eq	9.39	Water
	Nitrogen	3.99E-06	kg N eq	3.59	Water
Carcinogens	Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-	5.04E-03	kg benzene eq	95.61	Air
	Chromium	1.89E-04	kg benzene eq	3.59	Air
	Lead	1.72E-04	kg benzene eq	3.27	Air
Non-Carcinogens	Lead	6.43	kg toluene eq	80.02	Air
	Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-	5.57	kg toluene eq	69.28	Air
	Chromium	0.16	kg toluene eq	1.94	Air
	Zinc	0.11	kg toluene eq	1.34	Air
	Cadmium	0.02	kg toluene eq	0.31	Air
	Mercury	8.32E-03	kg toluene eq	0.10	Air
Respiratory Effects	Sulfur dioxide	2.57E-04	kg PM2.5 eq	82	Air
	Nitrogen oxides	5.64E-05	kg PM2.5 eq	18	Air

Aluminum

Table B.4: Kilograms of Trace Substances in 1 kg of Aluminum.

Trace Substance	kilograms of substance in 1 kg of aluminum
Dioxin	0
Lead	3.65E-4
Copper	.28
Arsenic	5.00E-08
Nitrogen	0
Carbon	5.00E-08
Sulfur	1.01E-04

Table B.5: Aluminum Trucking Impacts to SEMASS.

Impact Factor	Total (per 1 kg)	Total (per 661.68 kg annual waste)	Units
Global Warming	9.15E-03	6.06	kg Co2 eq
Acidification	3.03E-03	2.0	H+ moles eq
Eutrophication	2.89E-06	1.91E-03	kg N eq
Carcinogens	2.98E-06	1.97E-03	kg benzene eq
Non-Carcinogens	0.06	41.591	kg toluene eq
Respiratory	3.47E-06	2.30E-03	kg PM2.5 eq

Table B.6: Impacts of Aluminum Incineration at SEMASS.

Impact Factor	Total (per 1 kg)	Total (per 661.68 kg annual waste)	Units
Global Warming	4.90E-08	3.24E-3	CO2eq
Acidification	5.13E-03	3.39	H+moles eq
Eutrophication	0	0	kg N eq
Carcinogens	2.05	1,352.21	kg benzene eq
Non-Carcinogens	5,550.03	3,672,341.30	kg toluene eq
Respiratory	6.44E-03	6.44E-03	kg pm2.5 eq

Table B.7: Transportation Impacts for Aluminum Sent to Kentucky

Impact Factor	Total (per 1 kg)	Total (per 661.68 kg annual waste)	Units
Global Warming	7.49E-02	49.55	CO2eq
Acidification	4.36E-02	28.84	H+moles eq
Eutrophication	1.07E-04	0.07	kg N eq
Carcinogens	0.72	476.54	kg benzene eq
Non-Carcinogens	1.23E-04	0.08	kg toluene eq
Respiratory Effects	1.31E-04	0.09	kg pm2.5 eq

Table B.8: Facility Impacts for Aluminum Sent to Kentucky

Impact Factor	Total (per 1 kg)	Total (per 661.68 kg annual waste)	Units
Global Warming	0.427	282.54	CO2eq
Acidification	1.86	1230.72	H+moles eq
Eutrophication	2.18E-04	0.14	kg N eq
Carcinogens	1.48	979.29	kg benzene eq
Non-Carcinogens	7.41E-04	0.49	kg toluene eq
Respiratory	4.08E-05	0.03	kg pm2.5 eq

TableB.9 Facility Credits for Aluminum Sent to Kentucky

Impact Factor	Total (per 1 kg)	Total (per 661.68 kg annual waste)	Units
Global Warming	-3.18	-1,790.91	CO2eq
Acidification	-0.71	778.80	H+moles eq
Eutrophication	-2.66E-04	-0.11	kg N eq
Carcinogens	-.21	156.35	kg benzene eq
Non-Carcinogens	-241	-158,485.54	kg toluene eq
Respiratory	-2.83E-03	-1.33	kg pm2.5 eq

Table B.10: Aluminum Trucking Impacts to Schnitzer Steel via Conigliaro.

Impact Factor	Total (per 1 kg)	Total (per 806.8 kg annual waste)	Units
Global Warming	9.15E-03	7.39	kg CO2 eq
Acidification	2.68E-03	2.16	H+ moles eq
Eutrophication	2.85E-06	2.30E-03	kg N eq
Carcinogens	0	0	kg benzen eq
Non-Carcinogens	0	0	kg toluen eq
Respiratory Effects	2.67E-06	2.15E-03	kg PM2.5 eq

Table B.11: Impact of Aluminum Sorting At Schnitzer Steel.

Impact Factor	Total (per 1 kg)	Total (per 806.8 kg annual waste)	Units
Global Warming	0.184	148.45	kg CO2 eq
Acidification	8.02E-02	64.71	H+ moles eq
Eutrophication	9.40E-05	0.08	kg N eq
Carcinogens	0.794	640.60	kg benzen eq
Non-Carcinogens	3.20E-04	0.26	kg toluen eq
Respiratory	1.76E-05	0.01	kg PM2.5 eq

Table B.12: Aluminum Shipping Impacts to Overseas Processors (Shanghai, China).

Impact Factor	Total (per 1 kg)	Total (per 806.8 kg annual waste)	Unit
Global Warming	0.79	638.76	kg CO2 eq
Acidification	0.41	329.17	H+moles eq
Eutrophication	1.39E-03	1.12	kg N eq
Carcinogens	6.76E-04	0.55	kg benzene eq
Non-Carcinogens	5.46	4,407.82	kg toluene eq
Respiratory	9.69E-04	0.78	kg pm2.5 eq

Table B.13: Overseas Recycling Impact of Aluminum

Impact Factor	Total (per 1 kg)	Total (per 806.8 kg annual waste)	Unit
Global Warming	0.427	344.50	kg CO2 eq
Acidification	1.86	1500.65	H+moles eq
Eutrophication	2.18E-04	0.18	kg N eq
Carcinogens	1.48	1194.06	kg benzene eq
Non-Carcinogens	7.41E-04	0.60	kg toluene eq
Respiratory	4.08E-05	0.03	kg pm2.5 eq

Table B.14: Facility Credit for Aluminum Handling.

Impact Factor	Total (per 1 kg)	Total (per 806.8 kg annual waste)	Unit
Global Warming	-3.18	2565.62	kg CO2 eq
Acidification	-0.71	572.83	H+ moles eq
Eutrophication	-2.66E-04	169.43	kg N eq
Carcinogens	-.21	194438.80	kg benzene eq
Non-Carcinogens	-241	2.28	kg toluene eq
Respiratory	-2.83E-03	0.21	kg pm2.5 eq

Steel

Table B.15: Kilograms of Trace Substances in 1 kg of Steel Cans.

Trace Substance	kilograms of substance in 1 kg of steel
Dioxin	0
Lead	2.50E-03
Copper	6.00E-03
Arsenic	1.95E-03
Nitrogen	8.50E-05
Carbon	3.00E-03
Sulfur	9.00E-04

Table B.16: Steel Can Trucking Impacts to SEMASS.

Impact category	Total impact per 1kg	Total impact for 9,702.26 kg	Units
Global warming	9.15E-03	88.79	kg CO2 eq
Acidification	3.03E-03	29.37	H+ moles eq
Eutrophication	2.89E-06	2.81E-02	kg N eq
Carcinogens	2.98E-06	2.89E-02	kg benzene eq
Non-Carcinogens	0.06	609.85	kg toluene eq
Respiratory effects	3.47E-06	3.37E-02	kg PM2.5 eq

Table B.17: Steel Can Trucking Impacts to Mid-City Scrap Iron & Salvage Co Inc.

Impact category	Total impact per 1 kg	Total impact per 9,702.26 kg	Units
Global warming	1.95E-03	18.91	kg CO2 eq
Acidification	6.45E-04	6.25	H+ moles eq
Eutrophication	6.16E-07	5.97E-03	kg N eq
Carcinogens	6.34E-07	6.16E-03	kg benzene eq
Non-Carcinogens	1.34E-02	129.85	kg toluene eq
Respiratory effects	7.39E-07	7.17E-03	kg PM2.5 eq

Table B.18: Steel Can Shipping Impacts to Overseas Processors (Shanghai, China).

Impact category	Total impact for 1 kg	Total impact for 7,276.70 kg	Unit
Global warming	0.79	5,748.59	kg CO2 eq
Acidification	0.41	2,983.45	H+ moles eq
Eutrophication	1.39E-03	10.11	kg N eq
Carcinogens	6.76E-04	4.92	kg benzene eq
Non-Carcinogens	5.47	39,803.55	kg toluene eq
Respiratory effects	9.69E-04	7.05	kg PM2.5 eq

Table B.19: Impacts of Sending Steel Can Wastes by Rail (Ghent, Kentucky and Hamilton, Ontario).

Impact category	Total impact for 1 kg transported to KY	Total impact for 1,212.78 kg transported to KY	Total impact for 1 kg transported to Ontario	Total impact for 1,212.78 kg transported to Ontario	Units
Global warming	7.49E-02	135,941.73	4.18E-02	42,337.15	kg CO2 eq
Acidification	4.36E-02	79,119.43	2.43E-02	24,640.64	H+ moles eq
Eutrophication	1.31E-04	237.06	7.29E-05	73.83	kg N eq
Carcinogens	1.07E-04	193.75	5.96E-05	60.34	kg benzene eq
Non-Carcinogens	7.20E-01	1,307,282.04	4.02E-01	407,134.70	kg toluene eq
Respiratory effects	1.23E-04	223.17	6.86E-05	69.50	kg PM2.5 eq

Table B.20: Total Impacts of Steel Can Transportation from Wellesley to Ghent, KY, Hamilton, Ontario, and Shanghai, China

Impact Category	Total transportation impact for 1 kg	Total transportation impact 9,702.26 kg	Unit
Global warming	0.92	184,135.17	kg CO2 eq
Acidification	0.48	106,779.14	H+ moles eq
Eutrophication	1.60E-03	321.03	kg N eq
Carcinogens	8.46E-04	259.05	kg benzene eq
Non-Carcinogens	6.67	1,754,959.99	kg toluene eq
Respiratory effects	1.16E-03	299.76	kg PM2.5 eq

Table B.21: Total Impacts of Steel Can Incineration at SEMASS.

Impact category	Total impact per 1 kg	Total impact for 1,940.45 kg	Unit
Global warming	0.88	1,705.77	kg CO2 eq
Acidification	0.02	41.95	H+ moles eq
Eutrophication	7.53E-08	1.46E-04	kg N eq
Carcinogens	2.19	4246.31	kg benzene eq
Non-Carcinogens	27,224.38	52,827,540.47	kg toluene eq
Respiratory effects	9.01E-05	0.17	kg PM2.5 eq

Table B.22: Impact for Operating a Double Roll Crusher for 1 kg and 9,702.20 kg of Steel.

Impact category	Total for 1kg	Total for 9,702.20 kg	Unit
Global warming	1.19E-05	0.12	kg CO2 eq
Acidification	2.64E-06	0.03	H+ moles eq
Eutrophication	5.50E-08	5.34E-04	kg N eq
Carcinogens	7.50E-08	7.28E-04	kg benzene eq
Non-Carcinogens	5.31E-04	5.15	kg toluene eq
Respiratory effects	3.73E-08	3.62E-04	kg PM2.5 eq

Table B.23: Impacts of Operating a Hammer Mill for 1 kg and 9,702.20 kg of Steel.

Impact Category	Total for 1 kg	Total for 9,702.20 kg	Units
Global warming	0.13	1242.78	kg CO2 eq
Acidification	0.06	540.70	H+ moles eq
Carcinogens	6.53E-05	0.63	kg benzene eq
Non-Carcinogens	0.55	5352.77	kg toluene eq
Respiratory effects	2.22E-04	2.16	kg PM2.5 eq
Eutrophication	1.22E-05	0.12	kg N eq

Table B.24: Manufacturing Impacts of Forming Steel Slabs from Recycled Steel.

