EVALUATION OF WASTE DIVERSION STRATEGIES FOR LAWRENCE

SPECIAL FOCUS ON CURBSIDE COLLECTION OF RECYCLABLES

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INTRODUCTION

Periodically the Solid Waste Division evaluates the potential for increased recycling and waste reduction within the City of Lawrence, including the feasibility of establishing curbside collection of recyclables. A review of these studies follows below.

Based upon the findings and recommendations of these studies, the Division developed and implemented a targeted materials waste diversion strategy for increasing recycling. This strategy targets those recyclable materials that are the most abundant in the waste stream and can be recycled most cost efficiently.

Using this targeted materials waste diversion strategy, the City has achieved a 34 percent recycling rate in 2003 which is the highest in the state, higher than the national average, and higher than most communities which have more expensive curbside recycling programs.

Previous Studies

The 1992 Study. In 1992, the Division performed a detailed study of the solid waste management practices within the city, an evaluation of markets for recycled materials, the potential diversion of materials from being disposed in landfills utilizing various options, and the costs associated with each of those options. (See ATTACHMENT 1, "SUMMARY OF FINDINGS AND RECOMMENDATIONS" from the 1992 report.)

> **Result:** The recycling programs that were developed after the initial 1992 study targeted yard wastes (by far the largest component of the residential waste stream) and old newspapers (the second largest component of the residential waste stream). The Division has also developed programs designed to remove hazardous wastes and other "special" or regulated wastes, such as tires, refrigerators, batteries, and used oil from the waste stream.

The 1992 study also recommended the City take actions to increase the markets for recyclable materials in this area by:

- Having a policy to procure goods with recycled content whenever possible and economically feasible (an Environmental Procurement Policy was officially adopted by the City December 1, 2002);

- Encouraging industries that use recycled materials in their production process to locate in Lawrence;

- Encouraging State officials to actively take economic development steps that would increase the markets for recyclable materials within Kansas.

Finally, the study recommended the City explore opportunities for a public-private cooperative facility in which recovered materials could be processed for market.

> **Result:** Since the 1992 study, Wal-Mart built a community drop-off center for the collection and processing of recyclable materials. Wal-Mart funds the operation of the facility and hires Community Living Opportunities (CLO) clients to staff the facility.

The 1996 Study. The Douglas/Jefferson Counties Solid Waste Management Plan (written in 1996 and reviewed in 1999 and 2003), which is required by the Kansas Department of Health and Environment (KDHE), did not recommend that the City of Lawrence adopt a curbside recycling program at that time. The Plan, completed by Franklin Associates Limited, acknowledged the high recycling rate already achieved through existing programs (29 percent recycling rate in 1995), and pointed out the highly volatile condition of the end-markets for some of the materials (e.g., plastic and glass containers) which would be collected through a curbside program. The Plan recommended that the City reevaluate the potential for curbside from time to time which we have continued to do.

This study recommended the City pursue recovery of non-residential waste paper focusing on recycling cardboard in addition to the already established yard waste composting program.

> **Result:** A cardboard collection program was started in 1996. This program has grown to serve over 300 businesses, provides for residential drop-off sites, and successfully recovered 655 tons of cardboard in 2003 (in addition to the 692 tons recovered through the Wal-Mart community Recycling Facility).

The 2000 Study. The Solid Waste Division produced an in-depth evaluation of recycling options including curbside collection in June of 2000.

Recommendations from that study were:

1. The yard waste composting and wood recovery program should be expanded to include more woody debris such as pallets and clean wood wastes from construction and demolition. Tree trimmings should be added to the current mixture of grass and leaves for composting. Vegetative food wastes (such as spoiled produce from groceries and pre-consumer food waste from restaurants) should be examined as an additional component in composting.

> **Result:** A larger compost and wood recovery site was completed in 2004. A tubgrinder, windrow turner and front-end loader were purchased with the assistance of KDHE Solid Waste Implementation Grants. Tree trimmings will be collected with grass and leaves for inclusion in the compost mixture in 2005. Additional woody debris may be accepted on a case by case basis and evaluated for compatibility with the compost and mulch being produced. Vegetative food wastes will not be accepted due to stricter permitting KDHE requirements that we cannot meet at this time.

2. Office papers from the commercial/institutional sector should be targeted. Office papers make up 14 percent of the commercial waste stream and would have a significant positive impact

on the recycling rate since they have available markets. Office papers could be processed through the existing paper recovery facility.

> **Result:** An office paper collection program became fully operational in 2003 currently serving 122 customers. A second baler was purchased with a State grant. The program continues to be expanded to more offices and businesses.

3. Education efforts aimed at waste reduction and wise use of resources should continue.

> **Result:** Education efforts continue to increase through the use of integrated media and other outreach programs. The Division has developed an informational, interactive and educational website (www.LawrenceRecycles.org) that has been highly successful. Citizens are being urged to use compostable paper bags, cans, or carts for their yard waste instead of plastic bags as plastic bags must be disposed of in the landfill and can contaminate the compost with plastic shreds. The City is eliminating plastic bags for use with yard waste in 2005. Significant educational efforts regarding preferred containers (compostable bags, cans and carts) have been in place since 2002. These efforts have incorporated retail partnerships, neighborhood pilot programs and a multi-media ad campaign. The Division participates in many public outreach and education opportunities throughout each year.

4. The City should support a state-wide beverage container deposit bill which would remove plastic, glass and aluminum beverage containers from the waste stream. States with so-called "bottle bills" have achieved an average of 80 percent recovery using such a system. They have also reported a great reduction in littering. The beverage industry is on record as opposing "bottle bills" and typically spends very large amounts of money lobbying legislators against passing such bills.

> **Result:** The City Commission has been on the record in support of "bottle bill" legislation. The Douglas County Commission voiced their support during the 2003 review of the Douglas/Jefferson County Solid Waste Management Plan. There have been no such bills offered to the state legislature in the past several years. A national "bottle bill" has been introduced in the U.S. Senate. The legislation has received support from the glass container recycling industry. The glass container recycling industry has been struggling with the poor quality of glass received through curbside collection programs [source: *Waste News*, Nov. 24, 2003].

The 2003 Study. The 2003 study recognized the high recycling rate (32 percent in 2002) attained by the City and private sector programs and recommended that the current recycling programs should be continued and expanded upon. The study recommended that the cost of new programs be measured against the benefits, and money spent on those programs that provide the greatest benefits while maintaining economic stability. Specific recommendations were:

1. Plastic bags should be identified in the Solid Waste Regulations as unacceptable for packaging of grass, leaves, and other yard trimmings collected for composting. A public

education and information campaign should be conducted by the Division with the goal of implementing the restriction in 2005.

Result: Only compostable paper bags, cans and carts may be used for packaging of yard wastes in 2005. An intensive public education and awareness campaign is underway and will continue through 2005.

2. Newspaper, cardboard, and office paper recycling programs should continue to be expanded including additional drop-off sites. City buildings and schools should continue to be brought into the programs.

Result: Four cardboard drop-off containers and two additional newspaper containers were sited in the past year. The office paper recycling program became fully operational and is serving 122 customers including many businesses, city and county buildings, and schools.

3. The City should continue to support the concept of a statewide beverage container deposit law ("bottle bill") which would remove glass, plastic, and aluminum beverage containers from the waste stream.

Result: The City and the County Commissions expressed support for a "bottle bill" in 2003.

Historic Recycling Rates

City of Lawrence historical recycling rates were calculated in 1995 and have been calculated annually beginning in 1998. Notice that as the amount of Municipal Solid Waste (MSW) generated each year increases, the amount of material recycled also must increase just to maintain the previous year's recycling rate (Table 1).

The growth in "MSW Generated" as shown in Table 1 is driven primarily by population growth. The growth in "Material Recycled" since 2001 is likely due to increased population, hence more generation of material, combined with increased participation, as reflected by the "Recycling Rate."

Table 1.

Year	MSW Generated (Tons)	Material Recycled (Tons)	Recycling Rate (Percent)
1995	65,576	18,852	29
1996	*	*	*
1997	*	*	*
1998	69,900	20,000	29
1999	73,645	21,000	29
2000	74,792	21,500	29
2001	78,942	23,278	30
2002	80,550	25,566	32
2003	84,273	28,342	34

CURRENT STATUS OF RECYCLING IN LAWRENCE

In 2003, more than 28,300 tons of materials were recycled in Lawrence (an increase of almost 2,800 tons over 2002) representing a 34 percent recycling rate which is believed to be the highest in Kansas. (The 34 percent recycling rate means that of the municipal solid waste generated, 34 percent was recycled and 66 percent was disposed in the landfill.) This achievement was the result of a combination of public and private recycling initiatives.

City Administered Recovery Programs

Compost Program. The City provides the separate collection of grass and leaves from residences for composting. In addition, in 1999, the Waste Reduction and Recycling Division (WRR), part of the Solid Waste Division, initiated a yard waste reduction campaign. The purpose is to promote backyard composting, mulch-mowing or "grass-cycling" (leaving it lie on the ground), and leaf mulch-mowing because the most cost-effective strategy to reduce this waste stream is to encourage households to manage their own green wastes at home. The goal is to reduce the amount of yard waste that must be collected for composting. A new composting site was completed in 2004 and WRR, in conjunction with the Parks and Forestry Division, also established a woody debris drop-off area at the new compost site.

Paper Recovery Programs. The number of newspaper drop-off sites continues to be expanded and the recovery rate remains very high. The cardboard collection program for businesses has been a tremendous success and continues to grow, currently serving more than 300 customers. Drop-off sites for cardboard have been established at four locations and have been a success. More cardboard drop-off sites are planned. These are particularly convenient for residents or small businesses that don't generally produce enough cardboard to be on a collection route. The Office Waste Paper collection program is now fully operational and serves more than 120 customers. Locations are furnished small carts that are serviced once per week or less, depending on need.

