A Cost-Benefits Analysis of Campus Recycling:

The University of Texas

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Abstract: As people become aware of the impacts of their landfilled waste, recycling has gained popularity. Some citizens demand recycling. What is the right amount of recycling? If cities want more, then how can the amount of waste recycled be increased? A campus-wide recycling effort at The University of Texas can expand the amount of waste recycled; but, more importantly, will the private benefits outweigh private costs? And for some, will the social benefits outweigh the social costs?

Keywords: recycling, cost-benefit analysis, university recycling, waste diversion, valuing social benefits and costs, external cost of garbage

The University of Texas does not engage in recycling solely for environmental purposes. The university receives a rebate on recyclables, and it saves on landfill costs when recyclables are diverted to the recycling center. Currently, however, the university's campus-wide efforts to recycle include only paper. Expanding recycling efforts could divert more waste from the landfills, lessen the environmental impact of its refuse, and create jobs. Yet programs to recycle other goods can be limited by space, money, and man-power. Is it privately or socially profitable for The University of Texas to expand its recycling program to include materials such as plastic, glass or aluminum?

A number of studies conducted on the net costs of recycling compared to landfilling conclude that recycling costs more than traditionalwaste disposal; however, a study done by David Folz (1999) has evidence that recycling can have a lower net cost per ton of waste than traditional waste disposal. Revenues from selling recyclables do not always cover the entire cost of collecting, sorting and recycling waste, but revenues do offset some costs. At the time of Folz's study, a survey of 158 cities found the net cost per ton of recycling to be about $85, compared to $131 for traditional waste disposal. This amounts to a 35% lower net cost for recycling.

Folz's study also tries to determine why some programs are more successful than others. Recycling rates among cities differ. Folz determines several factors that contribute to increases in recycling rates for cities. The first factor for a city is being near its recycling goal. In this case, recycling directors can create an extra push towards more diversion of the waste stream to increase the recycling rate. Second, cities attempt to make recycling more convenient by providing free recycling bins and same-day pick-up for recyclables and non-recyclable waste. Folz believes that recycling increases when the costs of recycling becomes cheaper than costs of waste disposal. Yet, recycling does involve some economies of scale. The university can provide free recycling bins and same-day pick-up, but in order to achieve lower cost per ton of recycling, diversion rates must be high. The most cost-effective programs have the most successful recycling efforts. If indeed recycling has a lower cost per ton of waste, then the university can minimize total waste disposal costs by increasing the materials recycled.

The net benefits of recycling depends on the location where recycling occurs. Aadland and Caplan (2005) conclude that the social net benefit of curbside recycling on average is almost zero. The study surveys 20 western U.S. states, over 4,000 households, and recycling coordinators in 40 different communities. When looking at recycling on a city-by-city basis, monthly benefits in Tempe, AZ were $3.50 per household, while monthly benefits were -\$2.85 in Palto Alto. Aadland and Caplan find several reasons that contribute to the discrepancies in the benefits of recycling. Variation in costs is driven by differences in technology used for curbside pickup, education levels of households, average age of the population, and mandatory versus voluntary participation. Aadland and Caplan also find that their estimates of benefits could be overstated, because it is hard to measure the opportunity cost associated with diverting resources to recycling. Some of the cost and benefit variables that affect the net social benefits of recycling include tipping fees, willingness-to-pay, technology, recycling participation rates and education. Their study only covers the western states in the U.S. A study of the northeastern or southern states may yield different results because costs and benefits differ from city-to-city and different geographical locations.

The purpose of this paper is to determine whether The University of Texas should expand their recycling efforts to include plastic, glass, or aluminum. Recyclers typically think recycling benefits the environment by diverting solid waste from landfills, and by reducing energy and water use, pollution, and greenhouse gasses at various stages of production. At the same time, recycling programs are costly. They require more manpower, extra transportation costs, and additional collection bins. One question is: how much more will the university gain from recycling rather than disposing waste into landfills? This question entails only private costs and benefits to the university. In addition, I will also ask: How much more will society gain by the university's effort to recycle more waste? Will net recycling costs to society be less than net garbage disposal costs? These questions will be the basis of my analysis. I will conduct both a private and social cost benefit analysis.

Recycling is a costly undertaking. Recycling operations require large initial investments and may take many years to become economically efficient. Kinnaman (2000) finds that the cost of recycling exceeds the cost of a landfill at times. He points out that Folz's study must be read with caution. Folz found recycling to cost less than traditional waste disposal in some cities. Folz's study did not include Austin. Austin citizens face low tipping fees, and recycling rates are not among the highest in the nation. Only 8% of the cities in Folz's study were in the south, while 48% of the cities were in the northeast, where tipping fees are generally higher. Cost effectiveness is a reasonable criterion, given the absence of reliable estimates of the social benefits of recycling.

It is hard to account for and estimate every cost and benefit accurately when studying the case of The University of Texas' recycling program. Without having an extensive recycling program already in place at the university, data must be extrapolated from results of studies done in other places, which have consumption habits similar to Austin's or UT's. Costs of a particular pollutant might be overlooked if it is 'minimal' or immeasurable, or if these costs fell on others outside of the university. Even large effects sometimes cannot be measured; some effects that can be measured are small. By failing to account for all of the social costs and benefits of recycling, I cannot be certain whether the administration at The University of Texas made the socially optimal decision.

This study finds that private net benefits of recycling at the university can be positive even though the cost of recycling is more than the cost to dispose garbage. If the cost of recycling is greater than the cost of landfilling garbage, each type of material will have a positive net private gain from recycling only if the net collection cost of recycling is less than the price received for recyclables plus the benefit of the avoided tipping fee. Costs that are avoided by recycling become benefits of recycling.

Also, this study finds that the social net benefits of recycling at the university can be positive for all recyclable materials. This stems from the positive net external benefits provided by recycling. Measuring the net externalities of recycling requires much estimation and special valuation techniques. The reports that provide this study with estimations of the value of waste disposal's externalities employ many assumptions. Assumptions allow for generalizations to be made in order to have a chance at valuation. In this paper, I make several assumptions as well.

The first section describes the action of recycling and introduces the question The University of Texas faces. Recycling receives a great deal of attention from environmentalists, policy makers, and citizens. Because The University of Texas at Austin has a large student and faculty population, a new recycling project would require a lot of research, resources, and attention. The students and faculty must be educated and willing to engage in a new undertaking.

The second section summarizes and analyzes the data collected. These initial results include only information important for the private cost-benefit analysis; thus, results may be different than the socially optimal outcome. The choice to expand recycling can vary depending on the level of participation, the price received from recyclables, and the accuracy of the data. The social cost-benefit analysis relies on economic valuations of external costs and benefits of recycling and of traditional landfilling.

1. Recycling

Before anyone can analyze the cost and benefits of recycling, the term recycling must be defined. Recycling uses waste as material in making new products. Recycling does not prevent waste, because recyclers need waste in order to have material to recycle. The point of recycling is to re-process the recyclable waste into a new product. For this to occur, manufacturers must have interest in buying recycled materials for production, processors must have the resources to collect the recyclables, and individuals or businesses must supply their waste for recycling.

1.1 Overview of Recycling

A series of events must take place for recycling to occur. First, residences and public institutions must have their recyclable materials collected. Then, at the collection sites, materials are sorted, cleaned and prepared for sale to materials-recovering facilities. After the materials have been recovered, they are sold to manufacturers that make goods using the recycled materials. The demand for recycled materials is determined in part by laws that require a percentage of a product to be made with recycled materials, by consumer demand for these products, and by the price of primary raw materials. Finally, when the consumer chooses to buy a product that uses recycled materials, he or she completes the cycle of recycling. When that product has been used and discarded, the cycle repeats, but market factors affect each stage.

The price of virgin materials may differ from the price of recycled materials. Virgin materials require excavation, refining, and processing, while recyclable materials require collection, sorting, cleaning, and re-processing. Sometimes the cost to produce virgin materials is more than the cost to produce recycled materials of the same quality. When this occurs, the demand for recycled materials is expected to be strong because manufacturers can lower their production costs with lower input costs. Market values of each good change over time, depending on the demand for the material and the costs associated with preparing the product for sale in the market (i.e. supply). This market interaction determines the prices for recycled raw materials. The closer the material's quality is to its virgin counterpart, the higher its value. White office paper, aluminum cans/foil, natural HDPE plastics, and clear glass command high prices, while mixed paper, steel cans, and mixed glass are worth much less. In order to keep the quality of a product high, a manufacturer typically uses a combination of virgin materials and recycled materials.

Commingling of post-consumer waste also affects the price of the recycled materials. Such mixing contains a greater diversity of materials and costs more to separate and recycle. The quality cannot be compared to that of cleaner commercial recycling, which has a lower rate of contamination.[1] When materials can be presorted earlier in the waste stream, the waste stream is more homogeneous and less contaminated, resulting in higher quality recyclables, which have a higher market price per ton. On the other hand, commingling decreases collection costs, and in some cases it can boost recycling rates. In addition, commingling allows the consumer to place all of his or her waste into one receptacle instead of several differentiated bins, increasing the convenience of recycling. Commingling is an aspect of recycling that varies across different programs.

Industrial scrap from manufacturers also impacts the value of post-consumer recyclable waste. The leftover paper, metal, and plastic from the production process is almost always higher in quality than processed post-consumer recyclables, so it is often preferred by manufacturers – even over post-consumer commercial recycling. This will affect the price received for all recycled materials in the secondary market. The demand for recyclable materials can make the recycling efforts of an organization more or less profitable.

Successful statewide recycling programs require a "balance among three components: recovery of recyclables, processing infrastructure, and market demand for recycled materials." Growth can be hampered by the lack of a comprehensive collection system, a low market value for the recycled material or high collection, and transportation costs. Suppose for example, that PTB is private total benefits, and PTC is private total cost. Then, in order to make recycling privately profitable, the goal is to maximize [PTB-PTC], which might not be at minimum ATC. Lower costs will help maximize net gains to recycling. These aspects of recycling continually challenge solid waste administrators as they attempt to find the most cost-efficient way to dispose waste.

The popularity of recycling programs at universities across the U.S. continues to rise. Many times, students take initiative to start recycling programs in hopes that the university will adopt the program. A successful program needs funding, yet students have a harder time than the university in raising financial and physical capital. Students cannot devote all their time to starting a new program since they have other obligations. The university may need a full-time position to handle a new program. Because budgets are slashed

[1] The contamination rate is the percentage of unrecyclable waste commingled with recyclables. A recycler usually sets a maximum contamination rate, beyond which a container of recyclables allotted for recycling cannot be accepted for recycling because it contains too much unrecyclable waste.

and money is tight in all divisions, The University of Texas must evaluate and allocate its resources to provide the most efficient combination of waste disposal.

Alternatively, the university might consider only the costs and benefits to itself. The analysis below proceeds under each assumption, first that UT maximizes its own private net benefits, second, that UT maximizes social net benefits. A recycling program helps students and faculty become more aware of their consumption and waste disposal habits, in hopes that future generations will pay more attention to conserving their natural resources.

1.2 Senate Bill 1340

In 1991, the Texas Legislature established a commitment to a statewide residential and workplace recycling strategy. The Texas recycling program depends on voluntary participation by the public rather than mandated participation. Governmental entities at the state, county and city levels, however, are required to establish a collection program that individual consumers can participate in voluntarily. In other words, state-run entities must provide a recycling collection program, so that the public chooses whether or not to recycle.

Higher costs of landfills prompted the Texas Legislature to initiate a recycling law that aims to decrease the amount of municipal waste disposed. Senate Bill 1340, passed in 1991, established a statewide goal of recycling 40% of municipal solid waste (MSW) generated in the state. This goal was to be reached by January 1994. This bill was later amended in 1993 by SB1051, in which the goal was changed to a 40% reduction in the amount of MSW disposed in the state, using 1991 as a base year.[2] Before the amendment, composting yard trimmings was not included in the statewide diversion rate; it is now included. In response to SB 1340, The University of Texas at Austin created the Physical Plant Recycling program in June of 1993.

The recycling program started with just collection of white paper in a few buildings, but it has grown to include more recyclable waste and more buildings. The program has expanded to collect cardboard, magazines, colored paper, newsprint, envelopes, spiral notebooks, textbooks, and folders. In addition to these products, the university also recycles antifreeze, cleaning solvent, oil, transmission fluid, batteries, lead wheel weights, freon, scrap metal and organic materials.[3]

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[2] The original wording of the bill used the word generated instead of disposed.
[3] Source: UT's physical plant website: http://www.utexas.edu/physicalplant/general/recycling/index.html

Recycling paper receives most of the attention of the recycling program at the university. During the fiscal year from September 2004 to August 2005, the university saved $160,683.86 dollars through recycling paper rebates. All offices use paper, and separating out recyclable paper from the waste stream does not require too much extra effort. The university offers separate bins for paper, which are placed next to waste bins.[4] The university uses clear bags for recyclables, while black bags are used for waste sent to the landfill. The clear bags help collectors identify whether or not the contamination rate is too high to be acceptable. Sorting the recyclable paper early in the waste stream increases the quality of the recyclable paper because it lowers the contamination rate.

Besides paper, many other wastes could be recycled. The bulk of this other recyclable waste includes glass, aluminum, and plastic. This paper focuses on expanding the university's recycling services to these other materials.

At the University of Texas at Austin, students from the Campus Environmental Center started a recycling program 5 years ago. The Campus Environmental Center serves as the main organization for UT students interested in preserving the environment. The organization wants to reduce the university's environmental impact while promoting environmental awareness within the student body. The students receive donations from Austin businesses to help fund and aid in the expansion of their program. Currently, the students have 15 blue barrels that collect glass, aluminum, polyethylene terephthalate (PET) plastic and high density polyethylene (HDPE) plastic. The student volunteers strategically place barrels around campus to attract the most waste diversion. These outdoor barrels are emptied twice a week. Then, a work-study intern from the university's solid waste plant transports the recyclables to Ecology Action, a local non-profit recycling center, where student volunteers later sort the recyclables. The student organization has had mild success because they are limited by resources.

1.3 The University of Texas' Waste Stream

It is difficult to measure the exact amount of waste and composition of solid waste produced by the university. Some waste may be diverted to the recycling centers voluntarily by the students; some may be brought back to off-campus housing centers for disposal; some may even be collected by vagabonds who are

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[4] Waste bins collect solid waste that is sent to the landfill.

looking for extra money by recycling the waste they find. The estimates and other figures of waste composition used in this analysis are from data provided by the university, the student-run recycling organization, the City of Austin, the University of California at Berkeley, and national figures from the EPA.

1.3.1 Changing Composition of Recyclables

Just as Austin's consumption and disposal rates differ from the national average, the students at The University of Texas have different lifestyles than the households serviced by the City of Austin. Students consume different products and at different quantities. Vending machines and food service locations sell large amounts of bottled drinks and to-go packages. In the end, these products end up in the waste stream. It is therefore possible that the recyclable percentage of waste generated on campus is larger than the City of Austin's. If the university's waste stream contains a large quantity of recyclables, the university can save money on tipping fees and receive money from recyclables when it diverts waste from landfills.[5]

National figures compiled by the EPA show that plastic in the waste stream has increased at a faster rate than aluminum, glass, and paper. Plastic rose from 10.5% in 2000 to 11.3% in 2003 (see Table A-3a). Since 2000, tons of paper and glass generated have decreased; aluminum increased from 1.3% in 2000 to 1.4% in 2003. Over the last decade, increases in the production of plastic outgrew increases in plastics recycling; as a result, plastic recycling rates dropped. Recent high oil prices have caused the price of plastic to increase. If this trend continues, recycling plastic will have a lower net cost to recyclers, increasing its private net benefits of recycling.