Impact category	Total impact for 1kg	Total impact for 9,702.20 kg	Unit
Global warming	0.76	7,373.67	kg CO2 eq
Acidification	0.09	873.20	H+ moles eq
Eutrophication	0	0	kg N eq
Carcinogens	4.22E-03	40.94	kg benzene eq
Non-Carcinogens	6.43	62,385.15	kg toluene eq
Respiratory effects	2.50E-04	2.43	kg PM2.5 eq

Table B.25: Total facility impacts for SEMASS and Mid-City Scrap Iron & Salvage Co.

Impact Category	Total for 1 kg	Total for 9,702.20 kg	Unit
Global warming	1.77	10,322.34	kg CO2 eq
Acidification	0.17	1,455.88	H+ moles eq
Eutrophication	6.54E-05	0.63	kg N eq
Carcinogens	2.74	9.640.02	kg benzene eq
Non-Carcinogens	27230.81	52,889,932.93	kg toluene eq
Respiratory effects	3.52E-04	2.72	kg PM2.5 eq

Table B.26: Avoided Impacts for Waste-to-Energy at SEMASS for Steel Cans

Impact Category	Total Annual Energy Credit per 1 kg	Total Annual Energy Credit for 1,940.45 kg	Units
Global warming	-0.26	-1943.34	kg CO2 eq
Acidification	-0.11	-845.50	H+ moles eq
Eutrophication	-2.50E-05	-0.19	kg N eq
Carcinogens	-1.33E-04	-0.99	kg benzene eq
Non Carcinogens	-1.12	-8370.16	kg toluene eq
Respiratory effects	-4.53E-04	-3.37	kg PM2.5 eq

Table B.27: Avoided Impacts for Recycling Steel Cans.

Impact category	Total credit per 1 kg	Total credit per 9,702.20
Global warming	-0.95	-9,217.09
Acidification	-0.11	-1,067.22
Eutrophication	0	0
Carcinogens	-5.27E-03	-51.13
Non-Carcinogens	-8.04	-78,005.69
Respiratory effects	-3.13E-04	-3.04

Table B.28: Total Credit for Steel Cans Sent to SEMASS.

Impact category	Total credit per 1 kg	Total credit per 9,702.20
Global warming	-2.26	-11,160.43
Acidification	-0.68	-1,912.72
Eutrophication	-1.25E-04	-0.19
Carcinogens	-5.94E-03	-52.12
Non-Carcinogens	-13.66	-86,375.85
Respiratory effects	-2.58E-03	-6.41

Table B.29: Steel Can Trucking Impacts to Conigliaro and then to Schnitzer's Metal Shredding Facility.

Impact category	Total impacts for 1 kg	Total impacts for 4,778.72 kg	Unit
Global warming	0.01	43.75	kg CO2 eq
Acidification	2.68E-03	1.28E+01	H+ moles eq
Eutrophication	2.85E-06	1.36E-02	kg N eq
Carcinogens	-	-	kg benzene eq
Non-Carcinogens	-	-	kg toluene eq
Respiratory effects	2.67E-06	1.28E-02	kg PM2.5 eq

Table B.30: Steel Can Shipping Impacts to Overseas Processors (Shanghai, China).

Impact category	Total impact for 1 kg	Total impact for 3,584.04 kg	Unit
Global warming	0.79	2831.39	kg CO2 eq
Acidification	0.41	1469.46	H+ moles eq
Eutrophication	1.39E-03	4.98	kg N eq
Carcinogens	6.76E-04	2.42	kg benzene eq
Non-Carcinogens	5.47	19604.70	kg toluene eq
Respiratory effects	9.69E-04	3.47	kg PM2.5 eq

Table B.31: Impacts of sending Steel Can Waste by Rail (Ghent, Kentucky and Hamilton, Ontario).

Impact category	Total impact for 1 kg transported to KY	Total impact for 597.34 kg transported to KY	Total impact for 1 kg transported to Ontario	Total impact for 597.34 kg transported to Ontario	Units
Global warming	7.49E-02	66,956.44	4.18E-02	20,852.65	kg CO2 eq
Acidification	4.36E-02	38,969.31	2.43E-02	12,136.45	H+ moles eq
Eutrophication	1.31E-04	116.76	7.29E-05	36.36	kg N eq
Carcinogens	1.07E-04	95.43	5.96E-05	29.72	kg benzene eq
Non-Carcinogens	7.20E-01	643,885.83	4.02E-01	200,529.23	kg toluene eq
Respiratory effects	1.23E-04	109.92	6.86E-05	34.23	kg PM2.5 eq

Table B.32: Total Impacts of Steel Can Transportation from Wellesley to Ghent, KY, Hamilton, Ontario, and Shanghai, China

Impact Category	Total transportation impact for 1 kg	Total transportation impact 4,478.72 kg	Unit
Global warming	0.92	90,684.23	kg CO2 eq
Acidification	0.48	52,588.02	H+ moles eq
Eutrophication	1.60E-03	158.11	kg N eq
Carcinogens	8.43E-04	127.57	kg benzene eq
Non-Carcinogens	6.59	864,019.76	kg toluene eq
Respiratory effects	1.16E-03	147.63	kg PM2.5 eq

Table B.33: Impact for Operating a Double Roll Crusher for 1 kg and 4,778.72 kg of Steel.

Impact category	Total for 1kg	Total for 4,778.72 kg	Unit
Global warming	1.19E-05	0.05	kg CO2 eq
Acidification	2.64E-06	0.01	H+ moles eq
Eutrophication	5.50E-08	2.63E-04	kg N eq
Carcinogens	7.50E-08	3.59E-04	kg benzene eq
Non-Carcinogens	5.31E-04	2.54	kg toluene eq
Respiratory effects	3.73E-08	1.78E-04	kg PM2.5 eq

Table B.34: Impacts of Operating a Hammer Mill for 1 kg and 4,778.72 kg of Steel.

Impact Category	Total for 1 kg	Total for 4,778.72 kg	Units
Global warming	0.13	612.12	kg CO2 eq
Acidification	0.06	266.32	H+ moles eq
Carcinogens	6.53E-05	0.31	kg benzene eq
Non-Carcinogens	0.55	2636.45	kg toluene eq
Respiratory effects	2.22E-04	1.06	kg PM2.5 eq
Eutrophication	1.22E-05	0.06	kg N eq

Table B.35: Manufacturing Impacts of Forming Steel Slabs from Recycled Steel.

Impact category	Total impact for 1 kg	Total impact for 4,778.72 kg	Unit
Global warming	0.76	3,631.83	kg CO2 eq
Acidification	0.09	430.08	H+ moles eq
Eutrophication	0	0	kg N eq
Carcinogens	4.22E-03	20.17	kg benzene eq
Non-Carcinogens	6.43	30,727.17	kg toluene eq
Respiratory effects	2.50E-04	1.19	kg PM2.5 eq

Table B.36: Total Facility Impacts of Steel Sent to Schnitzer's Recycling Facility.

Impact Category	Total for 1 kg	Total for 14,480.98 kg	Unit
Global warming	0.89	4,244	kg CO2 eq
Acidification	0.15	696.41	H+ moles eq
Eutrophication	6.54E-05	0.31	kg N eq
Carcinogens	0.55	2,656.62	kg benzene eq
Non-Carcinogens	6.43	30,730.77	kg toluene eq
Respiratory effects	2.62E-04	1.25	kg PM2.5 eq

Table B.37: Credit for Recycling Steel Cans.

Impact category	Total credit per 1 kg	Total credit per 4,778.20
Global warming	-0.95	-4,254.29
Acidification	-0.11	-492.60
Eutrophication	0	0
Carcinogens	-5.27E-03	-23.60
Non-Carcinogens	-8.04	-36,004.73
Respiratory effects	-3.13E-04	-1.40

Appendix C: Paper

Table C.1: Substance Contributions to Impact Values for Aseptic Container Material Extraction and Manufacture Per 1 kg of Material.

Impact Category	Substance	Total	Unit	% of Category Emissions	Emission Medium
Global Warming	Carbon dioxide	1.24	kg CO2 eq	85.28	Air
	Methane	0.11	kg CO2 eq	7.56	Air
	Methane, tetrafluoro-, CFC-14	0.05	kg CO2 eq	3.72	Air
	Dinitrogen monoxide	1.64E-02	kg CO2 eq	1.13	Air
	Ethane, hexafluoro-, HFC-116	1.24E-02	kg CO2 eq	0.85	Air
	Carbon monoxide	1.14E-02	kg CO2 eq	0.79	Air
Acidification	Sulfur dioxide	0.20	H+ moles eq	57.07	Air
	Nitrogen oxides	0.14	H+ moles eq	40.33	Air
	Ammonia	4.44E-03	H+ moles eq	1.28	Air
	Hydrogen fluoride	2.39E-	H+	0.69	Air

		03	moles eq		
	Hydrogen chloride	2.17E-03	H+ moles eq	0.63	Air
Eutrophication	Phosphate	2.82E-03	kg N eq	65.56	Water
	COD, Chemical Oxygen Demand	7.37E-04	kg N eq	17.13	Water
	Nitrogen	1.83E-04	kg N eq	4.25	Water
	BOD5, Biological Oxygen Demand	1.75E-04	kg N eq	4.06	Water
	Nitrogen oxides	1.54E-04	kg N eq	3.59	Air
	Phosphorus	1.24E-04	kg N eq	2.88	Water
Carcinogens	Arsenic	1.76E-03	kg benzen eq	36.35	Air
	Lead	1.50E-03	kg benzen eq	30.97	Water
	Arsenic, ion	1.21E-03	kg benzen eq	24.93	Water
	Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-	1.02E-04	kg benzen eq	2.11	Air
Non-carcinogens	Lead	48.41	kg toluen	88.15	Water

			eq		
	Cadmium, ion	2.51	kg toluen eq	4.58	Water
	Lead	1.84	kg toluen eq	3.35	Air
	Vanadium	0.58	kg toluen eq	1.05	Air
	Aluminium	0.42	kg toluen eq	0.76	Air
	Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-	0.11	kg toluen eq	0.21	Air
Respiratory Effects	Sulfur dioxide	9.36E-04	kg PM2.5 eq	47.35	Air
	Particulates, < 2.5 um	4.58E-04	kg PM2.5 eq	23.16	Air
	Particulates, > 10 um	4.38E-04	kg PM2.5 eq	22.16	Air
	Nitrogen oxides	1.45E-04	kg PM2.5 eq	7.32	Air

Table C.2: Substance Contributions to Impacts for Office Paper Material Extraction and Manufacture Per 1kg of Material.