It should be noted that revenues for paper recycling are relatively stable and markets for the paper are readily accessible. Revenues for recycled paper products totaled more than $98,000 in

2003. Revenues for 2004 through September 4 are $106,424,06. For a complete review of City recycling programs, see ATTACHMENT 2, "ANNUAL RECYCLING REPORT FOR 2003".

Hazardous Wastes. The Household Hazardous Waste (HHW) program continues to increase both in participation rate and in amounts of material collected. This year, HHW is being received primarily by appointment throughout the week including evening appointment times. The more user-friendly hours have increased convenience and accessibility and have increased the quantities of HHW received. One staff person is dedicated to these programs approximately 85 percent and supplemented by other staff and interns to manage peak demand times.

A Small Quantity Generator (SQG) auditing and disposal program started up in 2000. This program assists small businesses, schools, and local government entities that produce small quantities of hazardous wastes in reducing the amount of wastes produced and properly disposing of the wastes presently accumulated.

Each of these programs have been partially the recipient of several State grants which have aided in facility expansion, education, and equipment purchases. These programs are intended to promote safety in the home or business and to safeguard solid waste workers, as well as protect the environment.

Private Recycling Programs

Curbside Collection Programs. There are three privately operated curbside collection services for recyclables in Lawrence. They are:

- Jeff's Curbside Recycling
- Home Recycling Service
- Community Living Opportunities

Jeff's Curbside Recycling and Home Recycling Service both are operated as businesses for profit. Community Living Opportunities collects from a limited number of customers and provides work opportunities for their clients.

Each of the services takes most of the material collected to the Wal-Mart Community Recycling Center. Some of the more valuable material is sold by the businesses. Together, the services are utilized by approximately 300-400 subscribers.

Wal-Mart Community Recycling Center. The Wal-Mart Community Recycling Center continues to receive large amounts of materials through their drop-off site and processing facility. Wal-Mart funds the facility and employs Community Living Opportunities (CLO) clients to staff the facility. The facility provides a convenient opportunity for residents to recycle a wide range of materials. Wal-Mart has also been allowing private curbside recyclers operating in Lawrence to bring recyclables to their processing facility. Approximately 75 percent of the tonnage received is paper (newspapers, cardboard, magazines, and mixed paper).

Material received at the facility is sorted, processed (baled, or placed in gaylord boxes or other suitable containers), and stored to await transportation to markets.

Commercial Entities. Another large contribution to the success of recycling comes from large commercial and warehousing establishments that recover cardboard in-house. Most large facilities (such as grocery stores, department stores, distribution centers, and production facilities) have installed their own balers for cardboard. The cardboard is periodically collected by brokers. These facilities receive revenue from the sale of the cardboard while at the same time reducing their waste stream.

Scrap Recyclers. Local scrap metal businesses also buy aluminum and other metals from private individuals and from businesses located in the area. There are currently two scrap metal businesses that will pay people for Aluminum cans and metal items brought to their business. They are:

- Lonnie's Recycling
- 12th and Haskell Bargain Center

All private recycling services (curbside collectors, drop-offs, and buy-back centers) are advertised through Waste Reduction and Recycling printed materials, website and other marketing outlets.

EVALUATION OF CITY OPERATED CURBSIDE RECYCLING

Additional Recovery of Materials

It is important to remember, but often misunderstood, that a great deal of the material that would be collected with a curbside collection program is already being collected through existing programs in Lawrence. A curbside collection program would greatly reduce the amount of material being collected at the Wal-Mart Community Recycling Center, by private curbside recycling businesses, and through the city-operated drop-off locations. This would transfer recycling costs to a significantly more expensive method of collection. This fact underscores that "curbside recycling" is not a recycling method but a collection method. The recycling happens after materials are collected.

In 1995, Franklin Associates, Limited, in their report entitled "Douglas/Jefferson Counties Regional Solid Waste Management Plan", estimated that a curbside collection program would add **no more** than 3.5 percentage points to the City's recycling rate (at that time the City's recycling rate was 29 percent). Therefore, at a maximum, one could expect the current recycling rate to increase from 34 percent to only 37.5 percent or less with the implementation of a curbside recycling program. To achieve the maximum percentage increase, single-family households, apartment complexes, group living quarters, downtown apartments, and trailer parks (virtually all living units within the city) would need to participate. An un-mandated subscription based service would not appreciably increase recycling rates, as subscription services are already available from the private curbside collection companies servicing the city.

Benefits and Other Impacts

The main benefit from having a curbside collection program for recyclables would be the convenience the program would provide to residents. The overall increase in the recycling rate would be very small and at considerable cost.

Additional fleet vehicles would be required to provide the additional, third city-wide curbside collection (in addition to yard waste and trash collections). These additional vehicles would consume additional fuel and contribute to air pollution. Curbside collection of recyclables is inherently inefficient in that collection time per ton is greatly increased while tons collected per mile and tons collected per truck are greatly decreased.

Although there may be some savings in fuel due to people not having to drive their own recyclables to a drop-off location, these are difficult to quantify. It is likely that most persons combine their visit to a drop-off facility with other shopping errands. This is one of the main reasons for locating drop-offs at shopping centers, grocery stores, or along main roads. Any fuel savings may benefit society as a whole but they won't pay for the costs of workers and equipment needed to collect and process recyclables on a daily basis. In fact one major 1999 study concluded that curbside collection of recyclables often expends more resources than are gained and therefore can actually have negative environmental effects. The authors [faculty members of Carnegie-Mellon University (Pittsburgh, Penn.), Department of Civil and Environmental Engineering and Graduate School of Industrial Administration] particularly point out that curbside collection and recycling of glass has a net negative benefit. One of their conclusions is:

> "From a review of the existing economic experience with recycling and an analysis of the environmental benefits (including estimation of external social costs), we find that, for most communities, curbside recycling is only justifiable for some postconsumer waste, such as aluminum and other metals. We argue that alternatives to curbside recycling collection should be explored…" [source: Lave L. et al, (1999), "Municipal Solid Waste Recycling Issues," *Journal of Environmental Engineering,* October. (see attached)].

Another benefit would be the creation of new jobs (approximately 20 positions with once per week collection and 14 positions with biweekly collection) and these would be funded through the City budget. However, it is unknown if the Wal-Mart Community Recycling Center would be maintained if the city developed a curbside recycling program. If not, this would result in the loss of an unknown number of positions filled with CLO clients and their associated supervisors while diverting a large amount of material presently collected into a much more expensive curbside collection program. It is likely that the existing private curbside collection businesses currently offering services within the city would be put out of business due to their services being duplicated by the city mandated program.

Implementation

A curbside recycling program would have to be mandatory (at least the cost would have to be spread among all households) and phased in over a period of time. A Material Recovery Facility (MRF) would have to be funded, sited, built, equipped and staffed before curbside collection could begin. Single-family households would be considered as Phase 1. Phase 2 could include apartment complexes, trailer courts, and other multi-unit dwellings and group living quarters. This is because the two phases would require entirely different collection methods and would consist of mostly different populations (single family households are more likely to be permanent residents while apartment complexes tend to be more non-permanent residents).

Specialized collection vehicles would have to be purchased and staff hired and trained to operate them. It is important to note that there would not be a corresponding reduction in refuse collection vehicles and personnel. This is because of the much larger capacity of refuse collection compactor trucks which are designed to tightly compact their payloads. Therefore they can carry much more tonnage per trip than a recycling vehicle. Also the refuse trucks still have to run the same routes and make the same number of stops. In addition, much of what would be collected through curbside recycling collection is not now being collected, rather it is already being recycled through existing programs. For example, in a typical curbside collection program, 75 percent of the material collected is newspapers (according to Waste Management of North America). The City and Wal-Mart, through their drop-off programs, are already collecting a large majority of the newspaper available (over 1,590 tons collected in 2003). (Note: The "rule of thumb" is that six or seven recycling trucks collect enough material to replace one trash truck.)

Recycling containers would have to be purchased and distributed to households. Educational materials would have to be prepared and distributed along with an on-going public education campaign. The City's billing system would not have to be revised if all ratepayers were required to pay into the program.

Program Cost

ATTACHMENT 3, "ESTIMATED COSTS FOR CURBSIDE RECYCLING IN LAWRENCE", shows the estimated start-up and operational costs for a curbside recycling program providing once per week service to single family households. The capital costs are amortized over seven years which is the recommended replacement schedule for recycling collection vehicles and equipment. The analysis shows the cost per household for the first seven years would be an estimated additional $11.24 per month in current dollars (not allowing for inflation or other cost increases), assuming the program was mandatory (all residential rate payers would pay the cost) for all households, and assuming once per week collection.

Fewer participating households, such as with a voluntary program, would cause the monthly fee per household to be significantly higher and recovery rates would be expected to be significantly lower. In fact, with a voluntary system, assuming the Wal-Mart Community Recycling Center ceased operating, recovery rates would likely decline from the present rate. The decline could be

significant since many persons may feel they now have to pay if they want to recycle when they could once recycle for free using the Wal-Mart facility.

Biweekly collection (every other week) would reduce the costs by requiring seven fewer collection vehicles and six fewer operators. The cost per household with a biweekly system for the first seven years would be an estimated $7.59 per month in current dollars, again assuming the program is mandatory for single-family households.

Note: See the general discussion of curbside collection of recyclables in the attached APPENDIX.

DISCUSSION

Lawrence has low landfill disposal fees and a nearby landfill (Hamm Sanitary landfill) with a projected life span of 175 to 200 years at its current usage rate. Consequently, Lawrence does not suffer from the same hardships of some cities throughout the nation, specifically scarce disposal space and high disposal costs. Nevertheless, Lawrence has achieved the highest recycling rate in the State (34 percent) and higher than the national average (29.7 percent).