1.3.2 Waste Audits

Waste audits show the amount of waste that can be potentially diverted by estimating the composition of the waste stream. The university's waste audits do not occur frequently enough and do not include a large enough sample to give an unbiased estimate of the university's waste stream. On March 3, 2005, UT students of the Environmental Center conducted a waste audit. The previous one took place over ten years beforehand.

[5] Appendix Tables A-1 and A-2 summarize the recycling rates of Austin, TX. A comparison between the university and city could be made, but waste audits for either party do not exist. Thus, the consumption habits of the citizen of Austin would only be a rough estimate of the consumption habits of those on campus.

Because consumption habits change over time, looking at the old data would not improve this analysis. Extensive waste audits would provide the information needed to make certain waste decisions.

Although UT's most recent waste audit only used a small sample size compared to the population, these data are still considered an estimate of the overall waste composition of the university. The data must be used with caution; however, because the waste audit only included a percentage of UT's total waste on that day. The location here trash is collected from and daily fluctuations in waste generation can create biased results. Table 1 summarizes the waste audit.

Table 1: UT's Waste Audit on March 3, 2005

	Weight (lbs)	% by weight
Total Waste Sorted	**1266**	100.0%
Trash	959	75.8%
Aluminum Cans	35	2.8%
Paper	156	12.3%
Plastic bottles	77	6.1%
Glass	14	1.1%
Cardboard	25	2.0%

Information provided by Corinna Kester, advisor of UT's Campus Environmental Center

The students of the university sorted through 1,266 pounds of waste, which amounted to 12.41% of the total waste on vehicle 205. Vehicle 205 brought 9,440 pounds (4.72 tons) of MSW to the landfill. The composition of the waste: 12.3% paper, 2.8% aluminum cans, 1.1% glass, 6.1% plastic bottles. Assuming the waste audit represents the disposal rates of the university, UT has a higher percentage of aluminum and plastic in its waste stream compared to the city's. In Austin, recycled metals were 0.739% of MSW and recycled plastics were 0.902% of MSW.[6] I use the national recovery and discard rates of each material to estimate the percentage of MSW that is recyclable. Steps to find these percentages are defined below.

(i) In 2003, aluminum totaled 9.5% of all recycled metals in the U.S.[7] Assuming that Austin's recycling habits are similar to those of the nation's, multiplying 0.739% times 9.5% yields 0.070%, which is recycled aluminum as a percentage of the total MSW. To find total aluminum cans in the unrecycled waste stream, divide

[6] Metals here include more than just aluminum. Data refers to information in Table A-2

[7] Table A-3f summarizes the figures for recycling and generation of metals in the U.S. in 2003. 650 tons of aluminum cans were recycled, while 6,840 tons of metals were recycled. To find the percentage of aluminum recycled compared to metals, divide 650 tons of aluminum recycled by 6,840 tons of metal recycled. This yields 9.5%.

0.070% by 43.9%, the national recycling rate of aluminum cans. Thus, 0.160% of Austin's total MSW is aluminum cans.

(ii) With plastics, the process is a bit more complicated because Austin does not separate PET and HDPE plastics in their statistics. So, I use the EPA's figures for materials generated to find the ratio of PET to HDPE. In 2003, the nation produced 2870 tons of PET bottles to 5140 tons of HDPE bottles.[8] Assuming that the recycling rate does not change with the amount of plastic bottles produced, 35.8% of plastics recycled are PET and 64.2% are HDPE. To find the percentage of PET recycled, multiply 0.902%, the percentage of plastics recycled, by 35.8%, yielding 0.323%. Taking the percentage of PET recycled and dividing it by 25.2%, the recycling rate of PET bottles will yield 1.281%, the percentage of total MSW that is PET bottles. Repeating the steps for HDPE bottles yields 1.815%, the percentage of total MSW that is HDPE bottles. Then, adding the two plastics together yields a 3.096%, the percentage of generated MSW that is plastic bottles.

Another caution about the waste audit concerns the recyclables collected by the student-run organization. The waste audit did not include the weight of the recyclables that were collected that day by the student-run recycling organization.[9] However, this amount would not have affected the percentages of the MSW composition significantly. In the 14 months between October 2003 and December 2004 (about 420 days), students only recycled 4.74 tons of waste. This amount of recycling weighs less than one day's worth of landfilled waste by the university.

1.4 University of California- Berkeley's Waste Stream

The University of Texas' waste audit did not provide a good estimation of the university's waste for all days and all locations; however, this study can use another university's waste audit to help estimate UT's waste composition. The university in study is the University of California at Berkeley. The best comparison of data would occur if the city of Berkeley had performed a waste audit as well. This would allow for a comparison

[8] Table A-3g summarizes figures for recycling and generation of plastics in the U.S. in 2003.
[9] The student-run organization collects recycling twice a week. In order to be as accurate as possible, I could take the weekly values of the recycling collection, divide that by 5 (for the five days of waste collection by the university), and add that value to the waste audit.

between a university's consumption habits and the city's. A city's culture can impact the culture of the students.[10]

1.4.1 Waste Audit

Because figures for the city of Berkeley do not exist, the second best option is comparing UC Berkeley's figures with national figures. MSW data for the country can give national trends in recycling and allow for broad assumptions. In Table A-4 of the appendix, UC Berkeley's numbers are broken down further by categories; for purposes of this paper, I combine values needed for this study into the categories required for comparison. Table 2 summarizes these results.

Table 2: 1998 Berkeley Waste Audit Compared to EPA's Waste Compositions

Material	UC Berkeley	EPA 1998	EPA 2003
Paper and Paperboard	42.47%	31.10%	35.20%
Plastic #1 (PET)	0.37%	0.37%	0.45%
Plastic #2 (HDPE)	0.24%	0.32%	0.31%
Glass bottles	2.29%	2.43%	2.73%
Aluminum cans	0.27%	0.70%	0.56%

Comparing Berkeley's waste composition to the nation's provides a basis for how to estimate UT's waste composition. The percentage of paper and paperboard in Berkeley's solid waste was significantly higher than the national figures, as this is definitely the case with UT's paper generation. Plastic #1 and glass waste compositions were nearly identical to the nation's. UT's Aluminum was significantly lower and plastic #2 was just slightly lower.

Earlier, I make the assumption that college students might consume more plastic because of the abundance of vending machines on campus and their grab-and-go lifestyles. At UC Berkeley, this was not the case for plastics, glass or aluminum. Comparing the 1998 UC Berkeley waste audit to the EPA's figures, percentages of these recyclables in the waste stream were lower than the nation's average. UC Berkeley's waste

[10] The municipal recycling data collected from the City of Austin can aide in the estimation of the percent of recyclables present in the university's waste stream. Data specific for Austin is preferred over national averages, because the demographics of a location influence consumption habits and waste restraints that may differ from other parts of the United States.

audit includes all waste on campus, garbage and recycling. Table 3 in the next section summarizes the national MSW composition in 2003.

1.4.2 Estimates of UT's Waste Stream

Because this study cannot rely on the waste audit performed at UT, many estimations and assumptions are made. I assume that all large public universities in America have similar consumption patterns. This assumption would lead me to believe that the paper and paperboard percentage of MSW generated at UT is higher than the national figure of 35.20%. This turns out to be the case because 37.24% of MSW generated at UT is paper that is recycled. UT recycled 1620.78 tons of paper while producing 4352.77 tons of total waste. Recycling rates do not capture 100% of all materials generated; therefore, UT's generation of paper waste is more than 37.24% of solid waste. When estimating the plastic, glass and aluminum composition of waste generated at UT, I will apply the ratio between 1998 UC Berkeley figures and the 1998 EPA figures according to the following formula:

$$\left(\frac{UCB\ 1998\ \%}{EPA\ 1998\ \%}\right) \times \left(EPA\ 2003\right) = \left(Estimated\ UT\ \ 2003\ \%\ composition\right).$$

Using HDPE as an example, UC Berkeley has a 0.24 to 0.32 ratio of HDPE generation to the national figure. When this ratio is multiplied by the 2003 EPA's 0.31% for HDPE, it generates an estimate of 0.23% for HDPE in the UT waste stream. I then multiply this value by 4352.77 tons, the total waste generated by UT in 2004-05. This yields 10.01 tons of HDPE, which is an estimate of the tons of HDPE generated. This estimate gives the maximum tons of recycling possible with a 100% recycling rate.

Table 3: Estimation of UT's Composition of MSW Generation

Material	**EPA '03**	**Estimated UT % Composition**	**Estimated UT Tons Generated**
Paper and Paperboard	35.20%	48.07%	2092.38
Plastic #1 (PET)	0.45%	0.45%	19.59
Plastic #2 (HDPE)	0.31%	0.23%	10.01
Glass bottles	2.73%	2.57%	111.87
Aluminum cans	0.56%	0.39%	16.98

Other methods can be used to estimate the waste composition at UT. The method this study uses could underestimate or overestimate the amount of recyclables in the waste stream. UC Berkeley may have different consumption habits than UT. Unless all the waste at UT was accounted for, the exact composition of the waste cannot be known. For purposes of this study, this method of estimating the amount of recyclables in the waste stream is the best available.

2. Theoretical Framework

A straightforward model measuring the benefits and costs of recycling will determine the net benefits of recycling. The private and social models are based on the same intuition. The horizontal axis represents the amount of recycling (*X*), and the vertical axis represents total cost (in dollars). For simplicity, initially assume fixed costs are zero. In figure 1, total costs (*TC*) increase at an increasing rate; thus, in figure 2 the marginal cost (*MC*) curve is upward-sloping. In figure 1, total benefits (*TB*) increase at a decreasing rate, so that in figure 2, the marginal benefit (*MB*) curve is downward sloping. *X* is the choice variable, and *X* affects all costs and benefits. *Z* measures net gains. Therefore, $Z(X) = TB(X) - TC(X)$ is a function of X. One can maximize this net gain by taking the derivative of the equation and setting the derivative equal to zero. So, $\frac{dZ}{dX} = 0 = \frac{dTB}{dX} - \frac{dTC}{dX}$.

The marginal benefit (MB) is $\frac{dTB}{dR}$, and marginal cost (SMC) is $\frac{dTC}{dR}$.

The optimally efficient amount of recycling is *X**, which is the same in both figures. Here, slopes of the *TC* and *TB* curves are equal, *MC = MB,* and profits are maximized. Z_0 measures "profits". If *MC* and *MB* are private marginal cost (*PMC)* and private marginal benefit (*PMB)*, then this is private profits. If it is social marginal cost (*SMC*) and social marginal benefit (*SMB*), then this *Z* is a measure of net gains to society.

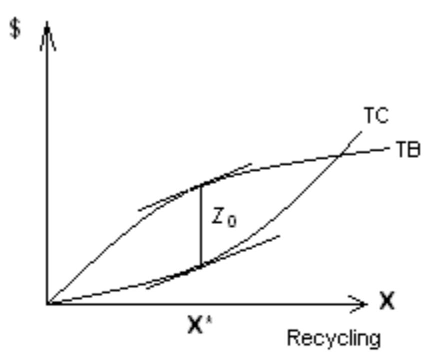

Figure 1: Maximization of *TC* and *TB* curves

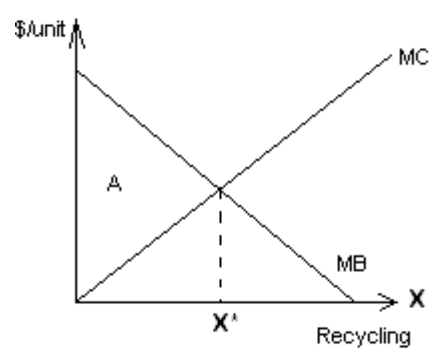

Figure 2: Maximization of *MC* and *MB* curves

Looking only at the private costs and benefits, the optimal level of recycling does not always result in profits. In figure 2, ignoring fixed costs (*FC*), it appears that *TB(X*) – TC(X*)* is equal to area A. X* is the optimal amount if you recycle at all, but if fixed costs are not zero, recycle (*X**) if $FC < A \equiv TB - TVC$. In figure 3, a scenario with high fixed costs is illustrated. The total variable cost (*TVC*) is added to *FC*, resulting in the total cost curve *TPC*.[11] Here, total private costs, $TPC = FC + TVC$, are greater than private total benefits at any amount of *X*. *MC* equals *MB* still defines the optimal level of recycling at *X**. In the case where *TPC* is always greater than total private benefits (*TPB*), *Z'* is less than zero. Losses are minimized at *X**, but $X = 0$ is the best choice.

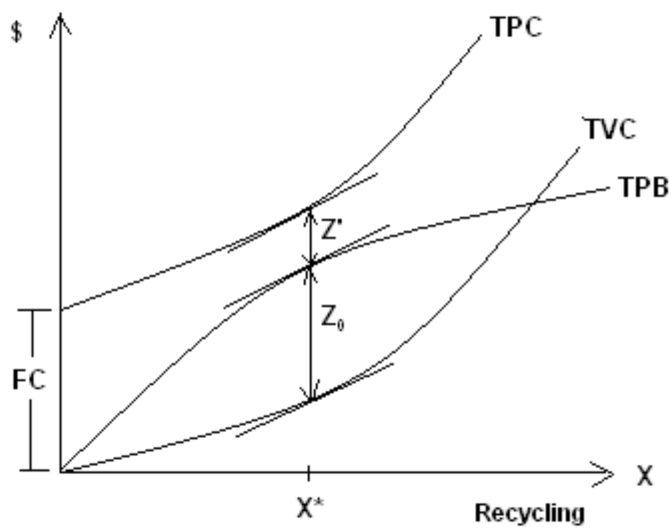

Figure 3: Private Costs and Benefits with Fixed Costs

First, consider private decisions:

(i) Continue to increase the amount of recycling until $PMC = PMB$, which is the privately optimal level of recycling, *X**. Area 1 + 2 equals the total benefits, and area 2 represents only variable costs. Net benefits equal $PTB – PVC$, which is area 1. At $\overline{X}$, an arbitrary amount of recycling, area 1 is not maximized; it is only maximized at *X**.

[11] Fixed costs of recycling do not have to be so large that the recycler always incurs a loss. TPC could be lower, where Z > 0.

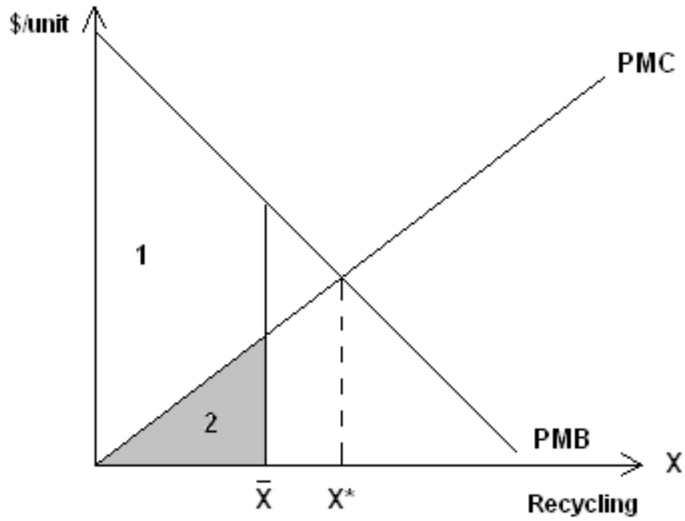

Figure 4: Calculate Area Under MC and MB Curves

(ii) Then, calculate total private costs as *FC* plus all *TVC* (the area under the *PMC* curve). Calculate total private benefits (*TPB*) as area under the *PMB* curve. At $\overline{X}$, the equation $TPC = FC + TVC$ becomes: $TPC = FC + \int_0^{\overline{X}} PMC(X)dx$. The decision to recycle at all should only proceed if *TPB(X*) > TPC(X*)*. In other words, recycle when $\int_0^{X^*} PMB(X)dx > FC + \int_0^{X^*} PMC(X)dx$.