Impact Category	Substance	Total	Unit	% of Category Emissions	Emission Medium
Non-Carcinogens	Lead	90.3	kg toluene eq	92.19	Water
	Lead	1.61	kg toluene eq	1.64	Air
	Cadmium, ion	2.80	kg toluene eq	2.86	Water
	Vanadium	0.54	kg toluene eq	0.55	Air
	Aluminium	0.52	kg toluene eq	0.53	Soil
	Manganese	0.36	kg toluene eq	0.36	Soil
Respiratory effects	Sulfur dioxide	0.00137	kg PM2.5 eq	0.57	Air
	Particulates, <2.5 um	0.00067	kg PM2.5 eq	0.28	Air
	Particulates, > 10 um	0.0002	kg PM2.5 eq	0.08	Air
	Nitrogen oxides	0.00016	kg PM2.5 eq	0.07	Air

Global Warming	Carbon dioxide, fossil	0.76	kg CO2 eq	92.28	Air
	Methane, fossil	0.03	kg CO2 eq	3.60	Air
	Dinitrogen monoxide	0.02	kg CO2 eq	2.26	Air
	Methane, biogenic	0.01	kg CO2 eq	0.92	Air
	Carbon dioxide, land transformation	3.24E-3	kg CO2 eq	0.39	Air
	Carbon monoxide, fossil	2.25E-3	kg CO2 eq	0.27	Air
Acidification	Sulfur dioxide	0.29	H+ moles eq	63.09	Air
	Nitrogen oxides	0.16	H+ moles eq	34.61	Air
	Ammonia	8.12E-3	H+ moles eq	1.78	Air
	Hydrogen chloride	2.0E-3	H+ moles eq	0.44	Air
Eutrophication	Phosphate	2.83E-3	kg N eq	43.68	Water
	Chemical Oxygen Demand	2.1E-3	kg N eq	32.43	Water
	Nitrogen	4.54E-4	kg N eq	7.01	Water
	Nitrate	3.61E-4	kg N eq	5.57	Water
	Biological Oxygen Demand	2.44E-4	kg N eq	3.77	Water
	Phosphorus	1.75E-4	kg N eq	3.36	Water

Carcinogens	Lead	2.79E-3	kg benzene eq	55.14	Water
	Arsenic	1.17E-3	kg benzene eq	23.04	Air
	Arsenic, ion	7.06E-4	kg benzene eq	13.93	Water
	Dioxin, 2, 3, 7, 8, Tetrachlorodibenzo-p-	1.89E-4	kg benzene eq	3.74	Air
	Arsenic	8.03E-5	kg benzene eq	1.59	Soil
	Chromium	5.12E-5	kg benzene eq	1.01	Air

Table C.3: Substance Contributions to Impact Values for Boxboard Material Extraction and Manufacture Per 1 kg of Material.

Impact Category	Substance	Total	Unit	% of Category Emissions	Emission Medium
Global Warming	Carbon dioxide	1.23	kg CO2 eq	94.03	Air
	Methane	0.05	kg CO2 eq	3.78	Air
	Dinitrogen monoxide	0.02	kg CO2 eq	1.39	Air
	Methane, biogenic	5.02E-3	kg CO2 eq	0.38	Air
	Carbon monoxide	3.48E-3	kg CO2 eq	0.27	Air
	Sulfur hexafluoride	1.87E-3	kg CO2 eq	0.14	Air
Acidification	Sulfur oxides	0.21	H+ moles eq	57.50	Air
	Nitrogen dioxide	0.14	H+ moles eq	39.62	Air
	Ammonia	7.46E-3	H+ moles eq	2.05	Air
	Hydrogen chloride	2.34E-3	H+ moles eq	0.64	Air
	Hydrogen fluoride	6.88E-4	H+ moles eq	0.19	Air
Eutrophication	Phosphate	4.15E-3	kg N eq	72.21	Water
	COD, Chemical Oxygen	7.44E-	kg N eq	12.94	Air

	Demand	4			
	Nitrate	3.60E-4	kg N eq	6.26	Water
	Nitrogen	1.72E-4	kg N eq	3.00	Water
	BOD5, Biological Oxygen Demand	1.61E-4	kg N eq	2.81	Water
	Nitrogen oxides			2.77	
Carcinogens	Lead	2.31E-3	kg benzene eq	43.12	Water
	Arsenic	1.64E-3	kg benzene eq	30.68	Air
	Arsenic, ion	8.43E-4	kg benzene eq	15.76	Water
	Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-	4.39E-4	kg benzene eq	8.21	Air
	Chromium	6.35E-5	kg benzene eq	1.19	Air
	Arsenic	5.56E-5	kg benzene eq	1.04	Soil
Non-Carcinogens	Lead	74.59	kg toluene eq	92.79	Water
	Cadmium, ion	1.83	kg toluene eq	2.27	Water

	Lead	1.77	kg toluene eq	2.21	Air
	Vanadium	1.33	kg toluene eq	1.66	Air
	Dioxin, 2,3,7,8	0.49	kg toluene eq	0.60	Air
	Aluminium	0.37	kg toluene eq	0.47	Air
Respiratory	Particulates, < 2.5 um	9.92E-4	kg PM2.5 eq	45.86	Air
	Nitrogen oxides	6.91E-4	kg PM2.5 eq	31.97	Air
	Sulfur dioxide	3.30E-4	kg PM2.5 eq	15.26	Air
	Particulates, > 10um	1.49E-4	kg PM2.5 eq	6.91	Air

Table C.4: Substance Contributions to Impact for Mixed Paper Material Extraction and Manufacture Per 1 kg of Material.

Impact Category	Substance	Total	Unit	% of Category Emissions	Emission Medium
Global Warming	Carbon dioxide	0.06	kg CO2 eq	95.20	Air
	Methane	1.89 E-3	kg CO2 eq	3.00	Air
	Carbon monoxide	2.68 E-4	kg CO2 eq	0.43	Air
	Dinitrogen monoxide	7.43E-4	kg CO2 eq	1.18	Air
	Ethane, 1,1,1,2-tetrafluoro-	8.77E-5	kg CO2 eq	0.14	Air
	Methane, tetrafluoro -, CFC	3.35E-5	kg CO2 eq	0.05	Air
Acidification	Nitrogen oxides	0.0199	H+ moles eq	84.59	Air
	Sulfur dioxide	0.00353	H+ moles eq	15.01	Air
	Ammonia	7.36E-5	H+ moles eq	0.31	Air
	Hydrogen chloride	1.55E-5	H+ moles eq	0.07	Air
	Hydrogen fluoride	5.43E-6	H+ moles eq	0.02	Air
Eutrophication	Phosphate	3.11E-5	kg N eq	42.98	Water
	Nitrogen oxides	2.2E-5	kg N eq	30.40	Air
	COD, Chemical Oxygen Demand	9.42E-6	kg N eq	13.02	Water

	BOD5, Biological Oxygen Demand	8.99E-6	kg N eq	12.42	Water
	Nitrate	8.54E-7	kg N eq	1.18	Water
Carcinogens	Arsenic	2.24E-5	kg benzene eq	42.83	Air
	Arsenic, ion	1.15E-5	kg benzene eq	21.99	Water
	Lead	1.11E-5	kg benzene eq	21.22	Water
	Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-	3.8E-6	kg benzene eq	7.27	Air
	Benzene	1.94E-6	kg benzene eq	3.71	Water
	Arsenic	1.56E-6	kg benzene eq	2.98	Soil
Non-Carcinogens	Lead	0.36	kg toluene eq	80.82	Water
	Lead	0.04	kg toluene eq	8.98	Air
	Cadmium, ion	0.03	kg toluene eq	6.74	Water
	Aluminum	0.01	kg toluene eq	2.25	Air

	Barium	1.22E-03	kg toluene eq	0.27	Water
	Dioxin,2,3,7,8 Tetrachlorodibenzo-p-	4.2E-3	kg toluene eq	0.94	Air
Respiratory	Particulates, < 2.5 um	2.8E-5	kg PM2.5 eq	37.37	Air
	Nitrogen oxides	2.06E-5	kg PM2.5 eq	27.50	Air
	Sulfur dioxide	1.67E-5	kg PM2.5 eq	22.29	Air
	Particulates, > 10um	9.62E-6	kg PM2.5 eq	12.84	Air

Table C.5: Contributions to Impact by Substance of Corrugated Cardboard Material Extraction and Manufacture for 1kg of Material.

Impact Category	Substance	Total	Unit	% of Category Emissions	Emission Medium
Non-Carcinogens	Lead	27.50	kg toluene eq	87.00	Water
	Cadmium, ion	1.13	kg toluene eq	3.56	Water
	Lead	1.11	kg toluene eq	3.53	Air
	Vanadium	0.63	kg toluene eq	1.99	Air
	Aluminum	0.31	kg toluene eq	0.98	Air
	Dioxin 2,3,7,8 Tetrachlorodibenzo-p-	0.13	kg toluene eq	0.40	Air
Global Warming	Carbon dioxide	0.70	kg CO2 eq	92.97	Air
	Methane, fossil	0.03	kg CO2 eq	4.26	Air
	Dinitrogen monoxide	9.38E-03	kg CO2 eq	1.25	Air
Acidification	Sulfur dioxide	0.11	H+ moles eq	49.05	Air
	Nitrogen oxides	0.11	H+ moles eq	48.04	Air

	Ammonia	4.22E-03	H+ moles eq	1.83	Air
	Hydrogen chloride	2.11E-03	H+ moles eq	9.15	Air
	Hydrogen fluoride	3.83E-04	H+ moles eq	1.66	Air
Eutrophication	Phosphate	3.01E-03	kg N eq	61.17	Water
	COD, Chemical Oxygen Demand	6.81E-04	kg N eq	13.87	Water
	Nitrogen	3.19E-04	kg N eq	6.50	Water
	Phosphorous	2.63E-04	kg N eq	5.33	Water
	Nitrate	2.51E-04	kg N eq	5.10	Water
	BOD5, Biological Oxygen Demand	2.15E-04	kg N eq	4.38	Water
Carcinogens	Arsenic	1.21E-03	kg benzene eq	42.75	Air
	Lead	8.51E-04	kg benzene eq	29.97	Water
	Arsenic, ion	5.35E-04	kg benzene eq	18.86	Water
	Dioxin 2,3,7,8 Tetrachlorodibenzo-p-	1.15E-04	kg benzene eq	4.06	Air
	Chromium	5.33E-05	kg benzene	1.88	Air

			eq		
	Lead	2.99E-05	kg benzene eq	1.06	Air
Respiratory Effects	Particulates, < 2.5 um	5.49E-04	kg PM2.5 eq	39.18	Air
	Sulfur dioxide	5.37E-04	kg PM2.5 eq	38.36	Air
	Particulates, > 10 um	1.99E-04	kg PM2.5 eq	14.24	Air
	Nitrous oxide	1.15E-04	kg PM2.5 eq	8.22	Air

Table C.6: Total Impacts of Paper Transportation from Wellesley to SEMASS

Impact Category	**Total transportation impact for 1 kg**	**Total transportation impact 154,898.74 kg**	**Unit**
Global warming	0.0092	1,425.07	kg CO2 eq
Acidification	0.003	464.7	H+ moles eq
Eutrophication	0.0000029	0.45	kg N eq
Carcinogens	0.000003	0.46	kg benzene eq
Non-Carcinogens	0.063	9,758.62	kg toluene eq
Respiratory effects	0.0000035	0.54	kg PM2.5 eq

Table C.7: Kilograms of Trace Substances Per 1 kg of Paper

Trace Substance	Kilograms of substance in 1 kg of paper
Dioxin	6.0E-9
Lead	1.5E-5
Nitrogen	2.8E-3
Carbon	0.4

Table C.8: Total Facility Impacts for Paper for SEMASS

Impact Category	Total for 1 kg	Total for 154,898.74 kg	Unit
Global warming	1.21	187,427.48	kg CO2 eq
Acidification	0.82	127,016.97	H+ moles eq
Eutrophication	0.82	127,016.97	kg N eq
Carcinogens	177.4	27,479,036.54	kg benzene eq
Non-Carcinogens	177.4	27,479,036.54	kg toluene eq
Respiratory effects	0.82	127,016.97	kg PM2.5 eq

Table C.9: Total Credit for Paper Sent to SEMASS.