The City has received much recognition for its innovative ("outside the box"), cost-efficient, and **sustainable** targeted materials waste diversion approach to successful and effective recycling programs. This recognition includes:

- 2002 – *Environmental Excellence Award*. Bridging the Gap, Inc. (Kansas City Metro area).
- 1999 – *Outstanding Public Education Award*. Kansas Recyclers Association, Inc.
- 1998 – *Pollution Prevention Award in Cooperative Efforts*. Kansas Department of Health and Environment.
- 1998 – *Program Innovation Award*. North American Hazardous Materials Management Association.

The City has also been featured in trade magazines several times such as *Biocycle, Waste Age*, *Kansas Government Journal*, and *World Wastes* for its innovative and cost-effective programs.

The practice of targeting high-volume materials in the waste stream which have readily accessible markets instead of installing a curbside collection program for recyclables has proved to not only achieve a high recycling rate, but made the City rather immune to the wild market fluctuations that have plagued many other curbside recycling programs throughout the nation. Many communities have been faced with dropping glass and plastic from their curbside programs, or dropping their curbside programs altogether.

The City also continues to build on its public-private partnerships in both the recycling and hazardous waste arenas. The Waste Reduction and Recycling Division actively promotes and publicizes both the Wal-Mart Community Recycling Center, which is a unique and efficient recycling opportunity that the City of Lawrence is fortunate to have, and the private curbside

recycling businesses that offer services in the Lawrence. All private recycling opportunities are represented in the Residential Recycling Guide and the Business and Industry Recycling Guide that we produce and distribute.

The Solid Waste Division actively seeks opportunities to increase recycling and waste reduction in an economical and cost-efficient manner. The Division is recently completed Phase 1 of the Composting and Wood Recovery Center (partly financed by State grant monies) in partnership with the Parks Department and the Utilities Department. This program expansion allows us to receive more woody wastes with the grass and leaves that are being collected for composting. These woody wastes have been turned into quality mulch and redistributed to the public as well as used in City landscaping projects.

The office paper collection program, over the past year, has grown from a pilot program to a fully operational service that is offered to businesses, offices, schools, public buildings, and other entities

RECOMMENDATIONS

The Solid Waste Division recommends that the current recycling strategy be continued and expanded upon. The costs of new programs should be measured against the benefits, realizing that public dollars are resources too and should be spent on those programs that provide the greatest benefits while achieving economic sustainability. Specifically the Division recommends:

1. The City continue to support the concept of a state wide beverage container deposit law ("bottle bill") which would remove glass, plastic, and aluminum beverage containers from the waste stream.

2. Newspaper, cardboard and office paper recycling programs should continue to be expanded including additional drop-off sites. Public buildings, schools and other private and commercial facilities that would benefit should continue to be brought into the programs.

3. Increase recycling of clean wood waste by developing a program and procedures for accepting wastes from construction, old pallets and other clean wood waste at the compost facility for reuse or as ingredients to mulching products.

4. Increased public education on waste reduction.

CONCLUSION

The Solid Waste Division believes that our current approach realizes the greatest gains while expending the least resources to achieve meaningful and sustainable recycling programs that significantly divert waste from disposal. While it is true that curbside recycling, largely due to persistent media treatment and the fact that it experienced a wave of popularity in the late

eighties and early nineties, is seen by a large segment of the public to be the only “true” form of recycling, other methodologies can achieve greater successes at less cost. The greatest asset of curbside collection of recyclables is often its convenience. If we are to consider curbside collection, we must ask, “What price are we willing to pay for convenience?”-- all the while realizing that the increase in the overall recycling rate will be very small. That is the central question. That question is especially important when considering those services are offered through the private market.

APPENDIX

CURBSIDE COLLECTION OF RECYCLABLES—BACKGROUND

Elements of Curbside Collection Programs

Collection. Specialized collection vehicles with separate compartments for different materials are recommended for curbside collection of recyclables. Materials are generally placed in bins or bags at curbside and must be separated either at the point of collection or later at a processing facility. Typical materials collected are newspapers, aluminum cans, steel cans, plastic (PET and HDPE) containers, and glass containers. High density neighborhoods (such as the Oread Neighborhood) present special problems due to the large amount of on-street parking, congestion in alleys, and lack of additional space in the alleys for additional placement of containers. Older neighborhoods with narrow alleys used as collection points can present similar difficulties. Multi-family housing units and large apartment complexes usually need to be serviced by a different collection method than that used for typical single-family neighborhoods**.**

The highest recovery rates are obtained with once per week collection. Some cities collect recyclables on the same day as trash. Others collect recyclables on a separate day from trash.

Processing. Collection of materials is only the first step in a recycling program. The materials must be separated from each other. PET plastic and HDPE plastic must be separated from each other. Other forms of plastic are not acceptable. Brown, green and clear glass must also be separated. Then the materials must be processed according to specifications of the end-users (markets). Processing can include baling, sorting, crushing, grinding, shredding, flattening, and removing contaminants (undesirable materials).

Processing is generally done in a Materials Recovery Facility (MRF). A MRF for a city the size of Lawrence would require a minimum of 20,000 square feet under roof for receiving, processing and storing materials. Processing equipment includes specialized task-specific balers and conveyors, and may include specialized sorting equipment. In addition to processing equipment, typical equipment includes rolling stock such as forklifts, front-end loaders and tractor trailers. Truck scales are also a necessary item. A MRF needs ample loading docks and a fenced, secure yard for storage and semi-trailer parking. MRFs are regulated by the Kansas Department of Health and Environment and require a solid waste management facility permit.

Markets. Available markets are one of the keys to a successful recycling program. Unfortunately, most markets for recyclables are not located near Lawrence. Aluminum and metals are an exception; they have maintained a high enough value over the years that scrap operations have found them profitable. They can be marketed locally. Yard wastes are another exception since the compost produced can all be used locally. All the compost produced by the City since the program's inception has been utilized, much of it going to City projects or distributed free to residents.

The markets for paper goods have remained fairly strong for years with only occasional serious downturns, usually corresponding to general economic downturns. In fact, paper collected from recycling is one of the largest export items for the United States. Paper mills have reused paper

pulp in their production process for years and therefore have a well-developed collection infrastructure. Furthermore, most recycled paper has a high enough value to bear the cost of transportation to market and still return some revenue to the recycler. Paper, such as newspaper and cardboard, typically account for about 75 percent of the material collected through recycling programs.

The markets for plastic (PET and HDPE) and glass are less optimistic for this part of the country. Most plastic markets are located near the coasts. Because of plastic's light weight it does not easily bear the cost of transportation to distant markets. Recycled plastic also does not compete well with virgin plastic because virgin plastic can be obtained as a resource cheaper than the recycled plastic. Glass also has a very low value (it is made from potash and sand which are abundant resources). The value of glass is so low that transportation even relatively short distances can cost more than the recycled glass is worth. Recycled glass has strict quality control requirements which make the processing of glass very expensive. In practice, most recycling programs experience high negative costs for the recycling of glass and plastics and must cover those costs from the revenues received from other materials and from other funding sources.

Sometimes when markets are in downturn, many materials have no value at all (there is no demand) and for others, communities have to pay the markets to take them or drop them from their collection program. Paying to get rid of recyclable materials can be a viable option if local disposal fees are high enough. This is because the amount communities have to pay to have their materials taken by the markets may be less than the cost of disposal. Communities experiencing $80 or $100 per ton or higher tipping fees, or with long haul distances to the nearest landfill (for example, rail-haul and barge-haul is common in some regions) may still realize savings in their waste management costs. Communities with tipping fees similar to those in Lawrence ($19.15 per ton) would not experience those savings, but would rather experience an overall increase in waste management costs.

Presently, for Lawrence, markets exist for compost, aluminum, metals, old newspapers, corrugated cardboard, and office papers and magazines. Markets for plastics and glass are much less available and would require large processing and transportation costs with little or no revenue from the sale of the material.

Transportation to Markets. Transportation of the materials to the markets (previously touched upon) is the final phase in a recycling collection program. Materials that can be marketed locally generally pose no special problems. Aluminum and other metals (including appliances) need only be transported to local scrap dealers. Yard wastes are transported to the local composting site. Newspapers, cardboard and office papers, collected and baled in Lawrence, are loaded onto semi-trailers and picked up by brokers out of Kansas City, Topeka or Wellsville and some by a broker from Oklahoma. The material is then shipped to paper plants in Hutchinson or Oklahoma or transferred to railcars and shipped to Mexico. The paper purchased by the Wellsville operation is utilized directly in that facility for the production of insulation and other products.

Glass and plastics present a problem. The nearest market for glass is in Oklahoma. Glass must usually be delivered to the buyer's dock with the cost of transportation being the responsibility of

the seller. Revenues for glass are so low they do not cover the cost of transportation. Plastic markets are generally much more distant. Most plastic markets are located on the East Coast and supply the textile industry. These markets are waning as the textile industry continues to relocate overseas. Plastic cannot bear the cost of long distance transportation due to its light weight and correspondingly low value per truckload. Again, the cost of transportation is usually borne by the seller.

Facilities that collect recyclables using low-cost collection methods, such as the Wal-Mart Community Recycling Center which is a drop-off, must still subsidize the cost of recycling and transporting the plastic and glass collected. Wal-Mart can sometimes use empty backhauls to get materials to market. The cost is less of a concern to Wal-Mart because they have assumed it as a cost of doing business and it also provides them with a great deal of goodwill and positive public relations.

Recycling Program Costs

The economic feasibility of a recycling program depends on the costs of operation and administration, disposal costs avoided, and revenues from the sale of materials. In communities where the disposal costs are relatively low, economic benefits to the community from recycling must come predominantly from the sale of the collected materials. When the revenues and avoided disposal costs do not cover the costs of the community recycling program, the economic support for recycling is shifted to the public through additional taxes or increased fees. Consequently, public subsidy of recycling is a reality and one that is most visible where disposal costs are lowest.

Most of the attributed benefits of recycling, such as resource conservation and energy savings, are not realized at the local level but are accrued during the industrial manufacturing process. Therefore, local communities are often subsidizing the supply of raw material to the industrial profit-seeking sector through the implementation of recycling programs. Most benefits locally must come from the avoidance of disposal costs or the preservation of scarce landfill capacity (if that is the case).