When recycling occurs, waste is diverted from the landfills, and new products can be manufactured using the recycled materials. Figure 5 includes the external benefits and costs of recycling. When recycling takes place, external costs from landfilling are avoided. External costs of garbage are external benefits of recycling. Total external benefits (TEB) of recycling are given. Total benefits to society (TSB) include total private benefits and total external benefits; so, *TSB* ≡ *TPB* + *TEB*. In addition, recycling has some negative externality from the re-processing manufacturer. This total external cost (*TEC*) is given. The total social cost (*TSC*) curve includes total private costs and total external costs; thus, *TSC* ≡ *TPC* + *TEC*, accounts for the second externality. The resulting optimal level (*X**)* is higher than *X*;* because, in this case, external benefits of recycling are greater than the external costs of recycling.

Second, consider social decisions:

(i) Continue to increase the amount of recycling until *SMC* = *SMB*.

(ii) Assume there are no social fixed costs. All social costs are variable. Thus, there is no need to check the discrete decision – recycle if *TSB(X**) > TSC(X**)*. This condition is true as long as *MB (X**) > MCB(X**)*.

Ignoring FC,

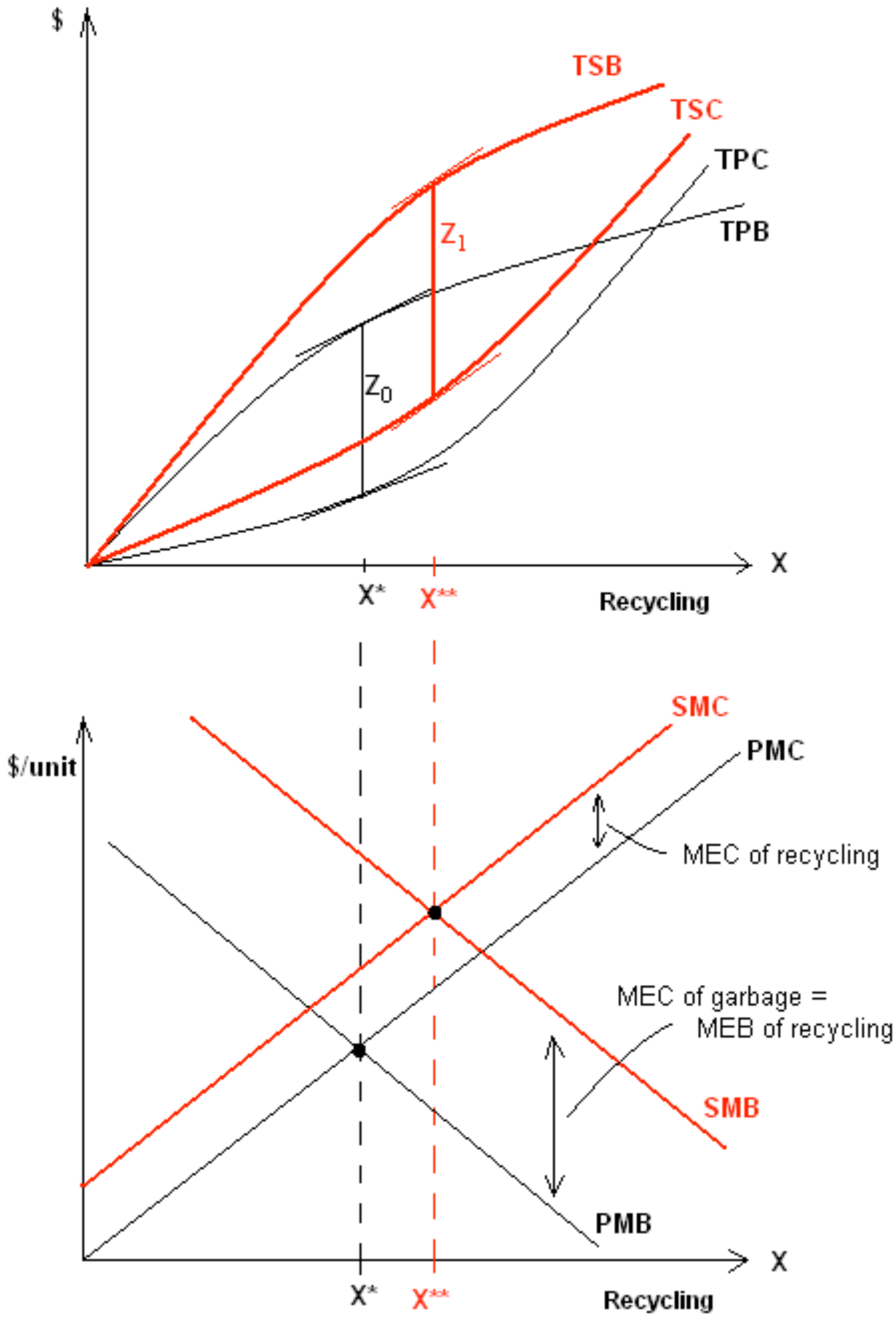

Figure 5: Social Costs and Benefits of Recycling

3. Methodology for UT's Cost-Benefit Analysis of Recycling

Cost-benefit analysis (CBA) is a simple economic evaluation method. It determines the net benefit of a project or policy by comparing all of its costs and benefits. Ward (2005) states, "a complete CBA compares alternative actions to determine which one provides society with the most economically beneficial use of its resources." The main criterion for evaluation is the question of net return to society as a whole.

Like other environmental policy issues, waste management is full of controversy. How are private costs allocated among different materials? How are environmental impacts and time use valued? Critics say a cost-benefit analysis ignores the distribution of benefits and costs, and simply sums up costs and benefits. The method of valuing the environmental impacts and the opportunity cost of time is important to finding the most efficient choice for waste disposal at The University of Texas.

A common task that must be undertaken when valuing recycling is how to value the environment. Non-market benefits and costs must be evaluated in order to compare all effects of recycling. Even if the valuation is filled with methodological and practical difficulties, it is usually not a good alternative to leave out an attempted estimation of these effects. The major environmental effects of waste are emissions from transportation, resource extraction, manufacturing, and discharges to air and water from the different treatment options, whether the waste is recycled, incinerated or landfilled. The difficulty lies in the steps taken to measure this environmental impact.

In order to value the environmental impact, the energy and resource use and environmental pollution of a product's life cycle must be quantified.[12] A product's life cycle includes all activities from resource extraction to the ultimate disposal of the waste. The Life Cycle Inventory (LCI) identifies life cycle steps that contribute to environmental impacts such as energy use, solid waste, and atmospheric and waterborne emissions. A more extensive extension of the LCI is the Life Cycle Assessment (LCA). A LCA identifies potential environmental and health impacts of products or processes. When the costs of different systems are compared - recycling versus waste disposal - a socially optimal decision can be made.

An incremental analysis will allow for identification of additional benefits and costs resulting from incremental changes in the recycling program rather than from a single all-or-nothing proposal (Ward 97). The

[12] Franklin Associates provides life cycle services for solid waste management and life cycle assessment information. The EPA uses their services for their life-cycle analysis.

university does not have to expand recycling to include aluminum, glass and plastic. UT may find it to their benefit only to expand the campus-wide recycling efforts also include just plastic, just aluminum, just glass, or a combination of two. If only one material provides a net gain, the university can choose to add only that one item, giving it more flexibility in its decision to expand the recycling program. Each material has a different market value and different environmental impacts, consequently affecting the net gains of recycling. This analysis benefits the university because the university does not have to reject complete expansion of the recycling program.

3.1 Private Costs and Benefits

To determine the private net gain from recycling each item (R_i) rather than putting it in the garbage (G_i), we have:

$Private\ Net\ Gain_i = [PRR_i - TCR_i - LCR_i] – [PRG - TCG_i - LCG_i]$, where i (i = 1, …4) is an index for the type of recycling (paper, aluminum, glass, plastic). Assume that the amount of garbage or any type of recycling is measured in tons.

The table below summarizes all the variables related to private costs and benefits, and then the variables are further described to avoid confusion.

Table 4: Private Cost and Benefit Variables for Recycling and Garbage

	Recycling	**Garbage**
Price “Received”	PRR_i	PRG
Transportation Costs	TCR_i	TCG_i
Labor Costs	LCR_i	LCG_i
Total Collection Costs	CCR_i	CCG_i

(i) PRR_i varies among different materials, while PRG does not vary among materials. The price received by the university for recycling, PRR_i can be positive or negative. The university receives a price for their recyclables or pays a fee to dispose of its waste. The price “received for garbage”, PRG , is simply the negative of the tipping fee. When a ton of waste is recycled, it no longer has a landfill cost; PRG is a cost to garbage disposal, thus its value is negative when interpreting it as price “received” for garbage. The tipping fee does not discriminate between materials collected, having the same fee per ton for all landfilled waste. If tipping fees internalize the scarcity value of landfill space, then the tipping fee reflects the true cost of purchasing new land once the current landfill has filled up. If the tipping fee does not internalize the scarcity value of landfill space, then the private cost of garbage disposal is understated.

(ii) Transportation costs include cost of the vehicle, maintenance, insurance, depreciation, and gasoline. This value would be equivalent to the gasoline costs plus the market rental price of the vehicle, if it were rented, because the owner would have to charge enough to rent to cover overhead costs of the rental company, including depreciation, maintenance, and insurance.

(iii) Labor costs include the time used in picking up the waste from the waste bins, and taking the waste to the end location, whether the location is a recycling center or landfill. Sorting costs included in the labor costs are only those sorting costs that affect the university. The university does not bear the opportunity cost of individual recyclers who spend time sorting their waste. When UT sells R_i to the recycling firm, UT does not have to worry about the recycling firm's costs.[13] The price the university receives for its recyclables, PRR_i, includes the sorting costs that a recycling firm incurs. Sorting costs do not apply to garbage, because I assume that all garbage travels directly from the waste bin to the landfill.

(iv) Total collection cost is the sum of transportation and labor costs. This term is defined now so it can be used later to generalize costs of collecting waste for landfilling or recycling.

3.1.1 Obtaining Private Costs and Benefits

Analyzing the private net benefits of recycling is difficult because of the volatility of the recycling revenue. Revenue equals price times quantity. Prices vary depending on the quality and quantity of recyclables and each price can change daily. The greater the price received from selling a ton of recyclables, all else equal, the greater the private net benefit of recycling that ton. The lower the price received from selling recyclables, the smaller the private net benefit of recycling.

The separate figures for recycling and landfill transportation costs must also be estimated from the information provided by UT's physical plant. The transportation costs the university incurs for recycling and solid waste disposal are combined. In order to find the transportation costs per ton of recycling or garbage, total transportation costs must be divided between recycling and garbage.

[13] Here I assume the recycler is the one who prepares the recyclables for selling in the secondary materials market. The university only participates in the collection phase of recycling.

Finding the labor costs for recycling and garbage requires many assumptions. The term "recycling workers" includes all waste workers at UT's physical plant. This includes the workers who drive the trucks, sort recyclables from garbage, and collect garbage and recycling for disposal. "Recycling workers" do not log the amount of time spent on garbage as opposed to recycling. They work set hours a day, and all workers work all areas of waste disposal. The method used will only provide an estimate of the true costs of labor for recycling and garbage. More documentation and investigation of the jobs performed by these workers will provide a better estimate of the costs of labor for recycling and garbage.

3.1.2 Private Costs and Benefits Data

The University of Texas' accounting of the solid waste department provides the disposal costs of waste. Known costs are the capital value of the transportation fleet, book value of the fleet, maintenance, gas, and labor costs.[14] Some costs for recycling can be extrapolated from the university's total waste disposal costs.

Table 5: Transportation Costs of Recycling and Garbage Disposal in FY 2005

Total number of trucks	8
Original purchase price of fleet	$532,614
Current book value of fleet	$254,257
Maintenance costs per year	$12,000
Total gasoline costs per year	$11,000
Total waste generated per year[15]	4352.77 tons
Distance to BFI	9 miles
Gas cost to BFI	$8,608.60
Trips per day to BFI	2
Tons of garbage	2629
Gas costs/ton to BFI	**$3.274**
Distance to Balcones	5 miles
Gas cost to Balcones	$2,391.40
Trips per day to Balcones	1
Tons of recycling	1723.77
Gas costs/ton to Balcones	**$1.387**

The university does not divide the total transportation costs between recycling and garbage disposal. Table 5 summarizes all of UT's transportation costs of waste disposal. In the fleet of eight UT waste vehicles,

[14] The university is self-insured; therefore, it does not buy insurance from an outside organization.
[15] Total waste for the university is found by adding the total recycling tonnage to total landfill tonnage in Table A-7.

four are heavy duty trucks: two transport solid wastes to BFI, one transports recycling to Balcones, and one acts as a back-up. The other four vehicles owned by UT aide in the collection of special pickups, such as waste from office file cleans-ups, large bulky objects, missed pick-ups, and tree limbs.[16] The original purchase price of the disposal vehicles for the university is $532,614. After depreciation (the fall in market value since purchase of each vehicle), the actual current book value of the fleet is $254,257. UT spent $12,000 on maintenance.

Special trips vary from year to year, making it difficult to sort the total truck costs into recycling and garbage disposal. Table A-5 in the appendix summarizes each vehicle. I could calculate the rental value of the fleet of trucks by finding the depreciation value.[17] However, I do not need to calculate the rental value of the fleet because the university will have to use all the vehicles for waste disposal, regardless of whether the waste is recycling or garbage. Truck costs per ton of recycling and garbage disposal would be identical, netting to zero in computation of the net benefit of recycling. The same intuition applies to maintenance costs. Therefore, both maintenance costs and truck costs per year are fixed costs, and do not affect marginal costs per ton when switched from garbage to recycling.

Differences in transportation costs between recycling and garbage disposal are small. The university spent $11,000 on gasoline for trips to the recycling center and landfill. UT uses BFI's landfill to store its waste, and sends its recycling to Balcones. BFI is nine miles away from UT, while Balcones is only five miles away. Two trips are made to BFI daily, and one trip is made to Balcones Recycling daily. As a result, 78.26% of gasoline costs are for trips made to BFI.[18] Multiplying $11,000 in total gasoline costs by the percentage of gasoline used for trips to BFI yields total gasoline costs for trips made to BFI. In order to find the gasoline cost per ton of garbage, simply divide the total cost of gasoline for BFI trips by the total tons of garbage disposed. This process is repeated for finding cost of gasoline per ton of recycling.

Labor costs are the most difficult to divide between recycling and garbage disposal. UT has eleven "recycling workers" who work 8 hours a day, 5 days a week. The total salary paid for these workers amounts to

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16 These are examples of waste that require special pickups because the amount of waste collected for disposal is too large to handle with the normal waste pickup truck and pickup schedule. These events do not occur on a daily basis.