Impact category	Total credit per 1 kg	Total credit per 154,898.74 kg	Unit
Global warming	-0.0016	-247.84	kg CO2 eq
Acidification	-0.00072	-111.53	H+ moles eq
Eutrophication	-0.00000016	-0.025	kg N eq
Carcinogens	-0.00000082	-0.13	kg benzene eq
Non-Carcinogens	-0.0071	-1,099.78	kg toluene eq
Respiratory effects	-0.0000028	-0.43	kg PM2.5 eq

Table C.10: Total Impacts of Paper Transportation from Wellesley to Coniglario, Casella, and Paper Mills

Impact Category	Total transportation impact for 1 kg	Total transportation impact 146,047.70 kg	Unit
Global warming	0.018	2,592.68	kg CO2 eq
Acidification	0.0052	758.1	H+ moles eq
Eutrophication	0.0000055	0.8	kg N eq
Carcinogens	0	0	kg benzene eq
Non-Carcinogens	0	0	kg toluene eq
Respiratory effects	0.0000052	0.75	kg PM2.5 eq

Table C.11: Total Facility Impacts of Paper for Sorter at Casella

Impact Category	Total for 1 kg	Total for 146,047.7 kg	Unit
Global warming	0.00012	1.74	kg CO2 eq
Acidification	0.0000026	0.38	H+ moles eq
Eutrophication	0.000000055	0.008	kg N eq
Carcinogens	0.000000075	0.011	kg benzene eq
Non-Carcinogens	0.00053	77.41	kg toluene eq
Respiratory effects	0.000000037	0.0054	kg PM2.5 eq

Table C.12: Total Facility Impacts of Paper for Pulper and Papermaking Machine in Paper Mills

Impact Category	Total for 1 kg	Total for 146,047.7 kg	Unit
Global warming	0.8	116,838.16	kg CO2 eq
Acidification	0.35	51,116.7	H+ moles eq
Eutrophication	0.000076	11.1	kg N eq
Carcinogens	0.00041	59.88	kg benzene eq
Non-Carcinogens	3.44	502404.09	kg toluene eq
Respiratory effects	0.0014	204.47	kg PM2.5 eq

Table C.13: Total Credit for Paper Sent to Conigliaro, Casella, and Paper Mills

Impact category	Total credit per 1 kg	Total credit per 146,047.7 kg	Unit
Global warming	-1.31	-191,322.53	kg CO2 eq
Acidification	-0.36	-52,577.18	H+ moles eq
Eutrophication	-0.0054	-788.66	kg N eq
Carcinogens	-82.2	-12,005,123.41	kg benzene eq
Non-Carcinogens	-0.0023	-335.91	kg toluene eq
Respiratory effects	-0.0059	-861.68	kg PM2.5 eq

Appendix D: Plastics

Table D.1: Substance contributions to impact values for #1 plastic container material extraction and manufacture for 1 kg of material.

Impact Category	Substance	Total	Unit	% of Category Emissions	Emission Medium
Global Warming	Carbon dioxide	4.11	kg CO2 eq	88.32	Air
	Methane	0.53	kg CO2 eq	11.39	Air
	Carbon monoxide	1.69E-02	kg CO2 eq	0.36	Air
Acidification	Sulfur dioxide	0.80	H+ moles eq	66.40	Air
	Nitrogen oxides	0.39	H+ moles eq	32.39	Air
	Hydrogen chloride	1.37E-02	H+ moles eq	1.13	Air
	Hydrogen fluoride	9.32E-04	H+ moles eq	7.72E-02	Air
Eutrophication	Nitrogen oxides	0.000432152	kg N eq	72.55	Air
	BOD5, Biological Oxygen Demand	9.95E-05	kg N eq	16.71	Water
	COD, Chemical Oxygen Demand	6.01E-05	kg N eq	10.09	Water
	Ammonium, ion	3.13E-06	kg N eq	0.53	Water

	Nitrate	7.36E-07	kg N eq	0.12	Water
Carcinogens	Chromium	2.54E-04	kg benzene eq	92.64	Air
	Nickel	1.00E-05	kg benzene eq	3.64	Air
	Ethylene oxide	7.36E-06	kg benzene eq	2.68	Air
	Benzene	2.32E-06	kg benzene eq	0.85	Air
	Arsenic	3.18E-07	kg benzene eq	0.12	Air
	Lead	9.07E-08	kg benzene eq	3.30E-02	Water
Non-Carcinogens	Nickel	0.48	kg toluene eq	68.84	Air
	Chromium	0.21	kg toluene eq	30.37	Air
	Lead	2.93E-03	kg toluene eq	0.42	Water
	Lead	9.77E-04	kg toluene eq	0.14	Air
	Copper, ion	4.86E-04	kg toluene	7.03E-02	Water

			eq		
	Ethylene oxide	4.13E-04	kg toluene eq	5.97E-02	Air
Respiratory	Sulfur dioxide	3.80E-03	kg PM2.5 eq	90.36	Air
	Nitrogen oxides	4.05E-04	kg PM2.5 eq	9.64	Air

Table D.2: Substance contributions to impact values for #2 plastic bottle material extraction and manufacture per 1kg of material.

Impact Category	Substance	Total	Unit	% of Category Emissions	Emission Medium
Global Warming	Carbon dioxide	2.60	kg CO2 eq	84.97	Air
	Methane	0.44	kg CO2 eq	14.38	Air
	Carbon monoxide	0.03	kg CO2 eq	0.98	Air
Acidification	Sulfur dioxide	0.55	H+ moles eq	67.90	Air
	Nitrogen oxides	0.25	H+ moles eq	30.86	Air
	Hydrogen chloride	0.01	H+ moles eq	1.23	Air
	Hydrogen fluoride	6.59E-04	H+ moles eq	0.081	Air
Eutrophication	Nitrogen oxides	2.76E-	kg N eq	75.41	Air

		04			
	COD, Chemical Oxygen Demand	7.83E-05	kg N eq	21.39	Water
	BOD5, Biological Oxygen Demand	7.76E-06	kg N eq	2.12	Water
	Ammonium, ion	1.20E-10	kg N eq	3.28E-5	Water
	Nitrate	6.04E-07	kg N eq	0.17	Water
Carcinogens	Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-	0.023	kg benzene eq	99.99	Water
	Arsenic	1.09E-06	kg benzene eq	4.80E-03	Air
	Lead	6.0E-07	kg benzene eq	2.65E-03	Water
	Lead	5.30E-07	kg benzene eq	4.86E-04	Air
	Arsenic, ion	5.94E-08	kg benzene eq	2.63E-04	Water
	Chromium	4.08E-08	kg benzene eq	1.80E-04	Air
Non-Carcinogens	Lead	0.02	kg toluene eq	9.23E-02	Water
	Lead	0.04	kg toluene eq	1.85E-02	Air

	Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-	21.64	kg toluene eq	99.91	Water
	Copper, ion	1.02E-03	kg toluene eq	4.7E-03	Water
	Antimony	9.82E-05	kg toluene eq	4.5E-04	Air
	Mercury	4.04E-04	kg toluene eq	1.86E-03	Air
Respiratory	Sulfur dioxide	2.60E-03	kg PM2.5 eq	90.96	Air
	Nitrogen oxides	2.59E-04	kg PM2.5 eq	9.04	Air

Table D.3: Substance contributions to impact values for #3 plastic wrap material extraction and manufacture per 1 kg of material.

Impact Category	Substance	Total	Unit	% of Category Emissions	Emission Medium
Global Warming	Carbon dioxide	2.29	kg CO2 eq	94.52	Air
	Methane	0.11	kg CO2 eq	4.53	Air
	Dinitrogen monoxide	0.02	kg CO2 eq	0.79	Air
	Carbon monoxide	2.24E-03	kg CO2 eq	0.09	Air
Acidification	Sulfur dioxide	0.202	H+ moles eq	51.52	Air

	Nitrogen oxides	0.182	H+ moles eq	46.42	Air
	Hydrogen chloride	3.76E-03	H+ moles eq	0.96	Air
	Ammonia	3.58E-03	H+ moles eq	0.91	Air
	Hydrogen fluoride	7.36E-04	H+ moles eq	0.19	Air
Carcinogenics	Lead	2.48E-03	kg benzen eq	53.50	Water
	Arsenic	7.52E-04	kg benzen eq	16.23	Air
	Arsenic, ion	6.20E-04	kg benzen eq	13.37	Water
	Ethane, 1,2-dichloro-	4.20E-04	kg benzen eq	9.06	Air
	Dioxin, 2,3,7,8 Tetrachlorodibenzo-p	1.29E-04	kg benzen eq	2.79	Air
	Ethene, chloro-	1.19E-04	kg benzen eq	2.57	Air
Non Carcinogenics	Lead	80.1	kg toluen eq	96.45	Water

	Cadmium, ion	0.83	kg toluen eq	1.00	Water
	Lead	0.70	kg toluen eq	0.84	Air
	Copper, ion	0.19	kg toluen eq	0.23	Water
	Mercury	0.19	kg toluen eq	0.23	Water
	Aluminium	0.17	kg toluen eq	0.21	Air
Respiratory	Sulfur dioxide	9.58E-04	kg PM2.5 eq	58.72	Air
	Particulates, > 10 um	2.47E-04	kg PM2.5 eq	15.12	Air
	Particulates, < 2.5 um	2.38E-04	kg PM2.5 eq	14.59	Air
	Nitrogen oxides	1.89E-04	kg PM2.5 eq	11.57	Air

Table D.4: Substance contributions to impact values for #4 plastic container material extraction and manufacture per 1 kg of material.

Impact Category	Substance	Total	Unit	% of Category Emissions	Emission Medium
Global Warming	Carbon dioxide	2.72	kg CO2 eq	84.60	Air

	Methane	0.48	kg CO2 eq	15.08	Air
	Carbon monoxide	0.01	kg CO2 eq	0.31	Air
Acidification	Sulfur dioxide	0.60	H+ moles eq	67.93	Air
	Nitrogen oxides	0.27	H+ moles eq	30.91	Air
	Hydrogen chloride	0.01	H+ moles eq	1.09	Air
	Hydrogen fluoride	6.59E-04	H+ moles eq	0.08	Air
Eutrophication	Nitrogen oxides	3.00E-04	kg N eq	76.75	Air
	COD, Chemical Oxygen Demand	7.87E-05	kg N eq	20.09	Water
	BOD5, Biological Oxygen Demand	8.10E-06	kg N eq	2.07	Water
	Ammonium, ion	3.45E-06	kg N eq	0.88	Water
	Nitrate	8.20E-07	kg N eq	0.21	Water
Carcinogens	Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-	5.18E-06	kg benzene eq	65.80	Water
	Arsenic	1.25E-06	kg benzene	15.83	Air

			eq		
	Lead	7.40E-07	kg benzene eq	9.41	Water
	Lead	5.30E-07	kg benzene eq	6.75	Air
	Arsenic, ion	1.10E-07	kg benzene eq	1.45	Water
	Chromium	5.00E-08	kg benzene eq	0.62	Air
Non-Carcinogens	Lead	0.02	kg toluene eq	43.41	Water
	Lead	0.02	kg toluene eq	35.99	Air
	Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-	4.95E-03	kg toluene eq	8.99	Water
	Copper, ion	3.30E-03	kg toluene eq	6.00	Water
	Antimony	1.22E-03	kg toluene eq	2.22	Air
	Mercury	5.13E-04	kg toluene eq	0.93	Air
Respiratory	Sulfur dioxide	2.83E-03	kg PM2.5	90.95	Air

			eq		
	Nitrogen oxides	2.81E-04	kg PM2.5 eq	9.05	Air

Table D.5: Substance contributions to impact values for #5 plastic container material extraction and manufacture per 1 kg of material.