In fact, at the local level, more resources are usually expended to operate a recycling program due to the costs of additional specialized collection equipment, less efficient collection methods, processing equipment costs, a materials recovery facility, transportation costs, additional administrative costs, higher fuel costs, and increased personnel and other operating costs.

The bottom line is that recycling increases the costs of waste management. Unless there are high disposal costs, the costs of waste management, especially with a curbside recycling program, can increase dramatically. Revenues from the sale of recyclables are not capable of offsetting but a small percentage of program costs in communities with curbside recycling. This underscores the fact that the impetus for most communities that develop curbside recycling programs is high disposal fees, dwindling landfill space or, usually, a combination of both.

ATTACHMENT 1

SUMMARY OF FINDINGS AND RECOMMENDATIONS

This study examined several methods for the collection of recyclable materials which would form a comprehensive recycling program. The methods are not interdependent; one, several or all could be implemented. The methods are:

- Separate collection of yard wastes from residences;
- Curbside collection of recyclables from residences;
- Collection of recyclables from bins at apartments and trailer courts;
- Collection of old corrugated containers from the retail sector; and
- Collection of office papers from office complexes, etc.

SUMMARY OF FINDINGS

It is estimated that the City generated 44,000 tons of municipal solid waste (MSW) in 1991. MSW is that portion of the waste stream generated by the residential and commercial sectors. It is estimated the above collection methods could recover the quantities of recyclable materials presented in Table S-1 (annual basis, with 1991 as the base year).

Table S-1

QUANTITIES RECOVERED WITH A COMPREHENSIVE RECYCLING PROGRAM

Method	Tons	% of MSW
Yard Waste Collection	7,150	16
Residential Curbside Collection	2,089*	5
Apartment/Trailer Court Collection	522*	1
Old Corrugated Container Collection	1,715**	4
Office Paper Collection	498**	1

* Much of what is currently recycled through drop-offs and private curbside collection would be diverted to these programs and is included in these estimates.

**In addition to what is currently recycled.

All of the materials collected, except for yard wastes, would require a facility for processing, storage and preparation for transportation. The facility would need to be equipped and staffed accordingly.

Curbside collection of recyclables would require the purchase of specialized vehicles plus the associated personnel. There would not be a corresponding reduction in refuse collection vehicles and personnel. This is because of the much larger capacity of refuse collection trucks, and because the trucks still have to make the same number of stops. Pete Grogan of R.W. Beck Associates, who is recognized as one of the foremost experts in recycling and solid waste analysis, estimates that six or seven recycling trucks divert enough trash for a city to withhold one regular refuse truck.

A curbside collection program for recyclables would significantly increase the costs of waste management and these costs would be passed on to the ratepayers. A yardwaste collection program would be the least costly waste reduction option and would remove the greatest amount of material from the waste stream.

Markets for most of the materials collected are highly uncertain in this part of the country and the revenues from sale of materials are low. Most recycling programs depend on the savings in disposal costs for economic justification. When disposal costs are low, as in Lawrence, the savings cannot begin to cover the costs of recycling.

Table S-2 summarizes in matrix form the relative costs and efficiencies of the collection methods evaluated here.

RECOMMENDATIONS

Should the City Commission wish to expand recycling efforts, the following recommendations are made based upon the findings in this study.

1. It is recommended the Earthbound program (yard waste collection program) be expanded city-wide, with curbside collection of grass clippings and leaves from all residences. Participation in this program should be mandatory, that is no yard waste would be collected with other refuse. Leaving grass clippings on the lawn and backyard composting should be encourage, but most residences will still need an outlet for leaves. Collected yard wastes should be composted and used in City projects as substitute for topsoil, as a planting medium and for protective cover for the old landfill located at the north end of Riverfront Park. Options for separate yard waste collection include:

    a. Once-per-week yard waste collection and once-per-week refuse collection (on separate days) with existing equipment and personnel.

    b. Twice-per-week refuse collection and once-per-week yard waste collection with an expanded collection fleet and additional personnel.

c. Contract for collection of yard wastes through the private sector, with the City continuing twice-per-week trash collection.

2. It is recommended the City continue and expand upon the current old newspaper collection system which has been successful.

3. It is recommended the City explore opportunities for establishing a program for the collection of old corrugated containers from the retail sector. Such a program may require a collection fee to cover the City's costs. Retail establishments may be able to save part of these fee costs through lower disposal costs since they could reduce their waste stream. This program would require a facility to be established for the aggregation, baling and storage of the collected corrugated containers.

4. It is recommended the City continue and increase the promotion of private recycling initiatives which exist within the city. Some of these operate for profit and some are not-for-profit organizations.

5. It is recommended the City use every opportunity to increase the markets for recyclable materials in this area. Several methods are:

   a. Continue the present policy to procure goods with recycled content whenever possible and economically feasible.

   b. Encourage industries that use recycled materials in their production process to locate in Lawrence.

   c. Encourage State officials to actively take economic development steps that would increase the markets for recyclable materials within Kansas.

6. It is recommended the City explore opportunities for a public-private cooperative facility in which recovered materials could be processed for market. Such a facility could be operated by a group that works with persons with disabilities, such as Community Living Opportunities. The facility could receive old corrugated, aluminum, and old newspapers at first, and expand to other materials in the future.

7. It is <u>not recommended</u> that a city-operated curbside collection program nor collection from apartments and trailer courts be implemented at this time. The costs would be very high and the markets for many materials are not financially viable. The private sector currently provides a number of outlets that residents can use for recycled materials. A city-sponsored program would not only be expensive to citizens, but would compete with existing collection alternatives.

8. It is <u>not recommended</u> that a city-operated office paper collection program be implemented at this time. The program would be expensive and would recover a relatively small amount of material. This type of program would become more feasible if a materials processing facility becomes available.

TABLE S-2

RELATIVE COSTS AND EFFICIENCIES OF EVALUATED COLLECTION METHODS

METHOD of COLLECTION	COLLECTION COSTS	TONS RECOVERED	COLLECTION COST PER TON	RECYCLING COST	MARKET VIABILITY
RESIDENTIAL					
YARD WASTE COLLECTION	LOW	HIGH	LOW	LOW	GOOD
RESIDENTIAL CURBSIDE COLLECTION	HIGH	MEDIUM	HIGH	HIGH**	GOOD-METALS OLD NEWSPAPERS, FAIR-GLASS POOR-PLASTICS
APARTMENT/TRAILER COURT COLLECTION	HIGH*	LOW	HIGH	HIGH**	GOOD-METALS, OLD NEWSPAPERS, FAIR-GLASS POOR-PLASTICS
COMMERICAL					
OLD CORRUGATED COLLECTION	MEDIUM	MEDIUM	MEDIUM	MEDIUM**	GOOD
OFFICE PAPER COLLECTION	HIGH	LOW	HIGH	MEDIUM**	FAIR

* Requires the purchase of specialized collection vehicles plus associated personnel.

** Requires a facility for receiving, storage, processing, and preparing for transportation, plus associated equipment and personnel.

ATTACHMENT 2

ANNUAL RECYCLING REPORT FOR 2003

INTRODUCTION

This report summarizes the materials, quantities, associated revenue, and avoided landfill costs derived from diverting recycled materials from the landfill for 2003. Numeric quantities of materials diverted for recycling by the City of Lawrence Solid Waste Division are in the attached tables.

In 2003, the City's Solid Waste Division collected an estimated 68,697 tons of municipal solid waste. Of this total, 12,766 tons of material was recycled by the City and approximately 55,931 tons were landfilled. An additional estimated 15,576 tons of material was recycled by the private sector, primarily through the Walmart's Community Recycling Center, University of Kansas, and by large retail, industrial and warehouse facilities and other smaller recycling operations. This also includes an estimated 1,600 tons due to backyard composting and grasscycling. (The Solid Waste Division also landfilled an estimated 12,800 tons of construction/demolition waste in 2003. Construction/demolition waste is not included in municipal solid waste data.)

TOTAL WASTE DIVERTED FROM LANDFILL BY THE CITY

A total of 12,766 tons of grass clippings and leaves, newspaper, cardboard, brushy wood waste, Christmas trees, white goods and metals, and office waste paper were recycled through City programs in 2003 for a savings in landfill costs of $ 244,523.00. Revenue from the sale of recycled materials was $103,429.00.

In 2003, more than 28,342 tons of materials were recycled through City and private sector efforts in Lawrence representing a 34 percent recycling rate, which is believed to be the highest in Kansas and is higher than the national average.

MATERIALS RECOVERED THROUGH CITY PROGRAMS

Grass Clippings/Leaves

The City of Lawrence's Solid Waste Division provides separate citywide collection services for grass clippings and leaves from Lawrence residences on Mondays from approximately March until near Christmas. These materials are trucked to the City's composting facility. Commercial landscape and lawn care companies also drop their grass and leaves at the compost facility in exchange for providing estimated tonnages. In 2003, 9,754 tons of grass clippings and leaves were collected and composted resulting in a savings of $186,789.00 in avoided disposal costs.

Finished compost was not distributed in the fall as unacceptable levels of the herbicide, Clopyralid, were detected and it was determined prudent not to distribute to the community for garden use until levels have decreased sufficiently. Community education and outreach regarding Clopyralid is underway within the Waste Reduction and Recycling Division.

Pending permit approval by KDHE-BWM, composting operation will begin at the new 1750 E. 11th Street facility in spring of 2004.

Old Newspapers

Nine city-sponsored drop boxes for newspaper recycling are located throughout Lawrence reflecting an increase from the previous year. In 2003, 790 tons were collected and recycled, representing a 10% increase in material collected from last year. This diversion resulted in savings of $15,129.00 in avoided disposal costs. Market values ranged from $55 per ton to $70 per ton over the course of the year for baled material. The sales of old newspapers provided revenue of $50,924.00.