17 The rental rate equals the depreciation of each vehicle plus maintenance costs and insurance. Depreciation measures the fall in economic value of the vehicle per year. The value of each vehicle is $V_t = V_o\,(1\text{-}\delta)^t$; where V_o is the original purchase price, V_t is the current market value, δ is the depreciation rate, and t is time in years. Solving for the depreciation rate, I get: $\delta = 1\text{-}(V_t/V_o)^{1/t}$. Therefore, total depreciation equals V_t times δ. The total value of the fleet is simply the sum of all the rental values of each vehicle.

18 Daily transportation miles to BFI is 36 and to Balcones is 10. Thus, total miles traveled per day is 48. So, 36 divided by 46 yields 78.26%.

$287,165. Collecting and transporting recyclables and garbage do not require the same skills and time; recyclables must be checked for contamination rates and manually handled. The recycling center will only accept recyclable waste that does not exceed their maximum contamination rate. While most of the university's garbage is picked up using the mechanical hand of the dump truck, recyclables must be hand collected. I assume the labor cost per ton of recyclable waste is 15% higher than for garbage disposal.[19] Thus, Labor costs for recycling equal $71.62 per ton and $62.27 per ton for garbage.

All materials in consideration have a positive net private benefit to recycle at the university. Table 6 sums up each material's net private benefit. Although total costs of recycling, CCR_i, are higher than total costs of garbage, CCG_i, the net private gain of recycling is still positive. The higher cost of recycling stems from the higher labor costs associated with recycling. Recycling is more labor intensive than garbage disposal. The only offset in higher costs of recycling is the farther distance of the landfill. However, this offset in higher costs of garbage disposal is small. The benefit of recycling is the avoided cost garbage, which is the tipping fee and cost of garbage disposal. If the net cost of disposal, $CCG_i - PRG$, is greater than the net cost of recycling, $PRR_i - CCR_i$, a net benefit of recycling is realized.

Table 6: Private Costs and Benefits of Recycling (per ton)
using BFI's Prices for Sorted Recyclables

i	Paper	Aluminum	Glass	PET	HDPE
PRRi*	**$99.14**	**$700.00**	**$0.00**	**$300.00**	**$300.00**
PRGi	**-$17.50**	**-$17.50**	**-$17.50**	**-$17.50**	**-$17.50**
*TCRi***	$1.39	$1.39	$1.39	$1.39	$1.39
LCRi	$71.62	$71.62	$71.62	$71.62	$71.62
CCRi	**$73.01**	**$73.01**	**$73.01**	**$73.01**	**$73.01**
*TCGi***	$3.27	$3.27	$3.27	$3.27	$3.27
LCGi	$62.27	$62.27	$62.27	$62.27	$62.27
CCGi	**$65.54**	**$65.54**	**$65.54**	**$65.54**	**$65.54**
private net benefit	**$109.18**	**$710.04**	**$10.04**	**$310.04**	**$310.04**

* February 2006 prices the university could receive for pre-sorted materials at BFI.
**The only transportation cost listed is the cost of gasoline because costs such as insurance, maintenance, truck rental costs are incurred whether or not the university switches any ton from garbage to recycling; therefore, they would cancel out.

[19] This assumes $LCR_i = 1.15 X LCG_i$. *Solving for* LCG_i *in the equation:* $LCG_i X (2629 \text{ tons } G) + 1.15 LCG_i X (1723.77 \text{ tons } R) = \$287,165$ *yields $62.27.* If labor costs for recycling are 20% more than labor costs for garbage disposal, using the same equation, $LCG_i = 61.13$ *and* $LCR_i = 73.36$. This will result in an increase in net collection costs of recycling, decreasing private net gains of recycling.

Net gains for each material vary because PPR_i vary. Recycling aluminum provides the university with the highest net private benefit because it has the highest price received. Next are the plastics, followed by paper and glass. Although glass does not provide the university with a source of revenue, the net collection cost of recycling, $CCR_i - CCG_i$, is less than the net benefits of recycling, $PRR_i - PRG$. As long as $CCR_i - CCG_i < PRR_i - PRG$, the net private benefit of recycling is positive.

3.2 The External Costs and Benefits

Private markets are perfectly efficient only in the case with no public goods, externalities, increasing returns to scale, disinformation, and distortions between the costs paid by buyers and the benefits received by sellers. Waste disposal does impose externalities; thus, external costs and benefits must be measured in order to find net gains of recycling to society.

Most studies show that recycling has a net benefit to the environment, though not all steps in the recycling process may have positive net benefits to the environment. Like traditional waste disposal, recycling has both costs and benefits to the environment. The extra costs to the environment when recycling include using clean water and increased pollution when making trips to the recycling center. The environmental benefits of recycling waste include fewer landfill emissions, decreased pollution from extraction of virgin natural resources (e.g. mining, refining), conservation of natural resources, water savings, and energy savings. The net external benefits of recycling equals the external benefits minus the external costs.

3.2.1 Obtaining External Costs and Benefits

Measures of economic value are based on what people want. The use of many environmental services (e.g. oxygen, water, carbon dioxide absorption) is not formally traded in markets. Some of the external costs associated with landfilling waste include air pollution, water contamination, and decreased land value. The decrease in external costs when recycling is the chosen method of waste disposal measures the environmental benefits of recycling. Thus, what is required is a measure of what people are willing to give up to receive a service of the environment, or how much they must get paid to give up a service or environmental amenity. The willingness-to-pay principle helps economists place an economic value on the environment, which does not already have a value given to it.[20]

The most obvious benefit of recycling is the reduced externalities produced by the total waste generated. The OECD (2004) study estimates the cost of the externalities produced by landfill waste. This includes mainly emissions of two greenhouse gases: carbon dioxide (CO_2), methane (CH_4). In addition to air pollution, contamination of water can occur if leachate leaks from the landfill when the lining of the landfill breaks. Landfills are required by law to capture and treat leachate. In the case that a breach occurs, the landfill absorbs most of the costs for damages caused by the breach; however, the potential damage to the environment may not be fully captured.[21] The OECD study includes the externalities associated with the transportation of waste to the landfill.

Assumptions simplify comparative life-cycle assessments; and, because of these assumptions, the assessments must be read with caution. It is assumed that the recycled materials perform exactly the same function as primary materials, but this is not always the case. For example, plastic bottles that are recycled cannot always be made into plastic bottles again because new bottles need a specific strength and quality of material. LCAs also assume that recycled materials are transported to a manufacturer that uses the same process of manufacturing primary products. If the recycled material is shipped abroad, different manufacturing processes arise, which change the life-cycle of that material. Countries have different regulations in product manufacturing and different standards products must uphold. When a life-cycle assessment of another country is used in comparison, the values provided in the study give only a rough estimate of the external impact of that material.

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[20] The willingness-to-pay principle is not the only way non-market activities can be valued. Another method to value the environmental impact of waste can be measured by taxation. Economic taxes internalize the costs of waste management and the environmental impacts of waste. There are three types of environmental taxes: cost-covering taxes, incentive taxes, fiscal environment taxes (EEA 1996). Incentive taxes best estimate the cost of environmental damage. Environmental taxes provide incentives to avoid the tax by generating less of the substance being taxed, which in this case is garbage. In order to value disposing garbage's impact on the environment, the tax must only reflect the external costs. Environmental taxes bring the cost of pollution and other costs of using the environment into the price of services provided by the environment. These taxes internalize the externalities of waste. The environmental tax in one country should reflect the external cost of pollution in all countries assuming the external cost imposed by garbage disposal does not depend on where the pollution occurs. The pollutants produced by one country affects the environment of another country because the ecosystem is intertwined. When tipping fees do not include environmental costs of waste, the quantity of waste disposed is greater than the optimal level of waste disposal. Therefore, environmental taxes can shift the cost of waste disposal (supply), and lessen the quantity of waste disposed, bringing the quantity disposed closer to the optimal level.

[21] Landfills do not compensate homeowners when wells are contaminated. Landfills only pay for the clean up of the leachate leak, and do not pay for external costs that do not affect the landfill.

The hard-to-measure benefit of recycling is the environmental savings when recycled materials are used in manufacturing instead of virgin materials. For example, manufacturing aluminum from recycled aluminum uses 95% less energy than primary aluminum production. While some materials use fewer resources to remanufacture new products, recycling plastic requires more water usage than production of plastic. The DEFRA (2004) study compares the life-cycle assessments of primary and secondary productions.

In addition to valuing recycling's impact on the environment, recycling requires the time of the participant. The cost of time spent on waste disposal is one's opportunity cost, the next best use of that person's time. In the case of recycling, the opportunity cost can be either leisure time or work time. If recycling displaces work time, the opportunity cost is the time spent on recycling times the hourly wage of the work. If recycling displaces leisure time, the opportunity cost becomes the value the person places on his or her leisure time. According to *welfare theory*, people supply work up to the point where the value of working one additional hour equals the value of that time as leisure. Assuming no constraints on their choice to work any number of hours, the value of an hour of leisure is equal to the net-of-tax hourly wage.

Although recycling imposes an opportunity cost on the un-paid individual doing the recycling, the act of recycling on campus does not have net external benefits. The recycler would not give up his or her time unless this external benefit of recycling was worth as much as her time given up. I can also assume that sorting has little or no costs. When a recycling bin is placed next to a garbage bin, placing the recyclable into the recycling bin does not create an extra time cost for the recycler or collector. The amount of time it takes to throw trash into the waste bin costs the same amount as the time it takes to throw trash into the recycling bin.

3.2.2 External Costs and Benefits Data

Because BFI is solely a landfill collection site, I will not focus on environmental impacts of incineration. Incineration provides energy and produces pollutants. I will not speculate to what extent this changes the environmental impact of garbage disposal. Other studies like DEFRA (2004) and OECD (2004) both include incineration in their calculations.

Most studies can only provide ranges of the value of landfill externalities. LCA valuations vary from study to study, and many environmental valuations rely on these secondary estimates and studies. In the end, an average or median value is determined. OECD (2004) estimates the value of landfill externalities to be range from £1.12 to £7.66 ($1.96 to $13.38) per ton.[22] With this range, the mean value of landfill externalities is estimated at £3.45 per ton of waste. Translated into dollar terms, the mean value of landfill externalities is $6.03 per ton.

Landfills also decrease the value of property near the landfill. The term associated with the negative localized impact of landfills is disamenity. The consensus reached by a number of studies concludes that a home located within one mile of the landfill is worth 5 to 10 percent less than a comparable home away from the landfill. To find the per ton disamenity cost, the total disamenity due to the landfill is divided by the total tonnage of garbage collected per facility in one year.[23] DEFRA (2003) estimates the disamenity cost to range from £2.50 to £3.59 ($4.36 to $6.27) per ton and a central estimate of £3.05 ($5.33) per ton.

The final external cost of garbage disposal involves the transportation of solid waste to the landfill. Davies and Doble (2004) estimates that congestion, air pollution, and increased probability of road accidents cost $0.51 per ton for urban landfills and $1.69 per ton for rural landfills. This value will not be added to the external costs of landfills because recyclables must also be transported to a recycling center for processing. I assume this external cost of recycling is very similar to the value of garbage's external transportation costs. Therefore, net external transportation costs of switching a ton of waste from garbage to recycling would equal zero.

The values from LCA calculations and environmental valuations cannot be taken as absolute; they are only estimations. Based on these assumptions and estimations, total external costs of solid waste transportation and disposal range between $6.32 and $19.65 per ton and have a mean value of $11.36 per ton. Each landfill's waste composition differs from another; therefore, the landfill at BFI may not have the same external impacts as the landfills under the DEFRA and OECD studies.

The external costs of landfilling need to be compared to the environmental costs and benefits of recycling, and this difference must be included to find the net social gain of recycling. In some cases, production of secondary materials using recycled materials has a lower net external cost than production of primary materials. DEFRA (2004) compares the life-cycle assessments of the production of secondary materials and primary materials. A generic life-cycle is constructed using the International Organization for Standardization's (ISO) standard ISO 14040. The summary of their findings can be found in Table 7.

[22] Using March 27, 2006's conversion of £1.747 = $1.
[23] The DEFRA (2003) study found that houses beyond the 0.5 mile radius of the facility had no changes in property value.

Table 7: Total External Benefits of Manufacturing Using Secondary Materials Instead of Primary Materials, $ per Ton of Finished Product

Impact		**Glass**	**HDPE**	**Paper**	**Aluminum**
Resource use (aggregates)		9.99	0.00	0.00	0.00
Greenhouse gases	CO_2 as C	-1.07	3.00	-1.28	-1.21
	CH_4	0.00	0.00	0.00	0.00
	N_2O as N	0.23	-0.01	0.16	3.49
Particulates		338.74	33.02	75.28	708.30
Acid gases	SO_2	-1.05	0.58	0.72	11.51
	NO_x	-0.65	7.56	0.94	25.38
Casualties		-9.45	-11.43	-10.81	-9.89
Total benefit not including noise and congestion		**337.49**	**32.72**	**64.99**	**737.62**
Road congestion		-23.71	-29.12	-27.57	-25.58
Traffic noise		-5.35	-6.71	-6.34	-6.01
Total external benefit (TEB) of using secondary materials		**308.43**	**-3.11**	**31.08**	**706.03**

Note: positive numbers indicate benefit, negative number indicates additional cost from using secondary materials.

Each LCA uses different methods of valuing the impact of recycling. DEFRA (2004) begins each life-cycle at the resource stage. For primary materials, the cycle begins at resource extraction. For recycled materials, the cycle begins at the recycling center, where pre-processed materials are collected. They define each external impact:

(i) Resource use (aggregates) is the savings in terms of energy use and other resources from the acquisition and processing of the primary product less the energy used in the reprocessing of secondary materials. Losses of secondary material during reprocessing and contamination are taken into account. DEFRA's (2004) study does account for the taxes placed on resource extraction. If taxes are present, the external costs of aggregate extraction are internalized and therefore are not counted. Otherwise, external cost is included in the analysis.

(ii) Greenhouse gases, particulates and acid gasses refer to the net emission benefits of using recycled products instead of primary materials to produce a product. The social impacts include a wide variety of human health effects and damage to the ecosystem.

(iii) Casualties are the value of lives potentially lost in traffic accidents.

(iv) Road congestion is caused by bringing primary or secondary materials for remanufacturing. The value of road congestion is the time saving as a result of reduced congestion.

(v) The total value of traffic noise is based on the distance materials travel before they are manufactured. This cost is divided by the average tonnage each trip carries to find the traffic noise cost per ton.

The DEFRA (2004) study does not include findings for PET plastic. A comparison of PET and HDPE's LCA will give a better estimate of the environmental benefits of recycling PET. Craighill and Powell (2005) in the UK also studied the environmental benefits of recycling. Just like the DEFRA (2004) study, the costs of using recycled materials for manufacturing are deducted from costs of using virgin materials for manufacturing to characterize the net environmental benefits of recycling. Craighill and Powell's study can be summarized in Table A-6 in the appendix. In order to apply the Craighill and Powell study to the DEFRA (2004) study, I make a comparison between PET and HDPE. Craighill and Powell value the net external gain of recycling HDPE at -$4.49 per ton and recycling PET at -$7.28 per ton. The negative gain signifies a cost to society when recycling either PET or HDPE. I used the ratio between Craighill and Powell's valuation of PET and HDPE to find the net external gain of recycling PET, which I value at -$8.81 per ton.