Impact Category	Substance	Total	Unit	% of Total Category Emissions	Emission Medium
Global Warming	Carbon dioxide, fossil	0.79	kg CO2 eq	66.27	Air
	Methane	0.33	kg CO2 eq	27.33	Air
	Methane, fossil	0.04	kg CO2 eq	3.71	Air
	Carbon dioxide	0.02	kg CO2 eq	1.70	Air
	Carbon monoxide, fossil	0.01	kg CO2 eq	0.77	Air
	Dinitrogen monoxide	2.27E-03	kg CO2 eq	0.19	Air
Acidification	Sulfur dioxide	1.31	H+ moles eq	89.11	Air
	Nitrogen oxides	0.09	H+ moles eq	6.44	Air
	Sulfur oxides	0.06	H+ moles eq	4.15	Air
	Hydrogen chloride	2.91E-03	H+ moles eq	0.20	Air

	Ammonia	8.18E-04	H+ moles eq	0.06	Air
	Hydrogen fluoride	6.43E-04	H+ moles eq	0.04	Air
Eutrophication	Nitrogen oxides	1.04E-04	kg N eq	42.35	Air
	COD, Chemical Oxygen Demand	8.98E-05	kg N eq	36.31	Water
	BOD5, Biological Oxygen Demand	5.17E-05	kg N eq	20.92	Water
	Ammonia	1.01E-06	kg N eq	0.41	Air
	Ammonium, ion	2.53E-08	kg N eq	0.01	Water
Carcinogens	Lead	7.90E-04	kg benzene eq	55.22	Water
	Arsenic, ion	3.88E-04	kg benzene eq	27.11	Water
	Arsenic	2.15E-04	kg benzene eq	15.07	Air
	Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-	2.33E-05	kg benzene eq	1.63	Air
	Benzene	9.84E-06	kg benzene eq	0.69	Water
	Lead	1.62E-06	kg benzene	0.11	Air

			eq		
Non-Carcinogens	Lead	25.55	kg toluene eq	97.14	Water
	Cadmium, ion	0.41	kg toluene eq	1.55	Water
	Barium	0.17	kg toluene eq	0.66	Water
	Lead	0.06	kg toluene eq	0.23	Air
	Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-	0.03	kg toluene eq	0.10	Air
	Arsenic, ion	0.02	kg toluene eq	0.07	Water
Respiratory	Sulfur dioxide	0.01	kg PM2.5 eq	98.44	Air
	Nitrogen oxides	9.82E-05	kg PM2.5 eq	1.56	Air

Table D.6: Substance contributions to impact values for #6 plastic container material extraction and manufacture per 1 kg of material.

Impact Category	Substance	Total	Unit	% of Category Emissions	Emission medium
Global warming	Carbon dioxide	2.58	kg CO2 eq	77.50	Air

	Methane	0.74	kg CO2 eq	22.23	Air
	Carbon monoxide	6.09E-03	kg CO2 eq	0.18	Air
	Methane, chlorodifluoro-, HCFC-22	2.69E-03	kg CO2 eq	0.08	Air
Non-carcinogens	Lead	0.59	kg toluene eq	50.98	Air
	Nickel	0.37	kg toluene eq	32.14	Air
	Chromium	0.17	kg toluene eq	14.18	Air
	Lead	0.02	kg toluene eq	1.97	Water
	Arsenic	4.77E-03	kg toluene eq	0.41	Air
	Copper, ion	1.02E-03	kg toluene eq	0.09	Water
Acidification	Sulfur dioxide	0.37	H+ moles eq	64.20	Air
	Nitrogen oxides	0.20	H+ moles eq	35.26	Air
	Hydrogen chloride	2.90E-03	H+ moles eq	0.51	Air
	Hydrogen fluoride	1.94E-04	H+ moles eq	0.03	Air

Respiratory effects	Sulfur dioxide	1.74E-03	kg PM2.5 eq	89.28	Air
	Nitrogen oxides	2.09E-04	kg PM2.5 eq	10.72	Air
Eutrophication	Nitrogen oxides	2.23E-04	kg N eq	66.75	Air
	COD, Chemical Oxygen Demand	8.64E-05	kg N eq	25.88	Water
	Ammonium, ion	1.42E-05	kg N eq	4.24	Water
	BOD5, Biological Oxygen Demand	8.41E-06	kg N eq	2.52	Water
	Nitrate	2.04E-06	kg N eq	0.61	Water
	Ammonia	8.46E-10	kg N eq	0.00	Air
Carcinogens	Chromium	2.00E-04	kg benzene eq	60.62	Air
	Arsenic	8.63E-05	kg benzene eq	26.15	Air
	Benzene	1.69E-05	kg benzene eq	5.12	Air
	Lead	1.59E-05	kg benzene eq	4.82	Air
	Nickel	7.87E-	kg	2.38	Air

		06	benzene eq		
	Benzene	1.86E-06	kg benzene eq	0.56	Water

Plastic Bags and Wraps

Table D.7: Substance contributions to impact values for HDPE plast-ic bags material extraction and manufacture per 1 kg of material.

Impact Category	Substance	Total	Unit	% of Category Emissions	Emission Medium
Global Warming	Carbon dioxide, fossil	1.376	kg CO2 eq	76.18%	Air
	Methane	0.347	kg CO2 eq	19.18%	Air
	Methane, fossil	0.069	kg CO2 eq	3.80%	Air
Acidification	Sulfur dioxide	1.510	H+ moles eq	89.81%	Air
	Nitrogen oxides	0.117	H+ moles eq	6.94%	Air
	Sulfur oxides	0.047	H+ moles eq	2.82%	Air
Eutrophication	Phosphate	0.003	kg N eq	85.86%	Water
	COD, Chemical Oxygen Demand	1.295E-04	kg N eq	4.25%	Water
	Nitrogen oxides	1.291E-04	kg N eq	4.24%	Air
	Nitrate	8.750E-05	kg N eq	2.87%	Water

	BOD5, Biological Oxygen Demand	7.662E-05	kg N eq	2.52%	Water
Carcinogens	Lead	1.337E-03	kg benzene eq	43.02%	Water
	Arsenic, ion	8.687E-04	kg benzene eq	27.96%	Water
	Arsenic	7.053E-04	kg benzene eq	22.70%	Air
	Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-	1.007E-04	kg benzene eq	3.24%	Air
	Chromium	4.695E-05	kg benzene eq	1.51%	Air
Non-carcinogens	Lead	43.193	kg toluene eq	94.57%	Water
	Cadmium, ion	0.994	kg toluene eq	2.18%	Water
Respiratory	Sulfur dioxide	0.007	kg PM2.5 eq	94.67%	Air
	Particulates, > 10 um	1.528E-04	kg PM2.5 eq	2.02%	Air
	Particulates, < 2.5 um	1.293E-04	kg PM2.5 eq	1.71%	Air
	Nitrogen oxides	1.210E-04	kg PM2.5 eq	1.60%	Air

Table D.8: Plastic Trucking Impacts to SEMASS By Total Plastics Weight and per 1 kg.

Impact Factor	#1	#2	#3	#4	#5	#6	Plastic Bags	Total by Plastics Weight	Total Per 1 kg	Units
Global Warming	15.58	4.61	57.85	2.35	6.57	12.22	6.91	106.11	7.49E-03	kg CO2 eq
Acidification	5.15	1.52	19.14	0.77	2.17	4.04	2.28	35.1	2.48E-03	H+ moles eq
Eutrophication	4.92E-03	1.45E-03	0.018	7.44 E-04	2.07E-03	3.90 E-03	2.18E-03	0.033	2.37E-06	kg N eq
Carcinogens	5.07E-03	1.50E-03	0.02	7.67 E-04	2.14E-03	4.00 E-03	2.25E-03	0.0.035	2.44E-06	kg benzene eq
Non Carcinogens	107.01	31.67	397.35	16.19	45.16	83.96	47.51	728.88	0.0514	kg toluene eq
Respiratory	3.73E-03	1.74E-03	0.02	8.93 E-04	2.49E-03	5.00 E-03	2.26E-03	0.041	2.86E-06	kg PM2.5 eq

Table D.9: Pre-incineration toxin content of plastics in kg per 1 kg of plastic.

Toxin	#1	#2	#3	#4	#5	#6	Plastic Bags	Total per 1 kg of Plastic	Units
Dioxin	2.56E-11[1]	1.18E-11	4.20E-08	1.18E-11	2.18E-11	1.36E-12	1.18E-11	6.01E-09	kg
Lead	-	-	-	-	-	-	1.73E-07	1.73E-07	kg
Copper	-	-	-	-	-	-	-	-	kg
Arsenic	-	-	-	-	-	-	-	-	kg
Nitrogen	-	-	8.00E-04	-	-	-	6.00E-04	7.00E-04	kg
Carbon	0.63	0.84	0.45	0.6	0.65	0.03	0.84	0.58	kg
Sulfur	-	0.03	1.40E-04	-	-	-	3.00E-04	1.01E-02	kg

Table D.10: Total Impacts of Plastics Incineration at SEMASS by Total Plastics Weight and Per 1 kg.

Impact Factor	#1	#2	#3	#4	#5	#6	Plastic Bags	Total by Plastics Weight	Total per 1 kg	Units
Global Warming	1,043.16	425.25	4333.35	154.46	455.67	2,050.58	164.31	9,398.16	1.1	kg CO2 eq
Acidification	-	-	378.2	-	-	352.41	16.11	769.7	0.09	H+ moles eq
Eutrophication	-	-	1.217	-	-	0.21	0.02	1.56	9.58E-05	kg N eq
Carcinogens	0.03	0.02	842.55	6.64E-03	1.08E-03	0.2	0.02	842.88	0.01	kg benzene eq
Non Carcinogens	1,319.63	23.46	842518.95	17.24	16.2	718.82	28.4	844,661.80	19.34	kg toluene eq
Respiratory Effects	-	-	1.748	-	-	1.2	0.14	3.25	3.47E-04	kg PM2.5 eq

Table D.11: Heating values of each plastic in kJ per kg of plastic.

#1	#2	#3	#4	#5	#6	Plastic Bags	Per 1 kg of Plastic (average)
24,000	81,000	22,687.80	43,000	48,822.74	39,600	45,791.96	43,557.50

Table D.12: Avoided Impacts for Waste-to-Energy at SEMASS for Plastics by Total Weight and per 1 kg. Heating value for 1 kg calculation was derived from the average of individual plastic heating values.

Impact Category	Total Annual Energy Credit for All Plastics	Total Energy Credit per 1 kg of Plastic	Unit
Global Warming	28,294.01	4.73	kg CO2 eq
Acidification	12,310.05	2.06	H+ moles eq
Eutrophication	2.70	2.24	kg N eq
Carcinogens	14.42	2.41E-03	kg benzene eq
Non Carcinogens	121,864.78	20.41	kg toluene eq
Respiratory Effects	49.08	8.22E-03	kg PM2.5 eq

Table D.13: Plastic Trucking Impacts to Conigliaro by Total Plastics Weight and per 1 kg.

Impact Factor	#1	#2	#4	#5	#6	Plastic Bags	Total by Plastics Weight	Total per 1 kg	Units
Global Warming	2.71	0.19	0.68	0.39	1.15	0.21	5.4	1.86E-03	kg CO2 eq
Acidification	0.79	0.05	0.2	0.11	0.34	0.06	1.57	5.46E-04	H+ moles eq
Eutrophication	8.43E-04	6.00E-05	2.14E-04	1.23E-04	3.59E-04	6.56 E-05	1.68E-03	5.81E-07	kg N eq
Carcinogens	-	-	-	-	-	-	-	-	kg benzene eq
Non Carcinogens	-	-	-	-	-	-	-	-	kg toluene eq
Respiratory Effects	7.90E-04	5.62E-05	2.00E-04	1.15E-04	3.36E-04	6.15 E-05	1.57E-03	5.45E-07	kg PM2.5 eq

Table D.14: Plastic Trucking Impacts to Casella By Total Plastics Weight and per 1 kg.

Impact Factor	#1	#2	#4	#5	Total By Plastics Weight	Total per 1 kg	Units
Global Warming	9.93	0.70	2.52	1.45	14.61	6.92E-03	kg CO2 eq
Acidification	2.90	0.20	0.73	0.42	4.27	2.02E-03	H+ moles eq
Eutrophication	3.03E-03	2.20E-04	7.84E-04	4.50E-04	4.54E-03	2.15E-06	kg N eq
Carcinogens	-	-	-	-	-	-	kg benzene eq
Non Carcinogens	-	-	-	-	-	-	kg toluene eq
Respiratory	2.89E-03	2.06E-04	7.35E-04	4.22E-04	4.26E-03	2.01E-6	kg PM2.5 eq

Table D.15: Total Annual Impact of Commingled Plastics Sorting At Casella for 99% of Plastics.