Old Corrugated Containers

The City's Solid Waste Division serves over 300 Lawrence businesses with cardboard recycling services. In 2003, 655 tons of materials were collected for recycling resulting in revenue of $46,227.00 and an avoided disposal cost of $12,600.70. Market values ranged from $58 per ton to $70 per ton over the course of the year for baled cardboard.

BRUSHY WOOD WASTE

In 2003, the City's Parks and Recreation Department diverted 1,369 tons of brushy wood waste from the landfill. Two programs administered by the Parks Division contributed to this diversion; (a) a residential drop-off chipping service at the 11th and Haskell Forestry facility (298 tons); and (b) Right of Way removal of tree and brush debris (1,071 tons). Wood chips produced through these programs were used on city landscape projects and made available to the community through the Parks Division Annual Fall Wood Chip sale. Avoided disposal costs attributed to the brushy waste programs was $26,216.00. Revenue generated from the sale of wood chips was $ 4,532.00.

Christmas Trees

On the first three Mondays following Christmas, the Solid Waste Division crews collected Christmas trees for recycling from Lawrence residents. Thirty three (33) tons of Christmas trees were collected, processed and used as erosion control and wildlife habitat enhancement at the closed landfill north of Riverfront Park. Diverting Christmas trees from the landfill resulted in $637.95 in avoided disposal costs.

White Goods & Metals

Bulky item pickup for appliances like refrigerators, washers and dryers is provided by appointment by the City's Solid Waste Division to Lawrence residents. Metal appliances and other collected metals are sold to a local metal recycler. One hundred and forty seven (147) tons were recovered and sold for revenue of $791.46 and provided an avoided disposal cost of $2,815.05.

SORTED Office WASTE Paper

Collecting from small businesses and some schools, this program diverted 16 tons of paper from the landfill. A grant from KDHE will assist in the procurement of a small packer truck allowing program expansion in 2004. Market values ranged from $70 per ton to $60 per ton over the course of the year for sorted office waste paper. Revenue derived from the sale of the paper was $829.80

OLD MAGAZINES

Generated by city offices, almost 2 tons of material was shipped loose in gaylord boxes to V.I.M Recyclers in Topeka. Revenue received for unbaled old magazines was $77.50.

Used Motor Oil

A total of 5,623 gallons of used oil was collected at the City's Maintenance Garage in 2003 of which 3,830 gallons were recycled as bunker fuel by Clearwater Recycling. One thousand seven hundred and ninety three (1,793) gallons were burned for heat at the garage. The collection of used oil generates no revenue.

Tires

A total of 2,678 tires were collected for proper disposal by the City's Solid Waste Division. The Solid Waste Division provides Lawrence residents, by appointment, free pickup for up to five passenger tires per year, per household. Thirty five percent (35%) of the tires were collected for recycling by Champlain Tire at the cost of $1,323.75 Remaining tires were collected by TireTown for shredding and monofill in Leavenworth County at the cost of $2,45.56.

Freon

Six hundred and forty (640) refrigerators and other freon-containing units were collected for recycling by the City's Solid Waste Division. Over 75 pounds of freon were captured and sent for reclamation by trained Container Maintenance personnel with EPA-approved equipment. Federal regulations require freon to be removed from appliances prior to salvaging. By moving this responsibility in-house, the city has greater regulatory control of the extraction process and saves money.

HOUSEHOLD HAZARDOUS WASTE

Over 94,000 pounds of hazardous household products were diverted from the Hamm regional landfill in 2003 with 1,710 participants including drop offs, homebound pickups, abandoned waste and orphan waste collection service.

In 2003, the Small Quantity Generator program provided technical assistance and environmentally-preferred disposal options to 51 small businesses, doubling the participation from the previous year.

CITY OF LAWRENCE
SOLID WASTE DIVISION

MATERIALS RECOVERED FOR RECYCLING - 2003

Material	Quantity	Revenue from Sales	Avoided Landfill Disposal Costs
Grass Clippings / Leaves	9,754 tons	N/A	$ 186,789.00
Old Newspaper	790 tons	$ 50,924.28	$ 15,128.50
Old Corrugated Containers	655 tons	$ 46,227.00	$ 12,600.70
Brushy Wood Waste[2]	1,369 tons	$ 4,532.00.	$ 26, 212.00
Christmas Trees	33 tons	N/A	$ 637.95
White Goods & Metals	147 tons	$ 791.46	$ 2,815.05
Office Waste Paper	16 tons	$ 829.80	$ 306.40
Old Magazines	1.77 tons	$ 77.50	$ 33.89
TOTAL	**12,765.77 tons**	**$ 103,429.06**	**$ 244,523.49**

Other Materials

Used Motor Oil	5,623 gallons
Tires	2,678 units
Freon Recovery	640 freon-containing units were processed

[2] Beginning in 2003, brushy wood waste recovered from both residential drop off and right-of-way clearance are recorded

CITY OF LAWRENCE
SOLID WASTE DIVISION
MATERIALS RECOVERED FOR RECYCLING

YEAR-TO-YEAR COMPARISON

MATERIAL	1996	1997	1998	1999	2000	2001	2002	**2003**
Grass Clippings/Leaves	6,317	7,667	7,864	5,963	5,206	6,066	9,052	**9,754**
Old Newspapers	426	606	866	852	790	950	704	**790**
Old Corrugated Containers	22	347	425	451	510	509	641	**655**
Brushy Wood Waste	N/A	N/A	122	186	215	456	311	**1,369**
Christmas Trees	43	49	46	50	36	39	38	**33**
White Goods & Metals	54	59	36	108	111	158	80	**147**
Sorted Office Waste Paper	N/A	2	7	8	11	13	19	**16**
Old Magazines	N/A	N/A	N/A	N/A	2	.29	0.5	**1.77**
TOTAL	6,862	8,730	9,366	7,618	6,881	8,191	10,846	**12,766**
OTHER MATERIALS								
Used Motor Oil (gallons)	6,465	5,300	8,955	5,764	8,281	5,026	4,337	**5,623**[3]
Tires (units)	1,768	2,943	3,670	4,129	3,006	2,304	2,791	**2,678**
Freon Recovery (units)	402	275	388	457	394	553	589	**640**

[3] 1,793 gallons burned for heat @ Central Maintenance Garage and Street Department; and 3,830 gallons collected by Clearwater Recycling for use as bunker fuel.

LAWRENCE WAL-MART COMMUNITY
RECYCLING CENTER - 2003[4]

	2003
NEWSPAPER	799
MIXED PAPER	408
MAGAZINES	400
CORRUGATED CARDBOARD	692
HDPE NATURAL	22
PET MIXED	39
HDPE COLORED	10
GLASS	514
WHITE LEDGER	54
ALUMINUM CANS	24
STEEL CANS	79
TOTAL	**3,041 tons**

[4] Walmart accepts materials from the following curbside recycling companies that service Lawrence: Jeff's Curbside Recycling, Community Living Opportunities and Home Recycling Service.

Household Hazardous Waste Program
Year-to-Year Report

	1994	1995	1996	1997	1998	1999	2000	2001	2002	**2003**
Number of Collection Events	6	6	7	7	7	7	7	7 events + Appts.	7 events + Appts.	**By Appointment Only**
Pounds Collected (HHW, SQG)	21,207	26,547	36,020	57,656	58,319	73,920	61,295	86,536	100,603	**97,980**
Pounds distributed through Product Reuse	10,687	12,115	5,367	13,819	12,155	15,280	9,506	8,342	7,644	**8,306**
Disposal Costs	$13,931	$10,088	$11,865	$19,275	$22,095	$20,005	$21,135	$40,350	$37,939	**$34,700**
No. Served	648	724	919	1,335	1,450	1,580	1,773	2053	2,016	**1,761**

ATTACHMENT 3

ESTIMATED COSTS FOR CURBSIDE RECYCLING IN LAWRENCE
(Present Year 2004 Dollars; Cost of debt or bonds not included))

Assumptions
1. 25,000 households participating—Cost per household rises with fewer participating.
2. Once a week collection, routes spread over four days per week.
3. 400 stops per route, per day.
4. One-person collection vehicle.
5. Capital costs amortized over 7 years

START-UP COSTS	**Weekly**	***Biweekly**
CAPITAL COSTS		
1. Material Recovery Facility (MRF)	$1,585,000	
2. Processing equipment (balers, forklifts, conveyors, etc.)	$750,000	
3. Collection containers (22,000 @ $15/ea.; 33,000 for biweekly)	$330,000	$445,000
4. Collection vehicles (16 routes plus 4 standby @ $130,000/ea.)	$2,600,000	$1,430,000
5. Vehicles for supervisors (3 @ $22,000: 2 with biweekly)	$66,000	$44,000
CAPITAL COSTS SUBTOTAL	**$5,321,000**	**$4,254,000**

ANNUAL COSTS

COLLECTION COSTS		
1. Operator I (20 @ $56,000/annum incl/benefits)	$1,120,000/yr.	$560,000/yr.
2. Field Supervisor (2 @ $60,000/annum incl/benefits; 1 biweekly)	$120,000/yr.	$60,000/yr.
3. Fuel/maintenance ($35,000/ coll. vehicle; $7,000/supv. vehicle)	$721,000/yr.	$399,000/yr.
4. Container replacement (5,000/yr. @ $15/ea.)	$75,000/yr.	
5. Education/promotion ($1 per household per year)	$25,000/yr.	
SUBTOTAL	$2,061,000/yr.	$1,119,000/yr.
MRF OPERATION COSTS		
1. Labor (6 persons @ $45,000/annum incl/ benefits)	$270,000/yr.	
2. Supervisor ($60,000/annum incl/benefits)	$60,000/yr.	
3. Maintenance, utilities, overhead	$100,000/yr	
SUBTOTAL.	$430,000/yr.	$430,000/yr.
OTHER COSTS		
1. Administrative Clerk ($45,000/annum incl/benefits)	$45,000/yr.	
2. Contingency	$75,000/yr.	
3. Billing system modifications	Unknown	
SUBTOTAL	$120,000/yr.	$120,000/yr.
ANNUAL COSTS SUBTOTAL	**$2,611,000**	**$1,669,000**
TOTAL COST/YEAR OVER 7 YEARS	**$23,608,000**	**$15,937,000**
AVERAGE COST/YEAR	**$3,372,571**	**$2,276,714**
COST/HOUSEHOLD/YEAR	**$134.90**	**$91.07**
COST/HOUSEHOLD/MONTH	**$11.24**	**$7.59**

***Costs for a biweekly system would be less due to fewer collection vehicles and operators.**
Note: Biweekly – 8 collection vehicles plus 3 standby; 10 Operator I's.