Table 8: Net External Benefits (NEB) from Recycling, per ton

low	**Paper**	**Aluminum**	**Glass**	**PET**	**HDPE**
TEB of using secondary materials	$31.08	706.03	308.43	-8.81	-3.11
External cost of landfill*	$6.32	$6.32	$6.32	$6.32	$6.32
Net external benefit (NEB)	$37.40	$712.35	$314.75	-$2.49	$3.21
high					
TEB of using secondary materials	$31.08	706.03	308.43	-8.81	-3.11
External cost of landfill*	$19.65	$19.65	$19.65	$19.65	$19.65
Net external benefit (NEB)	$50.73	$725.68	$328.08	$10.84	$16.54
mean					
TEB of using secondary materials	$31.08	706.03	308.43	-8.81	-3.11
External cost of landfill*	$11.36	$11.36	$11.36	$11.36	$11.36
Net external benefit (NEB)	$42.44	$717.39	$319.79	$2.55	$8.25

*external cost of landfill includes externalities of the landfill and transportation, and disamenity

The net external benefits can be summarized using the low and high range or a mean value. The low value has a lower value of the external cost of landfilling compared to the high value. The remainder of this study will only focus on the mean value. Other calculations can be performed with the low and high figures. The results include the total external benefits with the noise and congestion because all materials must be brought to manufacturers. Adding the external benefits of the production of secondary materials to the external costs of landfilling gives the net external benefits of recycling. The external cost of the landfill is a benefit of recycling because these costs are not incurred when recycling replaces landfilling.

4. Results and Analysis

Although all recyclable items are collected in different amounts, receive different prices per ton, and have different net environmental impacts, private and external net gains of recycling for all materials are positive. The private and external net gains for aluminum are the highest at $710.03 and $717.90 per ton, respectively, resulting in the highest net social gain per ton.

Table 9: Net Social Gain Per Ton and Total Tonnage

	Paper	**Aluminum**	**Glass**	**PET**	**HDPE**
Net Private Benefit ($/ton)	109.18	710.04	10.04	310.04	310.04
Net External Benefit ($/ton)	$42.44	$717.39	$319.79	$2.55	$8.25
Net Social Gain ($/ton)	**$151.62**	**$1,427.43**	**$329.83**	**$312.59**	**$318.29**
Total Tons Generated Using Ratio	2,092.38	16.98	111.87	19.59	10.01
Net Private Benefit, 100% Recovery ($)	$228,439.77	$12,056.43	$1,122.84	$6,073.62	$3,103.47
Net External Benefit, 100% Recovery ($)	$88,800.61	$12,181.28	$35,774.91	$49.95	$82.58
Net Social Gain , 100% Recovery ($)	**$317,240.38**	**$24,237.71**	**$36,897.75**	**$6,123.58**	**$3,186.05**
National Recovery Rate (%) [24]	48.10%	43.90%	19.40%	25.20%	31.90%
Tons Recycled Using Recovery %	1,620.78*	7.45	21.70	4.94	3.19
Net Private Benefit, Nat'l Recovery Rate ($)	$176,951.90	$5,292.77	$217.83	$1,530.55	$990.01
Net External Benefit, Nat'l Recovery Rate ($)	$68,785.90	$5,347.58	$6,940.33	$12.59	$26.34
Net Social Gain, Nat'l Recovery Rate ($)	**$245,737.80**	**$10,640.35**	**$7,158.16**	**$1,543.14**	**$1,016.35**

*Tons of paper recycled at UT in FY2004-05 was 1,620.78 tons. Estimate using the national recycling rate is too low.

The socially optimal decision looks at net social gains. Table 9 summarizes the net social gain from recycling. To find the net gains of recycling, the total costs are subtracted from the total benefits. All else equal, a positive value means recycling is the more economically efficient option of waste disposal. Consequently, a negative value means landfilling is the most economically efficient choice of waste disposal for the university. All materials have a positive net social gain, making recycling the most optimal choice for waste disposal.

[24] Recovery percentages were found using data from Tables A-3d to 3h in the appendix.

4.1 Paper

Because paper provides the university with a higher revenue stream than other recyclables, the university will continue to focus their efforts in the collection of paper for recycling. Paper is the largest recycled waste by weight at the university. Large, public universities like UT generate a large amount of paper waste. The estimated net private benefit of recycling paper is $176,951.90, much higher than aluminum, the closest counterpart. Net external gains are positive, increasing the net social gains of recycling paper. To maintain this high recycling rate, extra resources will not be required because the program for paper is already established. Other materials will require more resources to increase recovery rates. Revenue from paper rebates for the university can be found in Table A-7 of the appendix. The university received an average of $99.140 per ton of paper recycled during the fiscal year of 2004 to 2005. This is an average of the total paper rebates divided by the total tons of paper recycled.[25]

For paper, the quality required for the end product determines the recycling process. Higher grades of waste paper need little cleaning and are used to make writing paper, tissues and wrapping papers. Lower grade papers are used for packaging papers and paperboard. The general process for recycling paper requires the paper to be soaked and pulped, contaminants removed, de-inked, and thickened. Then the pulp is sprayed onto a carrier belt and dried on heated rollers. This study is unable to break down paper by its different grades. Breaking down paper into different grades may imply that some paper products are socially inefficient to recycle. The more impure the recycled paper, the higher the cost to recycle it.

The demand for recycled waste paper remains strong. The U.S. is a major exporter of waste paper to countries like Japan and South Korea who are fiber-poor countries (EPA 1995). The U.S. government requires federal agencies to purchase paper with a minimum 30% post-consumer content. The paper industry also adds to this demand by making investments in manufacturing paper and paper products using recycled materials. Selim Ariturk (2000) discusses the reasons why recycled paper products cost more than primary paper products. Paper's price is determined by supply and demand. In the case with recycled paper, demand is unusually strong. Consumers demand recycled products. Businesses want to enhance images, and use recycled products. All

[25] Total paper rebates includes all paper: office paper, mixed office paper, newsprint, magazines, envelopes.

these factors create a strong demand for recycled paper, which translates into a strong demand for recycling paper.

4.2 Plastic

Recycling plastics has the lowest environmental benefit. Using recycled plastic for manufacturing instead of primary materials uses more energy and water resources; however, despite the net negative external impacts of manufacturing post-consumer plastics, the private benefits of not landfilling plastics causes net social benefits to be positive. To recycle plastic, the sorted plastic has contaminants removed, washed, dried, and turned into pellets. Water and energy savings depends on the degree of contamination.

Plastic has the lowest recycling rate by weight at the university. Plastic has a higher volume-to-weight ratio than the other recyclable materials. This difference in transportation cost is not calculated because plastic's volume-to-weight ratio compared to other recyclables must be known.[26] This aspect of recycling plastic makes plastic more expensive to recycle; however, price received for recyclable plastics has been high due to high petroleum prices, offsetting higher recycling costs.

As oil and energy prices continue to rise, the net benefit of recycling plastic will be greater than in the past. When petroleum prices rise, the costs of producing virgin plastic also rise. This makes recycled plastic relatively cheaper for manufacturers and more valuable to suppliers of recycled plastic. Industry leaders predict petroleum prices will not fall significantly below current levels in the near future.

PET bottles will continue to displace aluminum cans in the soft drink market. Statistics show plastic's share of the soft drink industry on the rise, as metal and glass' shares of the industry are falling. Consumers prefer PET bottles' clarity, flexibility, and ability to be resealed. Although prices of recycled material can vary frequently, the near future does not show any signs of cooling demand for recycled plastics.

The different plastics cannot be seen as one category of collection. The benefits of recycling PET and HDPE differ. The net social gain of HDPE are higher than PET, because PET has lower net external benefits per ton. HDPE has a higher recycling rate than PET; however, the generation of PET is higher than HDPE, allowing for a greater total social gain of total tons recycled. Net social gains per ton cannot be the only factor when

[26] This situation applies to all materials. To find TCR_i , total gasoline costs must be allocated to each material based on its volume-to-weight ratio, then divided by the total tons recycled of that material.

considering adding materials to the recycling program. The tonnage of material collected for recycling must be taken into consideration because it affects the total gains the university can receive.

4.3 Glass

Recycling glass would not produce a source of revenue for the university. Glass has a low market price and a high contamination rates due to breakage. Commercial recycling of glass has a lower contamination rate than municipal or university recycling, increasing the recyclable glass' value. Recovered glass markets usually require material with very little contamination.

Recycling glass would solely be for environmental benefits. If the university's goal is to maximize social welfare, recycling glass has a positive net external benefit. Glass has a higher net external benefit than recycling plastics or paper. When looking at net social gains of recycling per ton, only aluminum has higher net social gains. When looking at the total benefits of recycling at the national recycling rate, paper and aluminum have higher gains to recycling. This results because collected paper tonnage is high and recycling aluminum has enormous private and external benefits.

Glass' advantage over plastics is the tonnage collected and recycled. Net social gains for recycling glass do not differ much from recycling plastics. However, estimated tonnage of glass generated or recycled is significantly higher than both plastics. Recycling glass would benefit the environment more than recycling plastic; but, plastic would benefit the university more. In this case, the university's decision to expand recycling to glass or plastic depends on whether it wants to maximize net private benefits or net social benefits.

4.4 Aluminum

Over the past few years, the soft drink industry's preferred form of packaging has shifted from aluminum to plastic bottles. On the consumer side, the demand for aluminum cans has waned. On the manufacturing side, aluminum cans are more expensive to produce because aluminum is more expensive. Because of the gradual switch towards plastic, aluminum now constitutes a smaller part of the university's waste stream.

The amount of aluminum in UT's waste stream limits the benefits of recycling aluminum. Aluminum's total social benefit depends heavily on the amount recycled. The 16.98 tons of aluminum cans the university generates is based on a 100% recycling rate. At a national average of 43.9% recycling rate for aluminum cans, only 7.45 tons of aluminum would be collected for recycling. Aluminum has the highest private and external benefits per ton; however, at national recycling rates, paper's net social gain based on total tonnage recycled exceeds aluminum's.

5. Limitations of the Research

The accuracy of the cost-benefit analysis hinges on how close the estimates used in the analysis are to their true values. Because The University of Texas does not have a recycling program already set up for recycling plastic, glass, or aluminum, these values are estimated. If the costs of recycling are more than estimated, the recycling program would have a less favorable outcome. If the benefits of recycling are more than estimated, an expansion of the recycling program would benefit the university.

5.1 Data Availability

A more comprehensive audit of the recycling and waste disposal programs at the university needs to occur in order to achieve a more accurate cost-benefit analysis of the waste management system. The most current UT waste audit may be a biased sample if most of the landfilled waste are collected from areas near the food service centers on campus. The waste could have also come from a remote part of campus, where very few students walk, possibly underestimating the number of recyclables in the university's waste stream. This would create an even stronger case for implementing a university sponsored campus-wide recycling program. Neither case can be verified, thus a conclusion on the validity of UT's waste audit cannot be made.

The state of Texas is not required by law to report on recycling. This creates a scarcity of detailed data on the waste disposal habits of Texans. Because tipping fees are lower in Texas compared to the national average, consumers have fewer incentives to recycle. Kinnaman and Fullerton (2000) find that exogenous variables such as socio-economic status, population density, and education levels affect recycling rates. The data available for Austin and the state of Texas generalize the recycling rates and do not provide detailed surveys or studies.

The environmental analysis that is performed prior to the economic valuation of the environmental impacts is based on LCA methods. LCA has been subject to standardization efforts, but some methodological limitations exist. Economic valuations are applied to environmental costs arising from recycling; however, models used to assess environmental impacts are limited by their assumptions, and LCA studies may not be accurate for specific local applications. Not every externality can reliably be valued in monetary terms, because some external effects are difficult to measure, and some environmental impacts are too site-specific to transfer the information to another study.

This study relies on the life-cycle assessments performed by others, and not all LCAs produce the same outcome. All the assessments are estimations of what the researchers believe to be the most accurate. These estimations usually come in a low, high and mean value to give a range of possible values for each life-cycle. One assessment may place more value on a different aspect of the life-cycle of the material; therefore, creating differences among various assessments. Also, both the DEFRA and OECD studies are performed in Europe, which has a slightly different process for manufacturing the same finished product. This creates a difference in energy and water use, emissions, and other resource use. If the UK and U.S. have different methods of manufacturing, benefits of recycling could be overstated or understated.

The concern of double counting benefits and costs of recycling arises when different studies are brought together to form a single estimation. Every study has a different method of acquiring data. Studies may start at different points in a product's life-cycle. Taxes may be considered in some studies, but not others. Each study must be read with scrutiny to discern their method of evaluation to avoid double counting.

The objective of a study can alter results. If a study is done to sway the reader that recycling is indeed a benefit to society, values for the cost of pollution and other negative externalities could be overstated, or costs of recycling understated. It may also seem unlikely to some that the external benefits of recycling aluminum and glass be as high as the figures in Table 7.

DEFRA (2004)'s study takes into account taxes placed on materials, making sure not to double count; however, the tax structure in the U.S. varies from that of the UK. How much of the tax actually goes towards environmental controls? Loopholes and tax breaks can change the effective amount of tax used for environmental improvement. All resource extraction must comply with state and federal laws, including air and water quality standards. The primary material's selling price already accounts for this cost. The LCA must base its external cost and benefit estimates on current methods of manufacturing.

This study could not separate the materials in the landfill when calculating the external costs of a landfill per ton of waste. Unlike the external landfill costs in Table 8, each waste contributes a different amount of externality. Wastes like glass, HDPE and PET are considered inert, meaning they contribute very little or nothing to external pollution in landfills because they do not break down as easily. This implies that these materials should have a lower external cost of landfilling.

The assumption that each material has the same collection costs per ton generalizes costs. Each material has a different volume per ton. This makes transporting a ton of paper and glass less expensive than a ton of aluminum or plastic because of their higher densities. More accurate collection costs would have to be weighted based on the composition of recyclables, which is unknown at this point in time, and also change constantly.

This study assumes $AC = MC$ and $AB = MB$; however, varying amounts of recycling can change both the marginal and the average cost or benefit of recycling. As recycling rates increase, the total cost per ton of recycling decreases to its minimum point, and then increases as capturing additional materials becomes harder. As recycling increases and diversion of waste from the landfill increases, I assume benefits of recycling to be unchanged. This is true only if each additional ounce of landfill pollutant, or each additional mile of road traveled by the truck pollutes the environment to the same degree.

5.2 Costs to Expand Current Recycling Efforts

The estimated cost of UT's recycling program does not account for increases in the cost of an expanded program. This study assumes no changes are made to the existing program as recyclables collected are added. This assumption is unlikely. New bins need to be purchased to hold recyclables, and students need to be educated about using the bins. A new program also requires more staff time. The additional administration cost increases fixed costs. In addition, it must not be forgotten that these bins also have externalities. They can be an eyesore or take up extra room in buildings or outdoors.

The cost of adding more bins to the recycling efforts on campus cannot be estimated accurately by this study. I do not know the exact number of rooms on campus, how many bins would be needed, or the location placement of the bins. Any estimate of mine would be a very rough estimate. Deciding how the costs are allocated also complicates matters. The university makes an initial investment in the bins. The bins are not repurchased or rented every year; therefore they are not a fixed cost of the program. The number of bins may or may not increase as recycling increases; thus, it may not be a variable cost.

Using the equations from the theoretical framework, costs of new recycling bins can be added into the equations to determine whether or not expanding recycling should occur. Without extra bins, the university recycles if $\int_0^{X^*} PMB(X)dx > FC + \int_0^{X^*} PMC(X)dx$.