Impact Category	Annual Impact for all Plastics (excluding plastic bags and #6)	Annual Impact per 1 kg	Unit
Global Warming	0.03	1.19E-05	kg CO2 eq
Acidification	7.17E-03	2.63E-06	H+ moles eq

Eutrophication	1.49E-04	5.50E-08	kg N eq
Carcinogens	2.04E-04	7.50E-08	kg benzene eq
Non Carcinogens	1.44	5.30E-04	kg toluene eq
Respiratory Effects	1.01E-04	3.73E-8	kg PM2.5 eq

Table D.16: Plastic Shipping Impacts to Overseas Processors (Shanghai, China).

Impact Category	Annual Impact for Plastics #1-5 Shipped by Barge to Shanghai, China for Processing by Total Weight	Total Impact per 1 kg	Unit
Global Warming	2,150.64	0.79	kg CO2 eq
Acidification	1,116.15	0.41	H+ moles eq
Eutrophication	3.78	0.0013	kg N eq
Carcinogens	1.84	0.00067	kg benzene eq
Non Carcinogens	14,891.19	5.47	kg toluene eq
Respiratory Effects	2.63	0.00096	kg PM2.5 eq

Table D.17: Combined Melting and Extrusion Recycling Impact for 99% of #1-5 Plastics Overseas, and for 100% of #6 Plastic in the USA.

Impact Category	Total Impact of Melting and Extruding for all Plastic Weight	Total Impact per 1 kg	Unit
Global Warming	3,152.30	1.15	kg CO2 eq
Acidification	724.27	0.26	H+ moles eq
Eutrophication	17.64	3.63E-03	kg N eq

Carcinogens	9.92	38.92	kg benzene eq
Non Carcinogens	106,197.58	1.57E-03	kg toluene eq
Respiratory Effects	4.28	6.46E-03	kg PM2.5 eq

Table D.18: Credits for Recycled Plastic Products.

Impact Factor	#1	#2	#4	#5	#6	Plastic Bags	Total by Plastics Weight	Total Per 1 kg	Units
Global Warming	6,439.48	8.03	761.76	403.75	1,228.84	5.55	8,847.42	1.76	kg CO2 eq
Acidification	11,319.80	3.88	150.88	71.66	210.98	2.68	1,759.88	0.34	H+ moles eq
Eutrophication	0.7	2.28E-03	0.06	4.78	0.12	-	5.67	1.77E-04	kg N eq
Carcinogens	2.41	4.92E-03	8.90E-04	4.78	0.12	-	7.32	2.45E-02	kg benzene eq
Non Carcinogens	2,390.23	18.39	15.47	4,566.00	433.06	20.3	23,454.49	5.91	kg toluene eq
Respiratory Effects	5.12	5.12	0.5	0.24	0.72	0.01	6.55	1.22E-03	kg PM2.5 eq

Appendix E: Organics

Food Waste

Table E.1: Substance contributions to impact values for food waste per 1 kg of material.

Impact Category	Substance not finish	Total not finish	Unit	% of Category Emissions not finish	Emission Medium not finish
Global Warming	Carbon dioxide, fossil	0.03	kg CO2 eq	96	Air
	Methane, fossil	8.98E-4	kg CO2 eq	3	Air
	Dinitrogen monoxide	2.47E-4	kg CO2 eq	1	Air
	Carbon monoxide, fossil	1.18E-4	kg CO2 eq	0	Air
	Ethane, 1,1,1,2-tertaflroro-, HFC-134a	6.1E-5	kg CO2 eq	0	Air
	Methane, biogenic	2.77E-5	kg CO2 eq	0	Air
Acidification	Nitrogen oxides	8.65E-3	H+ moles eq	82	Air
	Sulfur dioxide	1.88E-3	H+ moles eq	18	Air
	Ammonia	3.99E-5	H+ moles eq	0	Air
	Hydrogen chloride	1.71E-5	H+ moles eq	0	Air
	Hydrogen fluoride	6.38E-6	H+ moles eq	0	Air

Eutrophication	Phosphate	3.86E-5	kg N eq	68	Water
	Nitrogen oxides	9.57E-6	kg N eq	17	Air
	COD, Chemical Oxygen Demand	3.72E-6	kg N eq	7	Water
	BOD5, Biological Oxygen Demand	3.44E-6	kg N eq	6	Water
	Nitrate	1.08E-6	kg N eq	2	Water
	Ammonia	4.95E-8	kg N eq	0	Air
Carcinogens	Arsenic	1.81E-5	kg bensen eq	42	Air
	Arsenic, ion	1.09E-5	kg bensen eq	25	Water
	Lead	8.93E-6	kg bensen eq	21	Water
	Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-	3.08E-6	kg bensen eq	7	Air
	Chromium	1.1E-6	kg bensen eq	3	Air
	Lead	7.67E-7	kg bensen eq	2	Air
Non-Carcinogens	Lead	0.29	kg toluene eq	83	Water
	Lead	0.03	kg toluene eq	9	Air
	Cadmium, ion	0.02	kg toluene eq	6	Water
	Aluminium	5.08E-3	kg toluene eq	1	Air

	Dioxin, 2,3,7,8 Tetrachlorodibenzo -p-	3.41E-3	kg toluene eq	1	Air
	Lead	2.68E-3	kg toluene eq	1	Soil
Respiratory	Particulates, <2.5 um	9.31E-6	kg PM2.5 eq	27	Air
	Nitrogen oxides	8.96E-6	kg PM2.5 eq	26	Air
	Sulfur dioxide	8.92E-6	kg PM2.5 eq	26	Air
	Particulates, <10 um	7.11E-6	kg PM2.5 eq	21	Air

Table E.2: Trace Substances in Food Waste.

Material	Weight of Material in Food Waste
Dioxin	.79 pg I-TEQ/g[1]
Lead (Pb)	1.94 mg/kg[2]
Copper (Cu)	3.46 mg/kg[3]
Arsenic	1.50 mg/kg[4]
Nitrogen (N)	0.17 mg/kg[5]
Carbon (C)	0.15 mg/kg[6]
Sulfur	0.015 mg/kg[7]

[1] Garcia, A.J. et al. “Biodegradable municipal solid waste: Characterization and potential use as animal feedstuffs.” *Waste Management* 25.8 (2005): n. pag. Web. 29 April 2012.

[2] Pinamonti, F. et al. “The Use of Compost: Its Effects on Heavy Metal Levels in Soil and Plants.” *Resources, Conservation, and Recycling* 21 (1997): n. 136

[3] Pinamonti, F. et al. “The Use of Compost: Its Effects on Heavy Metal Levels in Soil and Plants.” *Resources, Conservation, and Recycling* 21 (1997): n. 136

[4] Zhang, Hua et al. “Source Analysis of Heavy Metals and Arsenic in Organic Fractions of Municipal Solid Waste in a
Mega-City (Shanghai).” *Environmental Science and Technology* 42 (2008): n. 1590

[5] Pinamonti, F. et al. “The Use of Compost: Its Effects on Heavy Metal Levels in Soil and Plants.” *Resources, Conservation, and Recycling* 21 (1997): n. 136

[6] Bingmemer, H.G. and Crutzen, P.J. “The Production of Methane from Solid Wastes.” *Journal of Geophysical Research.* 92.D2 (1987): 2181-2187.

[7] Durlak, Susan K., Biswas, Pratim, and Shi, Juchun. “Equilibrium Analysis of the Affect of Temperature, Moisture and Sodium Content on Heavy Metal Emissions from Municipal Solid Waste Incinerators.” *Journal of Hazardous Materials*. 56 (1997): 1-20.

Compostable Dishware and Cutlery

Table E.3: Substance Contributions to Impact Values for Compostable Cups (PLA-based) Material Extraction and Manufacture per 1 kg of Material.

Impact Category	Substance	Total	Unit	% of Category Emissions	Emission Medium
Global Warming	Carbon dioxide	4.38	kg CO2 eq	85.5	Air
	Dinitrogen monoxide	0.472	kg CO2 eq	9.22	Air
	Methane	0.241	kg CO2 eq	4.7	Air
Acidification	Sulfur dioxide	0.556	H+ moles eq	47.5	Air
	Nitrogen oxides	0.335	H+ moles eq	28.6	Air
	Ammonia	0.262	H+ moles eq	22.4	Air
	Hydrogen chloride	0.0121	H+ moles eq	1.03	Air
Eutrophication	Nitrate	0.0155	kg N eq	45	Water
	Phosphate	0.0151	kg N eq	44.3	Water
	Phosphorus	0.00128	kg N eq	3.75	Water
	Ammonium, ion	0.000622	kg N eq	1.82	Water
	COD, Chemical Oxygen Demand	0.00053	kg N eq	1.55	Water
	Nitrogen oxides	0.000371	kg N eq	1.09	Water

Carcinogens	Arsenic	0.00811	kg bensen eq	47.4	Air
	Arsenic, ion	0.00371	kg bensen eq	21.7	Water
	Lead	0.00291	kg bensen eq	17.0	Water
	Atrazine	0.00147	kg bensen eq	8.6	Soil
	Chromium	0.000299	kg bensen eq	1.75	Air
	Dioxin 2,3,7,8 Tetrachloro-	0.000244	kg bensen eq	1.43	Air
Non-Carcinogens	Lead	94.2	kg toluene eq	79.2	Water
	Cadmium, ion	9.4	kg toluene eq	7.9	Water
	Lead	6.22	kg toluene eq	5.23	Air
	Lead	2.62	kg toluene eq	2.2	Soil
	Aluminum	1.8	kg toluene eq	1.5	Air
	Aluminum	0.708	kg toluene eq	.06	Soil
Respiratory	Sulfur dioxide	0.00263	kg PM2.5 eq	55.5	Air
	Particulates, > 10um	0.000989	kg PM2.5 eq	20.9	Air
	Particulates, < 2.5um	0.000766	kg PM2.5 eq	16.2	Air
	Nitrogen oxides	0.000348	kg PM2.5 eq	7.34	Air

Compostable Dishware and Cutlery

Table E.4: Compostable Dishware Trucking Impacts to SEMASS.

Impact Factor	Total (Per 1 kg)	Total (Per 8878 kg annual waste)	Units
Global Warming	0.0198	175.85	kg Co2 eq
Acidification	0.0066	58.2	H+ moles eq
Eutrophication	0.0000063	0.0556	kg N eq
Carcinogens	0.0000065	0.0573	kg benzene eq
Non-Carcinogens	0.14	1207.8	kg toluene eq
Respiratory	0.0000075	0.0666	kg PM2.5 eq

Appendix F: Durable Goods

Melamine Dishware:

Table F.1: Melamine Dishware Transportation Impacts to SEMASS Per 1kg of Material

Impact Factor	Melamine Dishware	Units
Global Warming	0.020	kg CO2 eq
Acidification	0.0066	H+ moles eq
Eutrophication	0.0000065	kg N eq
Carcinogens	0.0000065	kg benzene eq
Non Carcinogens	0.14	kg toluene eq
Respiratory	0.0065	kg PM2.5 eq

Table F.2: Total Melamine Dishware Transportation Impacts to SEMASS

Impact Factor	Melamine Dishware	Units
Global Warming	61.09	kg CO2 eq
Acidification	20.21	H+ moles eq
Eutrophication	0.02	kg N eq
Carcinogens	0.02	kg benzene eq
Non Carcinogens	419.56	kg toluene eq
Respiratory	0.02	kg PM2.5 eq

Table F.3: Impacts of Melamine Dishware Incineration at SEMASS for 1 kg of Material

Impact Factor	Melamine Dishware	Units
Global Warming	0.36	kg CO2 eq
Acidification	0.076	H+ moles eq
Eutrophication	0.000013	kg N eq
Carcinogens	0.00019	kg benzene eq
Non Carcinogens	0.20	kg toluene eq
Respiratory	3.57	kg PM2.5 eq

Table F.4: Overall Impacts of Melamine Dishware Incineration at SEMASS.