MUNICIPAL SOLID WASTE RECYCLING ISSUES

By Lester B. Lave,[1] Chris T. Hendrickson,[2] Member, ASCE, Noellette M. Conway-Schempf,[3] and Francis C. McMichael,[4] Member, ASCE

ABSTRACT: Municipal solid waste (MSW) recycling targets have been set nationally and in many states. Unfortunately, the definitions of recycling, rates of recycling, and the appropriate components of MSW vary. MSW recycling has been found to be costly for most municipalities compared to landfill disposal. MSW recycling policy should be determined by the cost to the community and to society more generally. In particular, recycling is a good policy only if environmental impacts and the resources used to collect, sort, and recycle a material are less than the environmental impacts and resources needed to provide equivalent virgin material plus the resources needed to dispose of the postconsumer material safely. From a review of the existing economic experience with recycling and an analysis of the environmental benefits (including estimation of external social costs), we find that, for most communities, curbside recycling is only justifiable for some postconsumer waste, such as aluminum and other metals. We argue that alternatives to curbside recycling collection should be explored, including product takeback for products with a toxic content (such as batteries) or product redesign to permit more effective product remanufacture.

INTRODUCTION

The United States is a "throwaway" society whose total and per capita waste has been increasing for more than 40 years. The average American produces about 4.4 lbs of municipal solid waste (MSW) each day, resulting in roughly 210,000,000 tons/year for the nation (*Statistical* 1998). Most MSW goes to landfills. From examination of landfill wastes, Rathje and Murphy (1992) found that the composition of landfill mass deposited in the 1980s was roughly 40% paper, 8% organics, 8% plastic, 11% metal, 6% glass, 12% construction/demolition waste, and 15% additional, unclassified waste.

Some people dislike landfills because they are a nuisance. The closing of landfills, the threat of running out of space in landfills, and the waste of resources have alarmed others when MSW is sent to landfills.

The almost universal aversion to landfills comes from the history of city dumps that smelled, looked terrible, were infested with rats and other pests, and posed risks to health. Sanitary engineers responded by designing modern landfills that pose few of these problems. Modern landfills have a minimum odor nuisance, do not have pests, and pose few problems after they are closed. With rules mandating daily cover, clay and rubber liners, clay caps, and leachate collection systems, modern landfills are a tribute to sanitary engineering.

Even with these improvements, landfills are still unpopular. The traffic and other nuisances of even a modern landfill are a bother to nearby residents. Methane emissions from landfills can pose a safety hazard to nearby buildings and contribute to urban ozone problems and global warming. In most communities, groups attempt to close current landfills and have made it extremely difficult to site new ones. Dislike of landfills has led to a popular revolt in states like Pennsylvania and Virginia against taking MSW from other states, although interstate transfers of waste are the cheapest way of handling MSW in some situations (Louis 1996).

In the popular press, the closing of many landfills in the last decade and the opposition to opening new ones has led to concern that we are running out of landfills. The number of landfills has declined significantly because of new regulatory requirements for improved design and management. However, the decline in tipping fees in recent years is evidence that landfill space meeting the new regulatory requirements is readily available (Biocycle 1998).

The third objection that landfills waste precious resources has led to two actions: energy recovery units and recycling. MSW contains a great deal of energy that potentially could be recovered. It also contains a great deal of valuable raw materials. Although energy recovery reduces the landfill problem (it reduces the volume by 2/3) and extracts some of the raw materials value in the MSW, it recovers only a tiny fraction of the potential value in the materials.

Many states and cities have responded by requiring households to recycle; some have specific goals, such as requiring 50% recycling of MSW (Goldstein and Glenn 1997). However, little analysis underlies the recycling targets (Garrick 1998). There has been some analysis of whether MSW recycling is beneficial, particularly recycling with curbside collection of recyclables (Denison 1996; Tierney 1996). Germany required consumer product packaging to be recycled beginning in 1991 (OECD 1996); and more recently, in Germany, automobile and electronics manufacturers have "volunteered" (under threat of legislation) to take back their products and to meet recycling targets for these products at the end of their lives. These German initiatives are worth study, since they should be viewed as a "social experiment" that can help to enlighten our future policy.

This paper considers the life-cycle economic and environmental impacts of MSW recycling. We seek to identify cost-effective policies to achieve environmental and sustainability goals for MSW. Similar to Haith (1998), we emphasize that some recycling improves environmental quality and sustainability, whereas other recycling has the opposite effect. For example, recovering aluminum beverage containers in an urban area generally benefits the environment and lowers the use of energy and other resources; in contrast, the minuscule amount of aluminum in consumer packages is likely to require more energy and other resources to separate and recycle than it saves.

Before recycling can occur, the materials must be collected from consumers—a reversal of the logistics system that distributed products to consumers. People familiar with the com-

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plexity of the current distribution system should not be surprised at the difficulty of designing and operating a "reverse logistics" system that is universal, cheap, and reliable. Curbside pickup is one of several reverse logistics systems with its peculiar advantages and drawbacks. Other reverse logistics systems include consumers taking recyclables to a central collection point or returning them to the retailer as part of a deposit/refund system. The alternative systems have radically different implications for the amount of work that consumers must perform, the cost of collection and sorting, and the overall efficiency of the system.

WHAT SHOULD WE DO WITH PRODUCTS AT THE END OF THEIR LIVES?

Despite efforts of the Environmental Protection Agency ("Documents" 1999) and the legislation and regulations mandating recycling programs, there is no consensus on what constitutes MSW recycling, either on which postconsumer waste is included in MSW or on how to measure the fraction of material that is recovered for reuse.

When a consumer no longer wants to keep a product, any of the following options may be possible. The product might be

1. Reused (as with old furniture)
2. Remanufactured (as with copier machines or automobile alternators)
3. Recycled into the same use in a "closed loop" (as with asphalt pavements)
4. Recycled into a lower valued use (as with recycled plastic molded into park benches)
5. Incinerated (as with burning paper to recover energy)
6. Landfilled (as with most MSW)
7. Discarded directly to the environment (as with littering)

Individuals and organizations differ on how many of these categories should be included within the definition of "recycling," although most people would include Options 1–4. If incineration productively recovered most of the energy in MSW (Option 5), there would be a good case for including it as recycling. Storing the waste in a landfill until it is recovered might even be considered recycling; in a sense, a landfill can be thought of as a giant storage bin of materials that could be recovered in the future. The EPA has been working to standardize definitions and methods of calculating the proportion recycled.

The definition of recycling distracts society from the real issues: environmental quality and sustainability. The definition matters only because recycling goals have been specified. Note that the goal is not to increase recycling: it is to improve environmental quality and sustainability. Recycling, whatever the definition, is one possible way to accomplish these goals.

Some laws declare, for example, that 50% of MSW must be recycled without defining what is included in MSW. A strict definition might include only the waste collected at curbside from residences. However, this definition excludes important consumer products such as batteries and automobiles, as well as waste from residential construction and demolition. We prefer a broader definition that includes all postconsumer waste that ordinarily is sent to a landfill. However, because little of the demolition waste is a candidate for recycling, an arbitrary requirement for recycling does not make sense.

A final issue is the controversy about measuring what is recycled. Roughly 95% of automotive lead-acid batteries are returned for recycling. Does this mean that 95% of automotive batteries are recycled? We would answer no. Typically, all materials in the battery other than lead are discarded. Thus, 40% of the battery weight is discarded. Of the lead in these batteries, 95% is retrieved in the secondary smelter recovery process. Thus, of all lead-acid batteries taken from cars, 54% ($0.95 \times 0.6 \times 0.95$) of discarded automobile battery material is recycled, and 90% (0.95×0.95) of the lead in these batteries is recycled. In our judgment, the best measure of recycling is the proportion of discarded products that are returned to a productive use, or 54% in the case of lead-acid starting/lighting/ignition batteries.

WHAT SHOULD BE THE OBJECTIVES OF MSW RECYCLING?

Perhaps the most widespread goal for MSW recycling is to increase recycling. Many people feel guilty about our profligate lifestyle and feel that steps need to be taken to improve environmental quality and sustainability. Recycling seems to be an obvious response. We agree with the concern for the environment and sustainability but do not regard recycling itself as a goal. Instead, the four primary goals of this study are

1. To save landfill space.
2. To save money from handling MSW. Governments face fiscal difficulties and constant criticism for being inefficient in providing public services.
3. To increase environmental quality, by lowering discharges of pollutants. In particular, the goal is to eliminate dissipative emissions of hazardous and toxic materials to the environment, including greenhouse gases and toxic materials sent to MSW landfills.
4. To increase the sustainability of the economy. This implies minimizing the use of depletable resources such as ores or petroleum and reducing the use of renewable resources, such as lumber, to sustainable levels.

Low cost is important for environmental as well as fiscal reasons. For example, petroleum to run collection trucks is just as much a use of this resource as petroleum to make consumer products; future generations will not have a barrel of petroleum to use for either purpose. The resources going to recycling are an important aspect of which MSW alternative is best at achieving the goals of environmental quality and sustainability. Sound policy requires examining the full range of alternatives to compare the resources, energy, and labor needed for the entire life cycle of each alternative (*Facing* 1989). The comparison between recycling and making new products must be an evenhanded examination of the total use of energy and nonrenewable resources and dissipative emissions.