If the initial cost of the bins is a capital investment, it can be depreciated each year to find the rental cost per year (RC_{BIN}). With the additional cost of the new bins, the university recycles when

$$\int_0^{X^*} PMB(X)dx > RC_{BIN} + FC + \int_0^{X^*} PMC(X)dx.$$

The number of new bins required requires a bold estimate. Currently UT has 18,493 bins around campus that collects recycling: 15,437 in academic buildings, 2,600 in dorms, 432 in classrooms, 24 outdoor orange paper bins.[27] To expand recycling to plastic, aluminum and glass, the university would not need to purchase 18,493 bins. In a rough estimation, I estimate the university would need 825 additional 23-gallon bins for its recycling expansion. My calculation of bins includes: 3 bins per laundry room in the dorms, 3 bins per outdoor paper bin, 3 bins where the most foot-traffic on campus occurs. Three bins are required per area because glass, aluminum and plastic are collected separately to receive the price listed in Table 6.[28] The bins required for expansion of the program must be placed in areas where they will attract the most recyclables. Otherwise, the expansion of the program would be too costly, both privately and socially.

Additional bins are a cost to recycling. At $30 per bin, an estimate provided by UT's physical plant, 825 bins would cost $24,750. However, this cost is not incurred every year. Assume a bin life of 5 years before replacement. Then, RC_{BIN} = $4,950.

The same intuition lies behind the added administration and education costs. The extra private fixed cost of administration and education (PFC_A) means the university recycles when

$\int_0^{X^*} PMB(X)dx > PFC_A + RC_{BIN} + FC + \int_0^{X^*} PMC(X)dx$. These extra costs do not change the optimal

[27] Information found on UT's physical plant website, last modified April 23, 2006.
[28] With commingling of recyclables, the price received will decrease. This may be more cost effective if bins are not filled when collection occurs, or if the cost of bins outweighs the benefits of the recycled materials collected.

amount of recycling (*X**) in these equations (or in Figure 5), but they can affect whether the net gain at *X** is positive or negative – and therefore whether to recycle at all.

Should UT add materials to their recycling program? Table 9 calculates total net benefits. Assume no fixed marginal benefits. The expansion of the recycling program includes aluminum, glass, and plastic. It is impossible to collect 100% of all waste generated. Thus, I look at the total net benefits of total tonnage recycled at the national recycling rates.

(i) In the private case, the increase in net private benefits totals $8,031.16. Net private benefits must be greater than the sum of PFC_A , RC_{BIN} , and FC. With additional bins costing $4,950, private fixed costs of administration must be less than $3,081.13 to have a net private gain to recycling. Costs for a new recycling administrator and education would most likely cost more than $3,081.13; therefore, in the private case, UT would not expand recycling.

(ii) In the social case, the increase in net social benefits totals $20,358. It is still unlikely that PFC_A and other fixed costs total less than $15,408, which is net social benefits minus RC_{BIN}. Therefore, in the social case, UT would also not expand recycling.

I assume that UT recycles at the same rate as the national average. Perhaps, the university has higher recycling rates per material. If this is the case, the upper bound of net private gains equals $22,356.36 and the upper bound of net social gains equals $70,445.09. The upper bound of net social gains is based on a 100% recycling rate. Will the addition of new materials into the university's program cost less than $22,356.36 when looking at the private case, or $70,445.09 when looking at the social case?

5.3 Use of Other Data

Values for the entire nation and state do not reflect the waste disposal habits of the students and faculty at the university. A university is an entity different from the rest of the nation, because of the high concentration of young adults. Numerous studies have shown that consumption habits change with age. Also, the cultural difference among the students and faculty affect the consumption patterns of the campus. The best data set would include every ounce of waste landfilled and recycled by UT. However, the immense size of this undertaking renders it impossible. A solution to this problem would be to have more frequent and more extensive waste audits.

The University of Texas has not devoted resources to conducting an extensive waste audit; however, universities elsewhere have done so. Although the students at the University of Texas are mostly from Texas, its campus life is similar to many other big universities in America. Students nationwide represent a generation of young people who have similar lifestyles. Thus, it is assumed that the consumption habits of the University of Texas campus closely represent those of other campuses like UC Berkeley.

U.S. data on recycled material life-cycle assessments are not readily available; thus, studies from Europe were used. If LCAs performed in the U.S. could be accessed, the results of this study may have been slightly different. It is hard to say if recycling would be more or less socially optimal without U.S. data to compare to current findings.

6. Conclusion

Creating a new recycling program has difficulties. The costs of a university's collection, processing, and marketing operations depend on the types of materials collected, crew sizes, type of collection vehicles and routes, collection frequency and schedule, and types of revenue generators. The level of participation can determine how successful the recycling program at The University of Texas can become. Recycling properly means making sure materials are clean, recycling only materials that are collected, and reducing the contamination rate. The higher the participation rate in the university, the lower the cost per ton of recycling. This makes recycling a more competitive option for waste disposal.

6.1 Policies to Encourage Recycling

Because of externalities, private markets are not perfectly efficient on their own. State and local governments can correct these market failures by creating policies favorable towards recycling.

Some suggest higher tipping fees. Tipping fees raise the cost of traditional waste disposal, provide greater incentives to recycle and divert fewer waste to landfills. However, raising fees is likely to be politically difficult because fees would have to be raised very high in order to achieve the desired impact. Politicians want to please their constituents by creating the most economic stimulus to their economy. Raising tipping fees is not generally viewed as an economic stimulus. Collection and transportation costs amount to 75% of total waste disposal costs. A low fee increase does not create enough incentive to change behavior. Even though higher tipping fees favors policy for recycling, increased tipping fees places a burden on consumers, haulers, and local governments.

Education on the benefits of recycling can raise awareness of disposal habits. Many do not believe recycling is worth their time, or know the actual benefits of recycling. The private costs of waste disposal are the most evident result of consumption. Markets are only efficient when participants have full information. Some decisions on recycling are made with incomplete information, creating a market that is not completely perfect.

6.2 Economic Barriers to Recycling

Recycling may prove to be a cost-efficient alternative to landfilling with the available data; however, volatility in the recycling market can cause recycling to be the more expensive alternative at times. With the current prices received for recyclables, it may be optimal to expand recycling now. If prices fall a few years from now, with everything else held equal, recycling some materials would have to re-evaluated. Will the university want to continue a program even in a downturn of the recycling market? The recycling market has a cyclical nature that cannot be forecasted to precision.

Technology drives recycling and waste disposal programs – old and new. Technology can make a program more cost-efficient, therefore giving it an edge over its alternative. Technology also changes the cost structure of these solid waste programs. Initial costs would be high and in some cases undesirable. The decision to acquire new technology depends on each program. Different waste structures and waste demands require different solutions to achieve the most efficient collection system.

The collection of recyclables can be an extraordinarily expensive proposition. The university would have to expand their recycling program by buying barrels to hold recyclables, invest in campus education, retrain workers, and devote a position to recycling. In this analysis, these extra costs are not accounted for. The increased costs of recycling may result in some materials having negative private net gains.

6.3 Final Words

Both recycling and traditional waste disposal cost money. Assessing how recycling impacts the university requires a full appraisal of the environmental and economic benefits and costs of recycling compared to the one-way disposal of waste into a landfill. These factors determine if recycling is more cost effective than landfilling.

Solid waste management diverts attention to programs such as recycling and waste reduction. Sustaining and expanding popular support for recycling in the future depends on making this service as convenient as possible and on educating citizens about the true costs of traditional waste disposal methods compared to a full accounting of the costs and benefits of recycling. Recycling is not the only step towards decreasing traditional waste costs and environmental impacts of garbage. Reducing the amount of waste produced on campus will lower the environmental also impact of post-consumer waste and disposal costs.

Recycling can be economically efficient one year and not the other. The source of variation in program costs include the age of the program, the frequency of collection, the number and types of materials collected, and the total tonnage collected. Other sources of variation in recycling costs include exogenous attributes such as the population density, and the local costs of labor and fuel. Budgetary benefits such as saved disposal costs and revenue from the sales of materials also vary across the country due to varying land prices and proximity to manufacturing centers. For example, tipping fees and prices for recycled materials are higher in the northeast than in other regions of the country.

Waste's end use has more than just landfilling and recycling potential. Waste can be incinerated to produce energy and reduce the amount of volume landfilled. This energy has both economic benefits and environmental costs. Waste can also be reused before it is disposed. This alters the life cycle assessment because the environmental impacts vary when each process from production to disposal changes. It is always impossible to capture every aspect needed to value the net gains of recycling. The best estimations take all these variations into consideration when valuing the externalities of the production of primary and secondary materials.

The economy works together to keep the cycle of recycling going. Businesses improve public image by using recycled products and by displaying recycling logos. Consumers keep demand for recycled products high, creating a market with strong demand for recycled materials. Everyone participates in this market, directly or indirectly.

An entity that chooses to start or expand their recycling should not rely on studies done by others to make its decision. Each entity is affected by economic variables such as secondary material pricing, labor wages, education levels, people's valuation of the environment, and size of the program. This study does not use exact numbers; therefore, it can only be seen as an estimate of the net private gains and net social gains of recycling. Thus, a more extensive estimation of the waste generated on campus, and more research on the private and social costs and benefits of recycling should take place before the university makes its decision on expansion of their recycling program.

This study does not account for changes that could be made to the current system of recycling at the university. Changes to the current recycling system could alter costs and benefits of recycling. An increase in recycling collection efficiency would decrease collection costs, increasing the benefits of recycling. Commingling could be an option for the university. Commingling would decrease the price the university receives for its recycling, but would decrease bin and collection costs while increasing tonnage collected. The university cannot rely on one cost-benefit analysis when making its decision on expansion of the recycling program. Multiple cost-benefit analysis should be compared to find the best collection structure that suits the university.

Table A-1

Municipal Recycling Survey of Austin, TX
Calculated for fiscal year ending September 2004

Population:	672,011
Recycling rate (residential):	28.5%
Materials included: *(See key below)*	
Paper	NP, OCC, MG, MP, OP
Metal	ALC, TC
Plastic	PET, HDPE
Glass	GCON
Bulk	
Automotive	
Hazardous	
Organic	YARD
Other	
Tonnage collected per material:	
Paper	22,193
Metal	1,358
Glass	5,524
Plastic	1,478
Yard trimmings	18,232
Other	
Total tonnage collected:	48,785
Collection methods:	
Curbside (by city)	Yes
Frequency	Weekly
Number of households	152,869
Is program mandatory?	No
How are materials collected:	Source-separated
Program operated by:	City crews
Dropoff	Yes
Number of sites	1
Program operated by:	Private haulers
Multifamily dwelling	No
Financial information:	
Recycling budget	$6,464,748
Overall solid waste budget	$41,429,400
Recycling budget percentage of solid waste budget	15.6%
Monthly fee charged per household for recycling	$0
Recycling director:	Willie Rhodes
Telephone number	(512) 974-1943
Fax number	(512) 974-1999
Web site	www.austinrecycles.com

MATERIALS KEY: NP-newspaper; OCC-cardboard, corrugated containers; MG-magazines; TB-telephone books; MP-mixed paper; OP-office paper; ALC-aluminum cans; TC-tin cans; APP-appliances; PET-PET plastic; HDPE-HDPE plastic; PB-plastic bags; BVC-beverage cartons, drink boxes; GCON-glass containers; TEX-textiles; WOOD-wood waste; CND-construction debris; FRN-furniture; AUTO-automobiles; ABAT-automobile batteries; TIRE-tires; OIL-oil, oil filters, grease; FLP-fluorescent lamps; HH-household hazardous waste; ESRP-electronic scrap; FOOD-food waste; YARD-yard trimmings

Table A-2

Summary of Austin's Recycling Rates, Fiscal Year 2004-2005

Material	Weight in tons	% of recycled	% of MSW*
Paper	21,146	44.04%	12.35%
Metal	1,265	2.63%	0.739%
Glass	4,820	10.04%	2.81%
Plastic	1,545	3.22%	0.902%
Yard	19,237	40.07%	11.23%
	48,013	**100%**	**28.04%**

*Based on 171,238 tons of MSW

Information provided by Katherine Murray, Waste Diversion Planner, City of Austin Solid Waste Service

Table A-3a

MATERIALS GENERATED* IN THE MUNICIPAL WASTE STREAM, 1960 TO 2003
(In thousands of tons and percent of total generation)

	Thousands of Tons								
Materials	**1960**	**1970**	**1980**	**1990**	**1995**	**2000**	**2001**	**2002**	**2003**
Paper and Paperboard	29,990	44,310	55,160	72,730	81,670	87,740	82,660	84,200	83,100
Glass	6,720	12,740	15,130	13,100	12,830	12,620	12,580	12,830	12,470
Metals									
Ferrous	10,300	12,360	12,620	12,640	11,640	13,490	13,520	13,630	14,000
Aluminum	340	800	1,730	2,810	2,960	3,140	3,190	3,200	3,230
Other Nonferrous	180	670	1,160	1,100	1,260	1,560	1,570	1,570	1,590
Total Metals	*10,820*	*13,830*	*15,510*	*16,550*	*15,860*	*18,190*	*18,280*	*18,400*	*18,820*
Plastics	390	2,900	6,830	17,130	18,900	24,670	25,270	26,320	26,650
Rubber and Leather	1,840	2,970	4,200	5,790	6,030	6,530	6,670	6,660	6,820
Textiles	1,760	2,040	2,530	5,810	7,400	9,430	9,810	10,260	10,590
Wood	3,030	3,720	7,010	12,210	12,780	12,940	13,180	13,410	13,630
Other **	70	770	2,520	3,190	3,650	4,190	4,280	4,280	4,320
Total Materials in Products	54,620	83,280	108,890	146,510	159,120	176,310	172,730	176,360	176,400
Other Wastes									
Food Scraps	12,200	12,800	13,000	20,800	21,740	26,480	26,980	27,280	27,550
Yard Trimmings	20,000	23,200	27,500	35,000	29,690	27,730	27,980	28,300	28,600
Miscellaneous Inorganic Wastes	1,300	1,780	2,250	2,900	3,150	3,500	3,540	3,580	3,620
Total Other Wastes	33,500	37,780	42,750	58,700	54,580	57,710	58,500	59,160	59,770
Total MSW Generated - Weight	88,120	121,060	151,640	205,210	213,700	234,020	231,230	235,520	236,170
	Percent of Total Generation								
Materials	**1960**	**1970**	**1980**	**1990**	**1995**	**2000**	**2001**	**2002**	**2003**
Paper and Paperboard	34.0%	36.6%	36.4%	35.4%	38.2%	37.5%	35.7%	35.8%	35.2%
Glass	7.6%	10.5%	10.0%	6.4%	6.0%	5.4%	5.4%	5.4%	5.3%
Metals									
Ferrous	11.7%	10.2%	8.3%	6.2%	5.4%	5.8%	5.8%	5.8%	5.9%
Aluminum	0.4%	0.7%	1.1%	1.4%	1.4%	1.3%	1.4%	1.4%	1.4%
Other Nonferrous	0.2%	0.6%	0.8%	0.5%	0.6%	0.7%	0.7%	0.7%	0.7%
Total Metals	*12.3%*	*11.4%*	*10.2%*	*8.1%*	*7.4%*	*7.8%*	*7.9%*	*7.8%*	*8.0%*
Plastics	0.4%	2.4%	4.5%	8.3%	8.8%	10.5%	10.9%	11.2%	11.3%
Rubber and Leather	2.1%	2.5%	2.8%	2.8%	2.8%	2.8%	2.9%	2.8%	2.9%
Textiles	2.0%	1.7%	1.7%	2.8%	3.5%	4.0%	4.2%	4.4%	4.5%
Wood	3.4%	3.1%	4.6%	6.0%	6.0%	5.5%	5.7%	5.7%	5.8%
Other **	0.1%	0.6%	1.7%	1.6%	1.7%	1.8%	1.9%	1.8%	1.8%
Total Materials in Products	62.0%	68.8%	71.8%	71.4%	74.5%	75.3%	74.7%	74.9%	74.7%
Other Wastes									
Food Scraps	13.8%	10.6%	8.6%	10.1%	10.2%	11.3%	11.7%	11.6%	11.7%
Yard Trimmings	22.7%	19.2%	18.1%	17.1%	13.9%	11.8%	12.1%	12.0%	12.1%
Miscellaneous Inorganic Wastes	1.5%	1.5%	1.5%	1.4%	1.5%	1.5%	1.5%	1.5%	1.5%
Total Other Wastes	38.0%	31.2%	28.2%	28.6%	25.5%	24.7%	25.3%	25.1%	25.3%
Total MSW Generated - %	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

* Generation before materials recovery or combustion. Does not include construction & demolition debris, industrial process wastes, or certain other wastes.