Impact Factor	Melamine Dishware	Units
Global Warming	1,098.66	kg CO2 eq
Acidification	233.63	H+ moles eq
Eutrophication	0.04	kg N eq
Carcinogens	0.57	kg benzene eq
Non Carcinogens	615.4	kg toluene eq
Respiratory	1.4	kg PM2.5 eq

Table F.5: Avoided Impacts for Waste-to-Energy at SEMASS for Melamine Dishware for 1 kg of Material

Impact Category	Total Annual Energy Credit for Melamine Dishware	Unit
Global Warming	-0.0015	kg CO2 eq
Acidification	-0.00066	H+ moles eq
Eutrophication	-0.00000015	kg N eq
Carcinogens	-0.00000065	kg benzene eq
Non Carcinogens	-0.0065	kg toluene eq
Respiratory Effects	-0.013	kg PM2.5 eq

Table F.6: Cumulative Avoided Impacts for Waste-to-Energy at SEMASS for Melamine Dishware

Impact Category	Total Annual Energy Credit for Melamine Dishware	Unit
Global Warming	-4.66	kg CO2 eq
Acidification	-2.02	H+ moles eq
Eutrophication	-0.00045	kg N eq
Carcinogens	-0.002	kg benzene eq
Non Carcinogens	-20.04	kg toluene eq
Respiratory Effects	-40.71	kg PM2.5 eq

Clothing:

Table F.7: Weight of trace substances in 1kg of textiles

Trace Substance	Weight substance in 1 kg of textiles
Dioxin	8.84 picograms[1]
Lead	4.69E-06 kg[2]
Copper	-
Arsenic	-
Nitrogen	1.01E-03 kg[3]
Carbon	.40 kg[4]
Sulfur	0.000125 kg[5]

Personal Appliances:

Table F.8: Contributions to Impact Values by Substance of Personal Appliance (Extrapolated from a Rice Cooker) Material Extraction and Manufacture Per 1kg of Product.

Impact Category	Substance	Total	Unit	% of Category Emissions	Emission Medium
Non-Carcinogens	Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-	36.47	kg toluen eq	49.82	Water
	Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-	25.66	kg toluen eq	35.05	Air
	Lead	7.75	kg toluen eq	10.58	Water
	Chromium	1.64	kg toluen	2.25	Air

[1] Abad, E., Adaros, M.A., Caixach, J., Fabrellas, B., and Rivera, J. Dioxin Mass Balance in a Municipal Waste Incinerator. *Chemosphere* 40 (2000): 1143-1147. Print.

[2] Riber, C., Petersen, C. and Christensen, T.H. Chemical Composition of Material Fractions in Danish Household Waste. *Waste Management.* (2009): 1251–1257. Print.

[3] Riber, C., Petersen, C. and Christensen, T.H. Chemical Composition of Material Fractions in Danish Household Waste. *Waste Management.* (2009): 1251–1257. Print.

[4] Bingmemer, H.G. and Crutzen, P.J. The Production of Methane from Solid Wastes. *Journal of Geophysical Research.* (1987): 2181-2187. Print.

[5] Riber, C., Petersen, C. and Christensen, T.H. Chemical Composition of Material Fractions in Danish Household Waste. *Waste Management.* (2009): 1251–1257. Print.

			eq		
	Lead	0.67	kg toluen eq	0.92	Air
	Nickel	0.56	kg toluen eq	0.76	Air
Global Warming	Carbon dioxide, land transformation	3.31	kg CO2 eq	66.18	Air
	Carbon dioxide, fossil	0.61	kg CO2 eq	12.23	Air
	Carbon dioxide	0.56	kg CO2 eq	11.16	Air
	Methane	0.31	kg CO2 eq	6.20	Air
	Dinitrogen monoxide	0.20	kg CO2 eq	3.90	Air
	Methane, fossil	0.01	kg CO2 eq	0.15	Air
Acidification	Sulfur dioxide	0.86	H+ moles eq	66.87	Air
	Nitrogen oxides	0.41	H+ moles eq	32.32	Air
	Hydrogen chloride	0.01	H+ moles eq	0.56	Air
	Sulfur oxides	0.00	H+ moles eq	0.29	Air
	Ammonia	0.00	H+ moles	0.13	Air

			eq		
	Hydrogen fluoride	0.00	H+ moles eq	0.08	Air
Eutrophication	Nitrogen oxides	0.00045766	kg N eq	48.38	Air
	COD, Chemical Oxygen Demand	0.000379552	kg N eq	40.12	Water
	Nitrogen	0.000044	kg N eq	4.70	Water
	Nitrate	0.000040	kg N eq	4.19	Water
	BOD5, Biological Oxygen Demand	0.000012	kg N eq	1.22	Water
	Phosphate	0.0000075	kg N eq	0.80	Water
Carcinogens	Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-	0.038	kg benzen eq	59.55	Water
	Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-	0.023	kg benzen eq	36.26	Air
	Chromium	0.002	kg benzen eq	3.11	Air
	Arsenic	0.001	kg benzen eq	0.93	Air
Respiratory	Sulfur dioxide	0.00406	kg PM2.5 eq	87.62	Air
	Nitrogen oxides	0.00043	kg PM2.5 eq	9.26	Air
	Particulates, < 2.5 um	0.00014	kg PM2.5 eq	3.11	Air

Table F.9: Personal Appliance (Extrapolated from a Rice Cooker) Transportation Impacts to SEMASS Per 1kg.

Impact Factor	Personal Appliance	Units
Global Warming	0.0058	kg CO2 eq
Acidification	0.0019	H+ moles eq
Eutrophication	-	kg N eq
Carcinogens	-	kg benzene eq
Non Carcinogens	0.04	kg toluene eq
Respiratory	-	kg PM2.5 eq

Table F.10: Total Annual Personal Appliance (Extrapolated from a Rice Cooker) Transportation Impacts to SEMASS.

Impact Factor	Personal Appliance	Units
Global Warming	6.57	kg CO2 eq
Acidification	2.15	H+ moles eq
Eutrophication	-	kg N eq
Carcinogens	-	kg benzene eq
Non-Carcinogens	45.29	kg toluene eq
Respiratory Effects	-	kg PM2.5 eq

Table F.11: Impacts of Personal Appliance (Extrapolated from a Rice Cooker) Incineration at SEMASS per 1kg.

Impact Factor	Personal Appliance	Units
Global Warming	275.85	kg CO2 eq
Acidification	177.98	H+ moles eq
Eutrophication	0.06	kg N eq
Carcinogens	110.62	kg benzene eq
Non Carcinogens	3581601.20	kg toluene eq
Respiratory	0.30	kg PM2.5 eq

Table F.12: Total Annual Impacts of Personal Appliance (Extrapolated from a Rice Cooker) Incineration for 1,132.2 kg sent to SEMASS.

Impact Factor	Personal Appliance	Units
Global Warming	312,317.37	kg CO2 eq
Acidification	201,508.96	H+ moles eq
Eutrophication	67.93	kg N eq
Carcinogens	125,243.96	kg benzene eq
Non Carcinogens	4,055,088,879	kg toluene eq
Respiratory	339.66	kg PM2.5 eq

Table F.13: Cumulative Avoided Impacts for Waste-to-Energy at SEMASS for a Personal Appliance (Extrapolated from a Rice Cooker) Per 1kg.

Impact Category	Annual Energy Credit for 1lg of Personal Appliances	Unit
Global Warming	-6.13	kg CO2 eq
Acidification	-2.67	H+ moles eq
Eutrophication	-0.00059	kg N eq
Carcinogens	-0.0031	kg benzene eq
Non Carcinogens	-26.41	kg toluene eq
Respiratory Effects	-0.011	kg PM2.5 eq

Table F.14: Total Annual Cumulative Avoided Impacts for Waste-to-Energy at SEMASS for a Personal Appliance (Extrapolated from a Rice Cooker.)

Impact Category	Total Annual Energy Credit for a Personal Appliance	Unit
Global Warming	-6,940.39	kg CO2 eq
Acidification	-3,022.97	H+ moles eq
Eutrophication	-0.67	kg N eq
Carcinogens	-3.51	kg benzene eq
Non Carcinogens	-29,901.40	kg toluene eq
Respiratory Effects	-12.45	kg PM2.5 eq

Electronics

Table F.15: Personal Electronics Waste Student Survey: Chart and Graphs

	Ipod/ mp3	Cell Phone	Laptop	Camera
<1 year	2	16	9	3
1 year	7	16	9	3
2 years	23	52	7	18
3 years	18	30	34	19
4+ years	42	20	27	28
Still on my first	37	7	55	51
N/A do not own	13	1	1	20

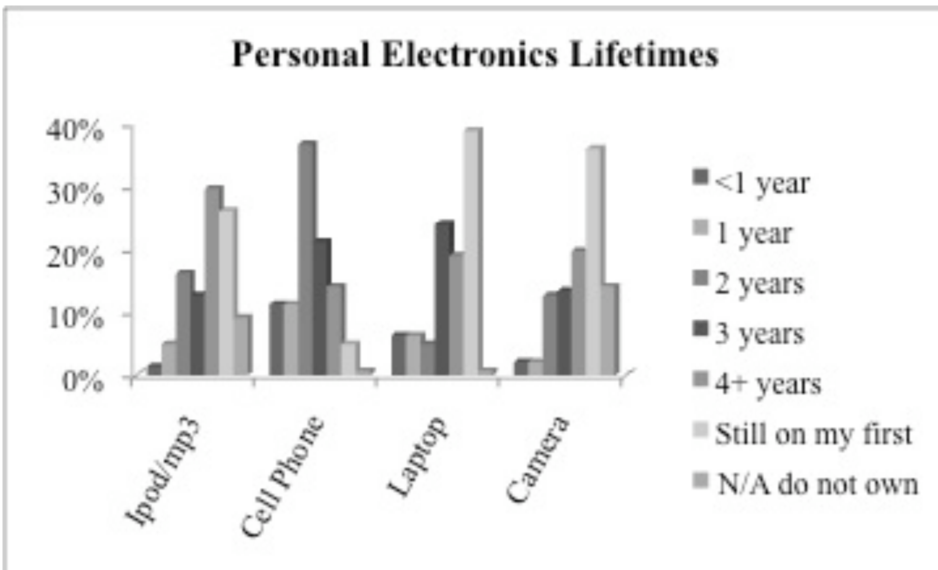

Figure F.1: Personal Electronics Lifetimes.

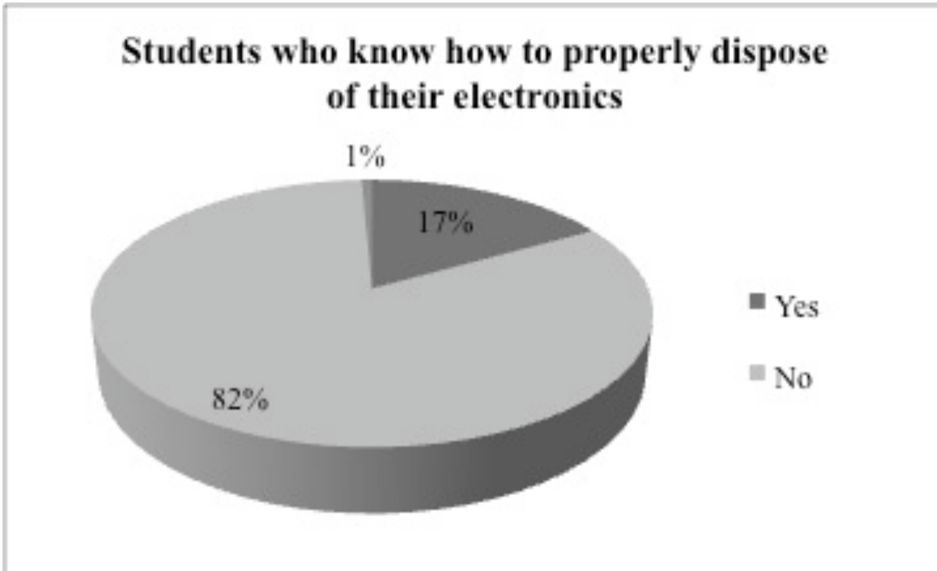

Figure F.2: Percent of Students who Properly Dispose of Electronic Waste.