We can state our conclusion as the "economic-environmental criterion": Recycling is good policy only if environmental discharges and the resources used to collect, sort, and recycle a material are less than the environmental discharges and resources needed to provide an equivalent virgin material plus the resources needed to dispose of the material safely.

For example, glass is made of sand and potash, neither of which is in short supply. Glass is nontoxic: discharging it to the environment poses no risk, save from cuts. For recycling of glass to be a sensible environmental policy, the energy, equipment, and labor associated with collection, separation, and recycling of glass should be smaller than the energy, equipment, and labor associated with producing the new glass, including the energy, equipment, and labor required to collect and landfill the postconsumer glass. If the resources associated with collecting, separating, and recycling of glass are larger than the resources associated with making new glass and with landfilling the used glass, recycling does not help either environmental quality or sustainability.

A more general form of the economic-environmental criterion applies to reuse, remanufacturing, and other programs for dealing with MSW such as resource reduction: A program is

beneficial to the environment and sustainability only if it actually reduces energy, resource use, and pollution, taking account of the full life cycles of the program compared with its alternatives.

A limitation to this statement of the economic-environmental criterion is that it neglects the fact that current products were not designed to be recycled. As a consequence, many cannot be recycled easily. For example, Lave et al. (1998) showed that nylon carpet could be redesigned to improve the implications of recycling for environmental quality and resource use.

Finally, recycling may also have ancillary benefits associated with community building and involvement. However, these activities would be more rewarding if they were channeled toward types of recycling (or other activities such as park cleanups) that are undoubtedly environmentally beneficial. Hence the need for pursuing the four goals articulated above.

IS MSW RECYCLING PROFITABLE?

At one time, advocates claimed that recycling of MSW would be profitable for municipalities. Recycling programs were expected to more than pay for themselves. A few categories of postconsumer wastes can be recycled or reused profitably; aluminum cans and automobiles are common examples. For most categories of MSW, the costs of collection are likely to exceed the revenue from sales. Based on national data, Ackerman (1996) estimated that curbside recycling cost $142/ton even after a credit for avoided tipping fees (Table 1). Revenues from the sale of some, but not all, recyclables might offset this cost. Revenue for a typical bundle of MSW recyclables (including metals, paper, and glass) was estimated at $140/ton in 1995 but only $45/ton in 1997 (Berenyi 1997). Combining the cost of $142/ton and the 1997 revenue of $45 would result in a revenue loss of $97/ton for municipalities. The composition of recyclables is also important, with aluminum cans commanding revenue more than 10 times that of recycled paper. However, at current price levels, curbside collection programs for most recyclable materials cost more than landfilling and must be justified on environmental grounds.

Separate collection of recyclables is particularly expensive, because each residence is visited twice (Lave et al. 1994). A collection truck that can carry regular MSW and recyclables is preferable, because each residence gets a single pickup. However, trash pickup is likely to become more expensive because the truck will be delayed by any sorting and because it must visit both the landfill and the recycling facility. Because the truck will be collecting trash and recyclables in different compartments, one compartment will fill first requiring the truck to go to the recycling site and landfill even though the other compartment(s) is partially empty. Having recycling compartments that are too big or too small will increase collection costs sharply. Drop-off points can reduce municipal costs but may incur substantial private costs if they require additional driving.

TABLE 1. Average Annual Curbside Recycling Costs in the United States

Curbside recycling (1)	Per household (dollars) (2)	Per ton (dollars) (3)
Avoided MSW disposal cost (savings)	(7)	(31)
Recycling collection	27	123
Avoided MSW collection	0	0
Recycling processing	11	50
Total cost (sum of four categories)	31	142
Revenue from sale of recyclables (1997)	10	45
Net cost after sale of recyclables	21	97

Note: From Ackerman (1996) for costs and Berenyi (1997) for revenue.

DOES MSW RECYCLING HELP THE ENVIRONMENT?

Denison (1996) reviewed several studies of overall environmental impact of recycling MSW, concluding that recycling saved energy and resource inputs. Denison evaluated the bundle of household recyclables rather than each component; he implicitly has the high value components subsidize the low value components. Pearce (1995) found that the net benefit of recycling is not always positive. Our analysis suggests that recycling some of the components (e.g., aluminum) have a much higher potential for recycling than do other materials (e.g., glass). An analysis of environmental externalities for curbside recycling in Milton Keynes, England, also found significant differences in benefits for different components of MSW (Craighill and Powell 1996).

Table 2 gives a direct indication of the environmental benefits of avoided production due to recycling of different commodities. This table summarizes electricity use, fuel use, energy (including electricity and fuels), industrial water intake, some conventional pollutant emissions, global warming potential, toxic air releases, and hazardous waste generation for 1,000 metric tons of different commodity productions. These environmental effects are calculated by tracing all of the economy-wide supply chain requirements for the various commodities using the 500 sector 1992 economic input-output model

TABLE 2. Environmental Effects of 1,000 Metric Tons of Production for Different Commodities—Savings Available from Recycling

Category (1)	Primary aluminum (2)	Blast furnaces and steel mills (3)	Glass containers (4)	Logging (5)
Electricity (kW·h)	21,000,000	1,000,000	100,000	60,000
Fuel use (metric tons)	1,700	850	470	800
Total energy use (TJ)	58	25	2	4
Water intake (gal.)	29,000,000	23,000,000	400,000	600,000
SO_2 emissons (metric tons)	46	27	1	0.9
Particulate emissions <10 μm (metric tons)	1	1.2	0.09	0.02
Global warming potential (metric tons CO_2 equivalent)	4,500	2,200	120	230
Hazardous waste generated—RCRA[a] (metric tons)	110	26	3	7
Toxic air emissions—TRI[b] (metric tons)	2	0.2	0.1	0.5
External cost due to criteria air emissions (dollars)	220,000	11,000	700	8,000

Note: Economic effects are calculated throughout the U.S. economy using the U.S. Department of Commerce's 500 × 500 commodity 1992 input/output model; prices for various commodities typically vary considerably over time and space, and assumed prices for these calculations are $135/ton for blast furnace and steel mills, $1,500/ton for aluminum, $50/ton for glass, $300/ton (or $500/thousand-board-ft) for logs. See EIOLCA 99.

[a]RCRA = Resource Conservation and Recovery Act.

[b]TRI = Toxics Release Inventory.

developed by the U.S. Department of Commerce coupled with ancillary environmental impact calculations (Horvath and Hendrickson 1997; Hendrickson 1998a; EIOLCA 1999). For example, toxic air emissions are computed by multiplying the level of activity in each of the 500 commodity sectors by the average level of toxic air emissions per dollar of output. These calculations show an upper bound on savings from recycling by avoiding this primary production; the figures are an upper bound because the resource costs of recycling are not included.

The final row in Table 2 represents a rough estimate of the external environmental costs of this production. It is based upon estimates of the social costs from air emissions of conventional pollutants (Hendrickson et al. 1998b; Matthews 1999). Chung and Poon (1997) and Craighill and Powell (1996) also made estimates of such external costs, for Hong Kong and the United Kingdom, respectively. Included in these costs are the estimated health effects related to ozone, particulate, and other conventional or "criteria pollutants." The estimates are reported in thousands of social cost dollars, and so a metric ton of primary aluminum is estimated to have an external environmental cost due to air emissions of $220 (Table 2). Comparing this number to the estimated cost of collection ($142/ton), aluminum appears to be a good candidate for recycling, even without counting the economic costs of producing a ton of aluminum.

Our calculations find that avoiding primary aluminum production has the greatest environmental benefit. Recycling aluminum is generally profitable because of the high price for this scrap. Ferrous metals and logging have intermediate benefits. Avoiding additional glass production has relatively small environmental benefits for the various categories of environmental emissions we analyzed, particularly because the numbers for glass are overestimates since they include the final container processes that would also be incurred for recycled glass.

A full analysis of the environmental effects would also include the environmental effects associated with collection, sorting, and processing of recycled materials. These processes require capital equipment (particularly trucks) and the use of energy (for truck operation and sorting).

POLICY TEST FOR RECYCLING

Should materials be recycled or put in a landfill? The question can be answered with the economic-environmental criterion.

One form of the economic-environmental criterion is that faced by companies. What should be done with the waste generated by a manufacturing plant, service center, or office? The company would like to reduce its costs and so calculates whether recycling is less costly than disposal. Consider, for example, a stamping plant that turns out steel parts for automobiles, generating large quantities of steel scrap. This "prompt scrap" is of high quality and commands a relatively high price. Automobile companies would laugh at the idea of paying to landfill this scrap steel, because they get paid handsomely to recycle it. Similarly, many companies find that recyclers will pay high prices for their scrap office paper.

A well-run company will recycle waste if it costs them less than disposing of it; they should separate and collect the valuable materials for recycling and dispose of other materials. This means that the market prices of scrap, landfill costs, and separating and transport costs determine whether "waste" is recycled or landfilled. Thus, the first form of the economic-environmental criterion is to recycle only if the cost of collection and separation is less than the cost of collection and disposal. An environmentally conscious company might decide to do more recycling than is implied by the economic-environmental criterion. However, as markets get more competitive, companies are forced to cut "unnecessary" expenses, but the companies need to be careful that the additional unit recycled actually reduces environmental discharges and materials use.

This "private" form of the economic-environmental criterion squarely faces the realities of companies. They are driven by costs. They will recycle materials where the costs of collection plus the tipping fee is greater than the cost of collecting and sorting the recyclables less the revenue from selling the recycled material. Although many companies would like to do well, they are severely limited by competition or current budgets.

Cities face tight budgets as well but may adopt a modification of the private rule. For a municipality, the economic-environmental criterion is modified slightly: The city seeks not only to minimize its costs, it also seeks to avoid local environmental nuisances. This means that a city might choose an alternative that is somewhat more expensive, if this avoided a nuisance.