** Includes electrolytes in batteries and fluff pulp, feces, and urine in disposable diapers.

Details may not add to totals due to rounding.

Source: Franklin Associates, Ltd.

http://www.epa.gov/epaoswer/non-hw/muncpl/pubs/03data.pdf

Table A-3b

RECOVERY* OF MUNICIPAL SOLID WASTE, 1960 TO 2003
(In thousands of tons and percent of generation of each material)

	Thousands of Tons								
Materials	**1960**	**1970**	**1980**	**1990**	**1995**	**2000**	**2001**	**2002**	**2003**
Paper and Paperboard	5,080	6,770	11,740	20,230	32,700	37,560	37,680	38,330	39,960
Glass	100	160	750	2,630	3,140	2,660	2,400	2,450	2,350
Metals									
Ferrous	50	150	370	2,230	4,130	4,610	4,570	4,910	5,090
Aluminum	Neg.	10	310	1,010	930	860	780	760	690
Other Nonferrous	Neg.	320	540	730	810	1,060	1,060	1,060	1,060
Total Metals	*50*	*480*	*1,220*	*3,970*	*5,870*	*6,530*	*6,410*	*6,730*	*6,840*
Plastics	Neg.	Neg.	20	370	990	1,350	1,400	1,370	1,390
Rubber and Leather	330	250	130	370	540	820	1,200	1,150	1,100
Textiles	50	60	160	660	900	1,290	1,440	1,490	1,520
Wood	Neg.	Neg.	Neg.	130	1,260	1,240	1,250	1,260	1,280
Other **	Neg.	300	500	680	750	980	980	980	980
Total Materials in Products	5,610	8,020	14,520	29,040	46,150	52,430	52,760	53,760	55,420
Other Wastes									
Food Scraps	Neg.	Neg.	Neg.	Neg.	570	680	730	740	750
Yard Trimmings	Neg.	Neg.	Neg.	4,200	9,030	15,770	15,820	16,000	16,100
Miscellaneous Inorganic Wastes	Neg.	Neg.	Neg.	Neg.	Neg.	Neg.	Neg.	Neg.	Neg.
Total Other Wastes	Neg.	Neg.	Neg.	4,200	9,600	16,450	16,550	16,740	16,850
Total MSW Recovered - Weight	5,610	8,020	14,520	33,240	55,750	68,880	69,310	70,500	72,270
	Percent of Generation of Each Material								
Materials	**1960**	**1970**	**1980**	**1990**	**1995**	**2000**	**2001**	**2002**	**2003**
Paper and Paperboard	16.9%	15.3%	21.3%	27.8%	40.0%	42.8%	45.6%	45.5%	48.1%
Glass	1.5%	1.3%	5.0%	20.1%	24.5%	21.1%	19.1%	19.1%	18.8%
Metals									
Ferrous	0.5%	1.2%	2.9%	17.6%	35.5%	34.2%	33.8%	36.0%	36.4%
Aluminum	Neg.	1.3%	17.9%	35.9%	31.4%	27.4%	24.5%	23.8%	21.4%
Other Nonferrous	Neg.	47.8%	46.6%	66.4%	64.3%	67.9%	67.5%	67.5%	66.7%
Total Metals	*0.5%*	*3.5%*	*7.9%*	*24.0%*	*37.0%*	*35.9%*	*35.1%*	*36.6%*	*36.3%*
Plastics	Neg.	Neg.	0.3%	2.2%	5.2%	5.5%	5.5%	5.2%	5.2%
Rubber and Leather	17.9%	8.4%	3.1%	6.4%	9.0%	12.6%	18.0%	17.3%	16.1%
Textiles	2.8%	2.9%	6.3%	11.4%	12.2%	13.7%	14.7%	14.5%	14.4%
Wood	Neg.	Neg.	Neg.	1.1%	9.9%	9.6%	9.5%	9.4%	9.4%
Other **	Neg.	39.0%	19.8%	21.3%	20.5%	23.4%	22.9%	22.9%	22.7%
Total Materials in Products	10.3%	9.6%	13.3%	19.8%	29.0%	29.7%	30.5%	30.5%	31.4%
Other Wastes									
Food, Other^	Neg.	Neg.	Neg.	Neg.	2.6%	2.6%	2.7%	2.7%	2.7%
Yard Trimmings	Neg.	Neg.	Neg.	12.0%	30.4%	56.9%	56.5%	56.5%	56.3%
Miscellaneous Inorganic Wastes	Neg.	Neg.	Neg.	Neg.	Neg.	Neg.	Neg.	Neg.	Neg.
Total Other Wastes	Neg.	Neg.	Neg.	7.2%	17.6%	28.5%	28.3%	28.3%	28.2%
Total MSW Recovered - %	6.4%	6.6%	9.6%	16.2%	26.1%	29.4%	30.0%	29.9%	30.6%

* Recovery of postconsumer wastes; does not include converting/fabrication scrap.
** Recovery of electrolytes in batteries; probably not recycled.
Neg. = Less than 5,000 tons or 0.05 percent.
^ Includes recovery of paper for composting.
Details may not add to totals due to rounding.
Source: Franklin Associates, Ltd.

Table A-3c

MATERIALS DISCARDED* IN THE MUNICIPAL WASTE STREAM, 1960 TO 2003
(In thousands of tons and percent of total discards)

	Thousands of Tons								
Materials	**1960**	**1970**	**1980**	**1990**	**1995**	**2000**	**2001**	**2002**	**2003**
Paper and Paperboard	24,910	37,540	43,420	52,500	48,970	50,180	44,980	45,870	43,140
Glass	6,620	12,580	14,380	10,470	9,690	9,960	10,180	10,380	10,120
Metals									
Ferrous	10,250	12,210	12,250	10,410	7,510	8,880	8,950	8,720	8,910
Aluminum	340	790	1,420	1,800	2,030	2,280	2,410	2,440	2,540
Other Nonferrous	180	350	620	370	450	500	510	510	530
Total Metals	*10,770*	*13,350*	*14,290*	*12,580*	*9,990*	*11,660*	*11,870*	*11,670*	*11,980*
Plastics	390	2,900	6,810	16,760	17,910	23,320	23,870	24,950	25,260
Rubber and Leather	1,510	2,720	4,070	5,420	5,490	5,710	5,470	5,510	5,720
Textiles	1,710	1,980	2,370	5,150	6,500	8,140	8,370	8,770	9,070
Wood	3,030	3,720	7,010	12,080	11,520	11,700	11,930	12,150	12,350
Other **	70	470	2,020	2,510	2,900	3,210	3,300	3,300	3,340
Total Materials in Products	49,010	75,260	94,370	117,470	112,970	123,880	119,970	122,600	120,980
Other Wastes									
Food Scraps	12,200	12,800	13,000	20,800	21,170	25,800	26,250	26,540	26,800
Yard Trimmings	20,000	23,200	27,500	30,800	20,660	11,960	12,160	12,300	12,500
Miscellaneous Inorganic Wastes	1,300	1,780	2,250	2,900	3,150	3,500	3,540	3,580	3,620
Total Other Wastes	33,500	37,780	42,750	54,500	44,980	41,260	41,950	42,420	42,920
Total MSW Discarded - Weight	82,510	113,040	137,120	171,970	157,950	165,140	161,920	165,020	163,900
	Percent of Total Discards								
Materials	**1960**	**1970**	**1980**	**1990**	**1995**	**2000**	**2001**	**2002**	**2003**
Paper and Paperboard	30.2%	33.2%	31.7%	30.5%	31.0%	30.4%	27.8%	27.8%	26.3%
Glass	8.0%	11.1%	10.5%	6.1%	6.1%	6.0%	6.3%	6.3%	6.2%
Metals									
Ferrous	12.4%	10.8%	8.9%	6.1%	4.8%	5.4%	5.5%	5.3%	5.4%
Aluminum	0.4%	0.7%	1.0%	1.0%	1.3%	1.4%	1.5%	1.5%	1.5%
Other Nonferrous	0.2%	0.3%	0.5%	0.2%	0.3%	0.3%	0.3%	0.3%	0.3%
Total Metals	*13.1%*	*11.8%*	*10.4%*	*7.3%*	*6.3%*	*7.1%*	*7.3%*	*7.1%*	*7.3%*
Plastics	0.5%	2.6%	5.0%	9.7%	11.3%	14.1%	14.7%	15.1%	15.4%
Rubber and Leather	1.8%	2.4%	3.0%	3.2%	3.5%	3.5%	3.4%	3.3%	3.5%
Textiles	2.1%	1.8%	1.7%	3.0%	4.1%	4.9%	5.2%	5.3%	5.5%
Wood	3.7%	3.3%	5.1%	7.0%	7.3%	7.1%	7.4%	7.4%	7.5%
Other **	0.1%	0.4%	1.5%	1.5%	1.8%	1.9%	2.0%	2.0%	2.0%
Total Materials in Products	59.4%	66.6%	68.8%	68.3%	71.5%	75.0%	74.1%	74.3%	73.8%
Other Wastes									
Food Scraps	14.8%	11.3%	9.5%	12.1%	13.4%	15.6%	16.2%	16.1%	16.4%
Yard Trimmings	24.2%	20.5%	20.1%	17.9%	13.1%	7.2%	7.5%	7.5%	7.6%
Miscellaneous Inorganic Wastes	1.6%	1.6%	1.6%	1.7%	2.0%	2.1%	2.2%	2.2%	2.2%
Total Other Wastes	40.6%	33.4%	31.2%	31.7%	28.5%	25.0%	25.9%	25.7%	26.2%
Total MSW Discarded - %	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

* Discards after materials and compost recovery. Does not include construction & demolition debris, industrial process wastes, or certain other wastes.

** Includes electrolytes in batteries and fluff pulp, feces, and urine in disposable diapers.

Details may not add to totals due to rounding.

Source: Franklin Associates, Ltd.

Table A-3d

PAPER AND PAPERBOARD PRODUCTS IN MSW, 2003
(In thousands of tons and percent of generation)

Product Category	Generation (Thousand tons)	Recovery (Thousand tons)	Recovery (Percent of generation)	Discards (Thousand tons)
Nondurable Goods				
Newspapers				
Newsprint	10,260	8,480	82.7%	1,780
Groundwood inserts	2,380	1,930	81.1%	450
Total Newspapers	12,640	10,410	82.4%	2,230
Books	1,030	190	18.4%	840
Magazines	2,270	750	33.0%	1,520
Office Papers	7,150	3,990	55.8%	3,160
Telephone Directories	640	100	15.6%	540
Standard (A) Mail*	5,400	1,750	32.4%	3,650
Other Commercial Printing	6,950	880	12.7%	6,070
Tissue Paper and Towels	3,250	Neg.	Neg.	3,250
Paper Plates and Cups	970	Neg.	Neg.	970
Other Nonpackaging Paper**	3,960	Neg.	Neg.	3,960
Total Paper and Paperboard Nondurable Goods	44,260	18,070	40.8%	26,190
Containers and Packaging				
Corrugated Boxes	29,710	21,180	71.3%	8,530
Milk Cartons	450	Neg.	Neg.	450
Folding Cartons	5,560	450	8.1%	5,110
Other Paperboard Packaging	180	Neg.	Neg.	180
Bags and Sacks	1,230	260	21.1%	970
Other Paper Packaging	1,700	Neg.	Neg.	1,700
Total Paper and Paperboard Containers and Packaging	38,830	21,890	56.4%	16,940
Total Paper and Paperboard	83,090	39,960	48.1%	43,130

* Formerly called Third Class Mail by the U.S. Postal Service.
** Includes tissue in disposable diapers, paper in games and novelties, cards, etc.
Neg. = Less than 5,000 tons or 0.05 percent.
Details may not add to totals due to rounding.

Source: Franklin Associates, A Division of ERG

Table A-3e

GLASS PRODUCTS IN MSW, 2003
(In thousands of tons and percent of generation)

Product Category	Generation (Thousand tons)	Recovery (Thousand tons)	Recovery (Percent of generation)	Discards (Thousand tons)
Durable Goods*	1,780	Neg.	Neg.	1,780
Containers and Packaging				
Beer and Soft Drink Bottles	6,440	1,250	19.4%	5,190
Wine and Liquor Bottles	1,520	350	23.0%	1,170
Food and Other Bottles and Jars	2,730	750	27.5%	1,980
Total Glass Containers	10,690	2,350	22.0%	8,340
Total Glass	12,470	2,350	18.8%	10,120

* Glass as a component of appliances, furniture, consumer electronics, etc.
Neg. = Less than 5,000 tons or 0.05 percent.
Details may not add to totals due to rounding.