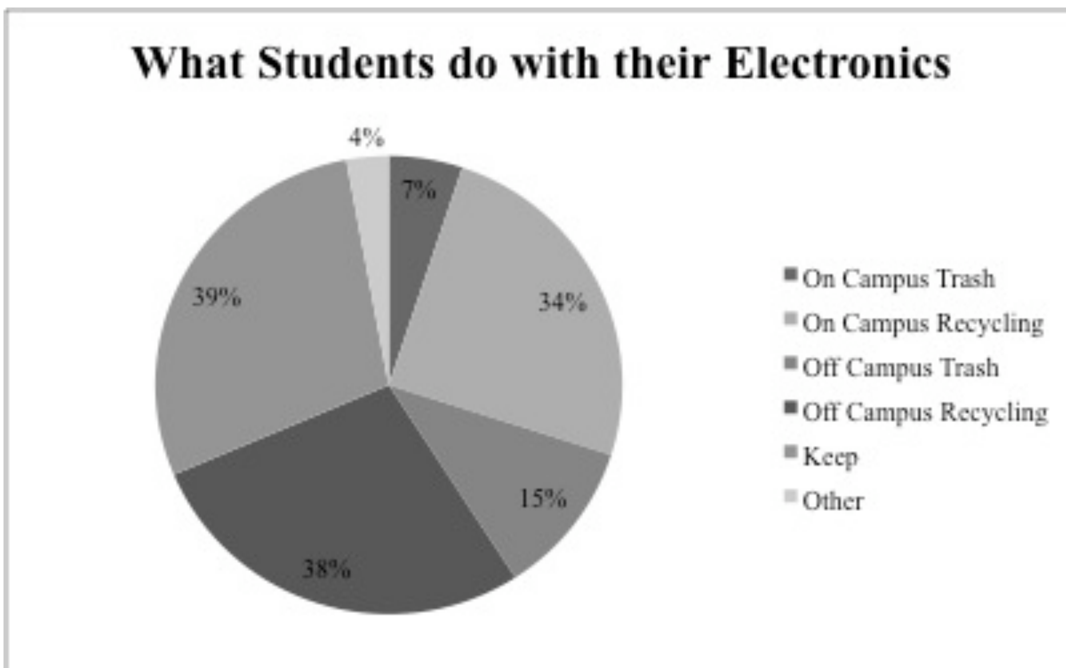

Figure F.3: Disposal Methods of Electronic Waste.

Table F.16 : Per 1kg Facility Impacts at NLR/ACB.

Impact Category	Shredding	Dismantling	Total (per kg)	Units
Global warming	0.026	0.41	0.44	kg CO2 eq
Acidification	0.0069	0.024	0.031	H+ moles eq
Carcinogens	0.00015	0.020	0.020	kg benzene eq
Non carcinogens	1.77	635.78	637.55	kg toluene eq
Respiratory effects	0.000038	0.00011	0.00015	kg PM2.5 eq
Eutrophication	0.00018	0.00049	0.00066	kg N eq

Table F.17: Total Facility Impacts at NLR/ACB.

Impact Category	Shredding	Dismantling	Total	Units
Global warming	124.43	1,974.81	2,099.24	kg CO2 eq
Acidification	33.30	117.31	150.61	H+ moles eq
Carcinogens	0.74	95.21	95.95	kg benzene eq
Non carcinogens	8,471.47	3,047,129.57	3,055,601.04	kg toluene eq
Respiratory effects	0.18	0.52	0.70	kg PM2.5 eq
Eutrophication	0.85	2.33	3.18	kg N eq

Table F.18: Per kg Facility Credits at NLR/ACB

Impact category	Impact	Unit
Global warming	-34.68	kg CO2 eq
Acidification	-9.03	H+ moles eq
Carcinogens	-0.88	kg benzene eq
Non carcinogens	-10909.08	kg toluene eq
Respiratory effects	-0.048	kg PM2.5 eq
Eutrophication	-0.56	kg N eq

Table F.19: Total Facility Credits at NLR/ACB

Impact category	Impact	Unit
Global warming	-166,225.85	kg CO2 eq
Acidification	-43,290.99	H+ moles eq
Carcinogenics	-4,225.55	kg benzene eq
Non carcinogenics	-52,284,382.03	kg toluene eq
Respiratory effects	-228.92	kg PM2.5 eq
Eutrophication	-2,702.17	kg N eq

Special recyclables

Table F.20: Destination of Compact Fluorescent Light Bulbs Waste by Percentage

	SEMASS	Northeast Lamp Recycling
% of Waste	70%	30%
Weight of Waste (kg)	2,233	957

Table F.21. Destination of Household Battery Waste by Percentage

	SEMASS	Northeast Lamp Recycling
% of Waste	86%	14%
Weight of Waste (kg)	583.28	94.95

Table F.22. Destination of Ink Cartridge Waste by Percentage

	SEMASS	IKon Industries
% of Waste	0%	100%
Weight of Waste (kg)	0	2030.4

Table F.23: Household Batteries Trucking Impacts to SEMASS

Impact Factor	Household Batteries Per 1 kg	Household Batteries Total	Units
Global Warming	0.020	13.43	kg CO2 eq
Acidification	0.0066	4.44	H+ moles eq
Eutrophication	.0000064	0.0044	kg N eq
Carcinogens	.0000064	0.0044	kg benzene eq
Non Carcinogens	0.014	9.23	kg toluene eq
Respiratory Effects	.0000075	0.0051	kg PM2.5 eq

Table F.24: Compact Fluorescent Light Bulbs (CFLs) Trucking Impacts to SEMASS

Impact Factor	CFLs Per 1 kg	CFLs Total	Units
Global Warming	0.020	63.18	kg CO2 eq
Acidification	0.0066	20.90	H+ moles eq
Eutrophication	.0000063	0.020	kg N eq
Carcinogens	.0000064	0.021	kg benzene eq
Non Carcinogens	0.14	433.98	kg toluene eq
Respiratory Effects	.0000075	0.024	kg PM2.5 eq

Table F.25: Facility Impact of Battery Disposal at SEMASS

Impact Category	Facility Impact Per 1 kg Battery	Total Facility Impact for Household Batteries	Unit
Global Warming	10.86	1030.02	kg CO2 eq
Acidification	8.61	817.12	H+ moles eq
Eutrophication	0.011	1.06	kg N eq
Carcinogens	0.048	4.57	kg benzene eq
Non-Carcinogens	4.0085	380.61	kg toluene eq
Respiratory Effects	0.038	3.59	kg PM2.5 eq

Table F.26: Facility Impact of Compact Fluorescent Light Bulb Disposal at SEMASS

Impact Category	Facility Impact Per 1 kg CFL	Facility Impact of CFLs Total	Unit
Global Warming	9.54	21314.06	kg CO2 eq
Acidification	3.51	7843.43	H+ moles eq
Eutrophication	0.0017	3.80	kg N eq
Carcinogens	0.023	51.83	kg benzene eq
Non-Carcinogens	19.55	43646.78	kg toluene eq
Respiratory Effects	0.019	42.90	kg PM2.5 eq

Table F.27: Household Batteries Trucking Impacts to Northeast Lamp Recycling

Impact Factor	Household Batteries Per 1 kg	Household Batteries Total	Units
Global Warming	0.025	16.64	kg CO2 eq
Acidification	.0071	4.87	H+ moles eq
Eutrophication	.0000076	.0052	kg N eq
Carcinogens	0	0	kg benzene eq
Non Carcinogens	0	0	kg toluene eq
Respiratory Effects	.0000071	.0048	kg PM2.5 eq

Table F.28: Compact Fluorescent Light Bulbs Trucking Impacts to Northeast Lamp Recycling

Impact Factor	CFLs Per 1 kg	CFLs Total	Units
Global Warming	0.025	78.26	kg CO2 eq
Acidification	.0071	22.9	H+ moles eq
Eutrophication	.0000076	.024	kg N eq
Carcinogens	0	0	kg benzene eq
Non Carcinogens	0	0	kg toluene eq
Respiratory Effects	.0000072	.022	kg PM2.5 eq

Table F.29: Ink Cartridge Trucking Impacts to IKon Facilities

Impact Factor	Ink Cartridge Per 1 kg	Ink Cartridge Total	Units
Global Warming	0.0045	9.24	kg CO2 eq
Acidification	.0013	2.7	H+ moles eq
Eutrophication	.0000014	.0029	kg N eq
Carcinogens	0	0	kg benzene eq
Non Carcinogens	0	0	kg toluene eq
Respiratory Effects	.0000013	.0027	kg PM2.5 eq

Table F.30: Facility Impact of Household Battery Disposal at Northeast Lamp Recycling

Impact Category	Facility Impact Per 1 kg Battery	Facility Impact of Battery Total Recycled Waste	Unit
Global Warming	7.23	4216.20	kg CO2 eq
Acidification	5.73	3341.76	H+ moles eq
Eutrophication	0.0074	4.33	kg N eq
Carcinogens	0.032	18.68	kg benzene eq
Non-Carcinogens	2.67	1556.61	kg toluene eq
Respiratory Effects	0.025	14.69	kg PM2.5 eq

Table F.31: Facility Impact of CFL Disposal at Northeast Lamp Recycling

Impact Category	Facility Impact Per 1 kg CFL	Facility Impact of Battery Total Recycled Waste	Unit
Global Warming	0.045	6081.42	kg CO2 eq
Acidification	2.34	2237.92	H+ moles eq
Eutrophication	0.0011	1.08	kg N eq
Carcinogens	0.015	14.79	kg benzene eq
Non-Carcinogens	13.013	12453.48	kg toluene eq
Respiratory Effects	0.013	12.24	kg PM2.5 eq

Table F.32: Facility Impact of Ink Cartridge Disposal at Ikon Industries

Impact Category	Facility Impact Per 1 kg Ink Cartridge	Facility Impact of Ink Cartridge Total Recycled Waste	Unit
Global Warming	7.30	388858.84	kg CO2 eq
Acidification	65.06	132089.91	H+ moles eq
Eutrophication	0.052	106.52	kg N eq
Carcinogens	0.25	496.99	kg benzene eq
Non-Carcinogens	293.34	595600.73	kg toluene eq
Respiratory Effects	0.33	677.32	kg PM2.5 eq

Table F.33: Facility Credit of Household Batteries and Compact Fluorescent Light Bulbs Processed at Northeast Lamp Recycling

Impact Factor	Household Batteries	Compact Fluorescent Light Bulbs	Total	Units
Global Warming	- 4,902.54	- 6,081.42	- 10,983.96	kg CO2 eq
Acidification	- 3,885.76	- 2,237.92	- 6,123.68	H+ moles eq
Eutrophication	- 5.04	- 1.08	- 6.12	kg N eq
Carcinogens	- 21.72	- 14.79	- 36.51	kg benzene eq
Non-Carcinogens	- 1,810.00	- 12,453.48	- 14,263.49	kg toluene eq
Respiratory Effects	- 17.08	- 12.24	- 29.32	kg PM2.5 eq

Table F.34: Facility Credit of Ink Cartridges Processed at IKon Industries

Impact Factor	Ink Cartridges	Units
Global Warming	- 388,858.84	kg CO2 eq
Acidification	- 132,089.91	H+ moles eq
Eutrophication	- 106.52	kg N eq
Carcinogens	- 496.99	kg benzene eq
Non-Carcinogens	- 595600.72	kg toluene eq
Respiratory Effects	- 677.32	kg PM2.5 eq