Recycling only those materials that satisfy this first form of the economic-environmental criterion is not fully satisfactory in protecting the environment or working toward a sustainable future. If there are externalities associated with extracting resources, landfilling, or sorting recyclables, or if there is a lack of foresight in managing resources, the private costs that are faced by companies or cities neglect important dimensions of the MSW decision. For example, the regulations governing landfills might be inadequate, leading to future environmental degradation. If so, the price of landfills will be "too low," and landfilling will damage environmental quality. The obvious remedy is to change the landfill regulations so that environmental quality will not suffer. Similarly, society may give too little weight to the needs of future generations for raw materials. If so, raw materials will be priced too low, and companies will choose to do too little recycling. An obvious remedy is to impose a tax to increase the prices of raw materials so that more will be saved for future generations.

Another example might be inadequate environmental regulations associated with mining coal, which is then used in producing aluminum and steel. If so, the cost of producing steel and aluminum would be too low, discouraging recycling of these materials. An obvious remedy is to improve environmental regulations concerning coal mining. Mandating steel and aluminum recycling decreases the amount of coal that is mined, but the coal is still mined in a way that damages the environment.

Still, another example might be the profligate use of fossil fuels leading to greenhouse gas emissions. If recycling is more energy efficient, low recycling rates lead to "too much" greenhouse gas emissions. The externality could be internalized either by a fee on greenhouse gas emissions (making production of virgin materials more expensive) or a cap on the total emission of greenhouse gases, which would mean the production of virgin materials was "inadequate" for the needs of the economy, thereby increasing the price of recycled materials. Generally, the externalities can be accounted for by having regulatory agencies give direct orders to firms and consumers that internalize the externalities. However, in an economy as large and complicated as that of the United States, regulatory agencies do not have the knowledge or personnel to figure out what actions will internalize the externalities. An alternative is to use the market system by imposing taxes to account for the externality. The use of market incentives has greatly reduced the cost of achieving such environmental objectives as reducing the emissions of sulfur dioxide to prevent acid rain and the emissions of chlorofluorocarbons to prevent the destruction of stratospheric ozone (Schmallensee et al. 1998).

The second form of the economic-environmental criterion, the "public" formulation, is to internalize all important externalities in prices or regulations so that prices and practice reflect the full environmental costs associated with each action, including the availability of resources for future generations. Once this is done, the private form of the recycling policy prescription becomes an accurate social formulation of the right decisions. Once the important externalities have been controlled or internalized, materials should be recycled only if the cost of collection and separation, less the revenue from selling the recycled material, is less than the cost of collection plus the tipping fee. The private version of the economic-environmental criterion helps to understand current recycling behavior. The social version of the economic-environmental criterion helps to guide us toward the best social policy.

Does this social version of the economic-environmental criterion help sustainability? It requires society to examine the need of future generations for resources and to satisfy this need either by explicitly preserving some resources for future generations or by raising the prices of raw materials through a "sustainability" tax. Such a tax may not be needed for metals and other durable resources. Because landfills simply store these materials, they are available whenever society decides to "mine" them.

For fossil fuels and other depletable resources, there is little alternative to explicitly examining the needs of future generations. This analysis is difficult because technology changes and the tastes of future generations are likely to change. For example, planting oak trees in the past to enable the current generations to have masts for sailing ships has not proven to be much of a boon. The technology for energy production has been changing rapidly. It is hard to know what future generations will desire and how much energy they will need to provide a lifestyle that they will find at least as good as the current generation finds its lifestyle.

CONCLUSIONS: IS MSW RECYCLING THE BEST POLICY?

The goal of MSW recycling programs should not be to increase MSW recycling. The goal should be to increase environmental quality and the sustainability of the economy. Our hopes concerning MSW recycling must be tempered by the economic-environmental criterion: Recycling will benefit the environment and sustainability only if the energy, resources, and environmental discharges associated with recovering the material are less than those associated with producing virgin material. Curbside recycling of postconsumer metals can save money and improve environmental quality if the collection, sorting, and recovery processes are efficient. Curbside collection of glass and paper is unlikely to help the environment and sustainability save in special circumstances.

Some alternative policies also deserve consideration as MSW recycling options. Deposit/refund schemes offer an important option. In these systems, products earmarked for recycling would require a consumer (or producer) deposit, with a refund to the consumer when they are returned. For example, each return of a nickel-cadmium battery would receive a refund sufficient to make it attractive to undertake the return. Aluminum cans and metal scrap are sufficiently valuable that "trash pickers" routinely search for these postconsumer wastes even without deposit/refund schemes. An advantage of these deposit/refund schemes is that products and materials can be individually targeted for removal from the MSW stream. Palmer et al. (1997) concluded that deposit/refund schemes can be more efficient at waste reduction than recycling subsidies. Although deposit/refund systems can recover the vast majority of the product, the energy and resources required could be large. For example, if consumers make a special trip to return the recoverable materials, the energy required is likely to exceed the energy saved by recovery.

Another policy that can be beneficial is product takeback by manufacturers, particularly when remanufacturing and reuse is available (Klausner 1998). This option attempts to preserve the value of the original goods. In contrast, recycling seeks to recover only the value of the raw materials. Product takeback for small appliances, such as handtools, might have significant benefits. In particular, the raw material value of most complicated products such as computers is only a small fraction of the product value. Also, manufacturers would have incentives to alter designs to make remanufacture and use more effective.

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APPENDIX. REFERENCES

Ackerman, F. (1997). "Recycling: Looking beyond the bottom line." *BioCycle*, May, 67.
Berenyi, E. B. (1997). "Materials recovery facilities: A 1997 update." *BioCycle*, September.
BioCycle. (1998). "The state of garbage in America." *Annu. Rep., BioCycle*, 39(4), 32–43.
Craighill, A., and Powell, J. C. (1996). "Lifecycle assessment and economic evaluation of recycling: A case study." *Resour., Conservation and Recycling*, 17, 75–96.
Chung, S.-S., and Poon, C.-S. (1997). "Quantifying externalities in solid waste management in Hong Kong." *J. Envir. Engrg.*, ASCE, 123(3), 282–289.
Denison, R. A. (1996). "Environmental life-cycle comparisons of recycling, landfilling and incineration: A review of recent studies." *Annu. Rev. of Energy and the Envir.*, 21, 191–237.
"Documents to aid measurement of recycling." (1999). Environmental Protection Agency, ⟨http://www.epa.gov/epaoswer/non-hw/recycle/recmeas/document.htm⟩.
EIOLCA. (1999). ⟨http://www.eiolca.net/⟩.
Facing America's trash: What next for municipal solid waste? (1989). Ofc. of Technol. Assessment, GPO, Washington, D.C.
Garrick, L. (1998). "Economics and environmental costs and benefits of recycling post-consumer waste: A systems view." Green Design Initiative Bibliography, Carnegie-Mellon University, Pittsburgh.
Goldstein, N., and Glenn, J. (1997). "The state of garbage in America." *BioCycle*, May, 71–75.
Haith, D. A. (1998). "Materials balance for municipal solid-waste management." *J. Envir. Engrg.*, ASCE, 124(1), 67–75.
Hendrickson, C., Horvath, A., Joshi, S., and Lave, L. B. (1998a). "Introduction to the use of economic input-output models for environmental life cycle assessment." *Envir. Sci. and Technol.*
Hendrickson, C., Horvath, A., and Matthews, H. S. (1998b). "External environmental costs of transportation equipment, materials and services." *Tech. Rep.*, Green Design Initiative, Carnegie-Mellon University, Pittsburgh.
Horvath, A., and Hendrickson, C. T. (1998). "A comparison of the environmental implications of asphalt and steel-reinforced concrete pavements." *Transp. Res. Rec.*, Transportation Research Board, Washington, D.C.
Huysman, M. (1994). "Waste picking as a survival strategy for women in Indian cities." *Envir. and Urbanizations*, 6(2), 155–174.
Klausner, M. (1998). "Design and analysis of product takeback systems: An application to power tools," PhD dissertation, Carnegie-Mellon University, Pittsburgh.
Lave, L., Conway-Schempf, N., Harvey, J., Hart, D., Bee, T., and MacCracken, C. (1998). *J. Industrial Ecology*, 2(1), 117–126.
Lave, L. B., Hendrickson, C. T., and McMichael, F. C. (1994). "Recycling decisions and green design." *Envir. Sci. and Technol.*, 28(1), 18A–24A.
Louis, G. (1996). "Regional integrated solid waste management in the Northeastern United States," PhD thesis, Carnegie-Mellon University, Pittsburgh.
Matthews, H. S. (1998). "An analysis of the economic effects of environmental externalities." *Tech. Rep.*, Green Design Initiative, Carnegie-Mellon University, Pittsburgh.

OECD. (1996). "Extended producer responsibility in the OECD area." *Phase 1 Rep., Working Papers No. 66*, Organization for Economic Cooperation and Development, Paris.
Palmer, K., Sigman, H., and Walls, M. (1997). "The cost of reducing municipal solid waste." *J. Envir. Economics and Mgmt.* 33, 128–150.
Pearce, D. W., and Turner, R. K. (1993). "Market-based approaches to solid waste management. *Resour., Conservation and Recycling*, 8(1–2), 63–90.
Rathje, W., and Murphy, C. (1992). "Rubbish! The archeology of garbage," *Harper Perennial*.
Schmalansee, R., Joskow, P. L., Ellerman, A. D., Montero, J. P., and Bailey, E. M. (1998). "An interim evaluation of sulfur dioxide emissions trading." *J. Economic Perspectives*, 12(3), 53–68.
Statistical abstract of the United States. (1998). 1998 Ed., Bureau of the Census, (http://www.census.gov/prod/3/98pubs/98statab).
Tierney, J. (1996). "Recycling is garbage." *New York Times Mag.*, June 30.