Source: Franklin Associates, A Division of ERG

Table A-3f

METAL PRODUCTS IN MSW, 2003
(In thousands of tons and percent of generation)

Product Category	Generation (Thousand tons)	Recovery (Thousand tons)	Recovery (Percent of generation)	Discards (Thousand tons)
Durable Goods				
Ferrous metals*	11,160	3,370	30.2%	7,790
Aluminum**	1,060	Neg.	Neg.	1,060
Lead†	1,140	1,060	93.0%	80
Other nonferrous metals‡	450	Neg.	Neg.	450
Total Metals in Durable Goods	13,810	4,430	32.1%	9,380
Nondurable Goods				
Aluminum	230	Neg.	Neg.	230
Containers and Packaging				
Steel				
Food and other cans	2,600	1,560	60.0%	1,040
Other steel packaging	240	160	66.7%	80
Total Steel Packaging	2,840	1,720	60.6%	1,120
Aluminum				
Beer and soft drink cans	1,480	650	43.9%	830
Food and other cans	50	Neg.	Neg.	50
Foil and closures	410	40	9.8%	370
Total Aluminum Packaging	1,940	690	35.6%	1,250
Total Metals in Containers and Packaging	4,780	2,410	50.4%	2,370
Total Metals	18,820	6,840	36.3%	11,980
Ferrous	14,000	5,090	36.4%	8,910
Aluminum	3,230	690	21.4%	2,540
Other nonferrous	1,590	1,060	66.7%	530

* Ferrous metals (iron and steel) in appliances, furniture, tires, and miscellaneous durables.
** Aluminum in appliances, furniture, and miscellaneous durables.
† Lead in lead-acid batteries.
‡ Other nonferrous metals in appliances and miscellaneous durables.
Neg. = Less than 5,000 tons or 0.05 percent.
Details may not add to totals due to rounding.
Source: Franklin Associates, A Division of ERG

Table A-3g

PLASTICS IN PRODUCTS IN MSW, 2003
(In thousands of tons, and percent of generation by resin)

Product Category	Generation (Thousand tons)	Recovery (Thousand tons)	Recovery (Percent of Gen.)	Discards (Thousand tons)
Durable Goods				
PET	470			
HDPE	630			
PVC	490			
LDPE/LLDPE	740			
PP	1,320			
PS	710			
Other resins	4,030			
Total Plastics in Durable Goods	8,390	330	3.9%	8,060
Nondurable Goods				
Plastic Plates and Cups				
LDPE/LLDPE	20			20
PS	710			710
Subtotal Plastic Plates and Cups	730			730
Trash Bags				
HDPE	270			270
LDPE/LLDPE	750			750
Subtotal Trash Bags	1,020			1,020
All other nondurables*				
PET	220			220
HDPE	450			450
PVC	630			630
LDPE/LLDPE	1,670			1,670
PP	910			910
PS	620			620
Other resins	100			100
Subtotal All Other Nondurables	4,600			4,600
Total Plastics in Nondurable Goods, by resin				
PET	220			220
HDPE	720			720
PVC	630			630
LDPE/LLDPE	2,440			2,440
PP	910			910
PS	1,330			1,330
Other resins	100			100
Total Plastics in Nondurable Goods	6,350	0	0.0%	6,350
Plastic Containers & Packaging				
Soft drink bottles				
PET	1,070	270	25.2%	800
Milk and water bottles				
HDPE	720	230	31.9%	490

HDPE = High density polyethylene
LDPE = Low density polyethylene
LLDPE = Linear low density polyethylene
PET = Polyethylene terephthalate
PP = Polypropylene
PS = Polystyrene
PVC = Polyvinyl chloride

* All other nondurables include plastics in disposable diapers, clothing, footwear, etc.

** Other plastic packaging includes coatings, closures, caps, trays, shapes, etc.

Details may not add to totals due to rounding.

Source: Franklin Associates, A Division of ERG

PLASTICS IN PRODUCTS IN MSW, 2003
(In thousands of tons, and percent of generation by resin)

Product Category	Generation (Thousand tons)	Recovery (Thousand tons)	Recovery (Percent of Gen.)	Discards (Thousand tons)
Plastic Containers & Packaging, cont.				
Other plastic containers				
PET	940	100		840
HDPE	1,280	190		1,090
PVC	80			80
LDPE/LLDPE	40			40
PP	70			70
PS	0			0
Other resins	400			400
Subtotal Other Containers	2,810	290	10.3%	2,520
Bags, sacks, & wraps				
HDPE	780	30		750
PVC	70			70
LDPE/LLDPE	2,640	150		2,490
PP	690			690
PS	0			0
Other resins	200			200
Subtotal Bags, Sacks, & Wraps	4,380	180	4.1%	4,200
Other Plastics Packaging**				
PET	170	40		130
HDPE	1,010	20		990
PVC	200			200
LDPE/LLDPE	350			350
PP	620	10		610
PS	230			230
Other resins	350	20		330
Subtotal Other Packaging	2,930	90	3.1%	2,840
Total Plastics in Containers & Packaging, by resin				
PET	2,180	410		1,770
HDPE	3,790	470		3,320
PVC	350			350
LDPE/LLDPE	3,030	150		2,880
PP	1,380	10		1,370
PS	230			230
Other resins	950	20		930
Total Plastics in Cont. & Packaging	11,910	1,060	8.9%	10,850
Total Plastics in MSW, by resin				
PET	2,870	410		2,460
HDPE	5,140	470		4,670
PVC	1,470			1,470
LDPE/LLDPE	6,210	150		6,060
PP	3,610	10		3,600
PS	2,270			2,270
Other resins	5,080	350		4,730
Total Plastics in MSW	26,650	1,390	5.2%	25,260

HDPE = High density polyethylene
LDPE = Low density polyethylene
LLDPE = Linear low density polyethylene
PET = Polyethylene terephthalate
PP = Polypropylene
PS = Polystyrene
PVC = Polyvinyl chloride

* All other nondurables include plastics in disposable diapers, clothing, footwear, etc.

** Other plastic packaging includes coatings, closures, caps, trays, shapes, etc.

Some detail of recovery by resin omitted due to lack of data.

This table understates the recovery of plastics due to the dispersed nature of plastics recycling activities.

Source: Franklin Associates, A Division of ERG

Table A-3h

RECOVERY* OF PRODUCTS IN MUNICIPAL SOLID WASTE, 1960 TO 2003
(WITH DETAIL ON CONTAINERS AND PACKAGING)
(In percent of generation of each product)

Percent of Generation of Each Product									
Products	1960	1970	1980	1990	1995	2000	2001	2002	2003
Durable Goods	3.5%	6.4%	6.2%	11.6%	16.1%	17.2%	18.3%	18.7%	18.1%
(Detail in Table 13)									
Nondurable Goods	13.8%	14.9%	13.6%	16.9%	23.8%	27.4%	29.6%	29.0%	31.0%
(Detail in Table 16)									
Containers and Packaging									
Glass Packaging									
Beer and Soft Drink Bottles	6.4%	2.5%	10.8%	33.5%	32.6%	24.7%	21.2%	21.4%	19.4%
Wine and Liquor Bottles	Neg.	Neg.	Neg.	10.3%	26.3%	20.9%	20.5%	20.4%	23.0%
Food and Other Bottles & Jars	Neg.	Neg.	Neg.	12.5%	21.6%	24.9%	24.4%	24.1%	27.5%
Total Glass Packaging	1.6%	1.3%	5.4%	22.1%	27.2%	24.1%	22.0%	22.0%	22.0%
Steel Packaging									
Beer and Soft Drink Cans	1.6%	1.3%	9.6%	26.7%	Neg.	Neg.	Neg.	Neg.	Neg.
Food and Other Cans	Neg.	1.7%	5.3%	23.2%	56.1%	58.2%	58.1%	58.7%	60.0%
Other Steel Packaging	Neg.	Neg.	Neg.	30.0%	23.8%	66.7%	66.7%	66.7%	66.7%
Total Steel Packaging	Neg.	1.5%	5.5%	23.9%	53.8%	58.9%	58.8%	59.4%	60.6%
Aluminum Packaging									
Beer and Soft Drink Cans	Neg.	10.0%	36.5%	63.9%	56.6%	54.6%	49.0%	48.3%	43.9%
Other Cans	Neg.	Neg.	Neg.	Neg.	Neg.	Neg.	Neg.	Neg.	Neg.
Foil and Closures	Neg.	Neg.	Neg.	6.1%	8.6%	7.9%	10.3%	10.0%	9.8%
Total Aluminum Pkg	Neg.	1.8%	25.2%	53.2%	47.0%	44.1%	40.0%	39.2%	35.6%
Paper & Paperboard Pkg									
Corrugated Boxes	34.4%	21.6%	37.4%	48.0%	64.2%	67.3%	68.7%	68.7%	71.3%
Milk Cartons**			Neg.	Neg.	Neg.	Neg.	Neg.	Neg.	Neg.
Folding Cartons**			Neg.	Neg.	20.3%	7.0%	8.2%	8.1%	8.1%
Other Paperboard Packaging			Neg.	Neg.	Neg.	Neg.	Neg.	Neg.	Neg.
Bags and Sacks**			Neg.	Neg.	17.2%	20.1%	21.5%	21.5%	21.1%
Wrapping Papers**			Neg.	Neg.	Neg.	Neg.	Neg.	Neg.	
Other Paper Packaging	7.5%	9.2%	35.3%	Neg.	Neg.	Neg.	Neg.	Neg.	Neg.
Total Paper & Board Pkg	19.4%	14.5%	27.4%	36.9%	52.3%	52.7%	53.8%	54.3%	56.4%
Plastics Packaging									
Soft Drink Bottles**			3.8%	32.6%	46.2%	34.9%	35.6%	26.5%	25.2%
Milk Bottles**			Neg.	3.8%	30.6%	30.4%	28.4%	31.0%	31.9%
Other Containers	Neg.	Neg.	Neg.	1.4%	12.7%	9.9%	10.3%	10.0%	10.3%
Bags and Sacks**			Neg.	3.2%	3.3%	0.6%	0.6%	0.6%	0.6%
Wraps**			Neg.	2.0%	2.3%	6.7%	6.6%	6.2%	6.2%
Other Plastics Packaging	Neg.	Neg.	Neg.	1.0%	0.9%	3.2%	3.7%	3.2%	3.1%
Total Plastics Packaging	Neg.	Neg.	Neg.	3.8%	9.8%	9.2%	9.6%	8.8%	8.9%
Wood Packaging	Neg.	Neg.	Neg.	1.6%	14.8%	15.3%	15.3%	15.3%	15.4%
Other Misc. Packaging	Neg.	Neg.	Neg.	Neg.	Neg.	Neg.	Neg.	Neg.	Neg.
Total Containers & Pkg	10.5%	7.7%	16.1%	26.0%	38.9%	37.9%	37.7%	37.8%	38.8%
Total Product Wastes†	10.3%	9.6%	13.3%	19.8%	29.0%	29.7%	30.5%	30.5%	31.4%
Other Wastes									
Food Scraps	Neg.	Neg.	Neg.	Neg.	2.6%	2.6%	2.7%	2.7%	2.7%
Yard Trimmings	Neg.	Neg.	Neg.	12.0%	30.4%	56.9%	56.5%	56.5%	56.3%
Miscellaneous Inorganic Wastes	Neg.	Neg.	Neg.	Neg.	Neg.	Neg.	Neg.	Neg.	Neg.
Total Other Wastes	Neg.	Neg.	Neg.	7.2%	17.6%	28.5%	28.3%	28.3%	28.2%
Total MSW Recovered - %	6.4%	6.6%	9.6%	16.2%	26.1%	29.4%	30.0%	29.9%	30.6%

* Recovery of postconsumer wastes; does not include converting/fabrication scrap.
** Not estimated separately prior to 1980. Paper wraps not reported separately after 1996.
† Other than food products.
Details may not add to totals due to rounding.
Neg. = Less than 5,000 tons or 0.05 percent.
Source: Franklin Associates, Ltd.

Table A-4

UC Berkeley's 1998 Waste Audit

Material	Weight	Percent
White Paper	1574.1	10.33%
Colored Paper	684.7	4.49%
Newspaper	507.1	3.33%
Glossy Paper	1248.6	8.19%
Mixed Paper	1379.4	9.05%
Computer Paper	21.0	0.14%
Cardboard	1057.7	6.94%
#1 Plastic	57.0	0.37%
#2 Plastic	37.0	0.24%
Other Plastic	390.0	2.56%
Styrofoam	47.2	0.31%
Glass	348.3	2.29%
Aluminum	40.4	0.27%
Bi-metal	31.2	0.20%
Scrap metal	399.3	2.62%
Paper Towels	804.0	5.28%
Food Packaging	242.7	1.59%
Coffee Cups	145.7	0.96%
Lab Waste	856.7	5.62%
Soil	39.7	0.26%
Yard Waste/Wood	488.4	3.20%
Liquid	122.9	0.81%
Food	1251.7	8.21%
Reusables	1007.6	6.61%
Reusable Food	96.3	0.63%
Textiles	76.4	0.50%
Hazardous Waste	34.1	0.22%
C and D	886.4	5.82%
Trash	1364.3	8.95%
Total	15239.9	100.00%
Fiber Content		42.47%
Recycling Potential		**48.46%**
Diversion Potential		67.13%

Materials in bold are used in comparison.

Table A-5

UT's Waste Transportation Fleet

Door #	Year	Make	Aquired Date	Capital Value	Book Value	Service Yrs	Cost/Year
203	1993	Ford	3/4/1997	$5,000	$500	8	$563
218	1995	Ford	11/1/1994	$37,389	$3,738	11	$3,059
220	1983	Ford	6/28/1983	$66,979	$6,697	22	$2,740
201	1998	Crane Carrier	9/29/1998	$115,850	$11,585	7	$14,895
217	1994	Ford	7/18/1994	$14,749	$1,474	11	$1,207
211	1985	Ford	1/30/1985	$20,399	$2,039	20	$918
207	2005	Crane Carrier	1/28/2005	$136,124	$114,247	1	$21,877
208	2005	Crane Carrier	1/28/2005	$136,124	$114,247	1	$21,877
Total				**$532,614**	**$254,527**		**$67,136**

Information provided by Kenneth Limbrick, Manager of General Services at the University of Texas

Table A-6

Economic Valuation of Net External Costs (₤/ton)

Material	Waste Disposal	Recycling	Net Benefit from Recycling
Aluminum	1880.27	111.41	1768.86
Glass	254.78	67.2	187.58
Paper	299.85	73.73	226.07
Steel	269.4	31.64	237.76
HDPE	9.49	12.07	-2.57
PET	13.98	21.25	-7.28
PVC	7.46	11.55	-4.1

Source: Craighill and Powell, CSERGE (2005)

Table A-7

The University of Texas at Austin
General Services Refuse & Recycling Statistics
FY 2004-2005

2004-2005 Recycling (% of total waste & cost savings)								
					Cost Avoidance	Rebates to UT		
Month	**Total Tons of Landfill Waste**	**Total Tons of Recycle Paper**	**Total Tons of Other Recyclables**	**Actual Recycled (% of Total Waste)**	**Landfill Savings**	**Paper Recycle Rebate**	**Other Recycle Rebates**	**Estimated Cost Savings***
Sept.	249.46	162.03	15.39	41.56%	$2,835.53	$16,484.58	$778.90	$20,099.01
Oct.	253.99	131.26	11.7	36.01%	$2,297.05	$14,520.39	$829.58	$17,647.02
Nov.	263.87	146.33	0	35.67%	$2,560.78	$13,429.51	$488.20	$16,478.49
Dec.	172.68	96.68	0	35.89%	$1,691.90	$14,104.26	$811.05	$16,607.21
Jan.	173.23	122.7	0	41.46%	$2,147.25	$9,760.44	$1,400.35	$13,308.04
Feb.	225.51	128.62	0	36.32%	$2,250.85	$13,002.47	$4,061.10	$19,314.42
Mar.	236.99	132.23	0	35.81%	$2,314.03	$12,648.94	$462.75	$15,425.72
Apr.	239.28	140.45	0	36.99%	$2,457.88	$13,232.74	$997.73	$16,688.35
May	238.48	130.89	0	35.44%	$2,290.58	$14,382.20	$566.00	$17,238.78
Jun	192.61	127.57	0	39.84%	$2,232.48	$13,184.95	$1,256.53	$16,673.96
Jul	170.36	145.57	10.75	47.85%	$2,547.48	$12,109.78	$1,416.65	$16,073.91
Aug	212.54	156.45	0	42.40%	$2,737.88	$13,823.60	$3,555.10	$20,116.58
Total	**2629**	**1620.78**	**102.99**	**39.71%**	**28363.65**	**160683.9**	**16623.94**	**$205,671.45**

***Estimated Cost Savings based on Recycling Rebate plus landfill cost avoidance.**

Source: The University of Texas Physical Plant, General Services, Available Online:
http://www.utexas.edu/physicalplant/general/recycling/index.html

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