SALVAGING THE FUTURE: WASTE-BASED PRODUCTION

INSTITUTE FOR LOCAL SELF-RELIANCE

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To
David Morris,
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The INSTITUTE FOR LOCAL-SELF RELIANCE (ILSR) is a non-profit research and educational organization, providing technical information and assistance to city and state governments, citizen and neighborhood organizations, and industry. ILSR has been dedicated since 1974 to providing those people adversely affected by decisions surrounding energy and waste with the information they need not only to understand the issues but to develop alternatives.

ILSR works extensively in urban areas, focusing on energy and waste utilization for community economic development. Our philosophy is guided by the principle that, by joining technical ingenuity with a sense of community, cities can once again become models of independent economic development. This entails a new vision of a city, one that seeks to extract the maximum amount of value from local resources, be they people or money or materials. By considering the by-products of any one process as the feedstock for another, cities can overcome structures that encourage wasted materials and wasted energy, and encourage instead sustainable, environmentally benign forms of consumption and production.

ILSR has been investigating the possibilities of self-reliant communities by studying examples of closed-loop manufacturing, materials recovery, energy efficiency, and small-scale production. In so doing it has uncovered patterns of development: communities that mine their waste streams for materials and export the knowledge they develop, communities that track their flows of resources and restructure them more efficiently, communities that stimulate the creation of jobs and simultaneously create their own end-markets. These communities maximize the value inherent in their own resources.

ILSR presents a vision of self-reliant cities and provides the hard numbers to support that vision. Salvaging the Future: Waste-Based Production is part of an ongoing series of technical reports prepared by ILSR staff. For more information on ILSR philosophy and practice, write:

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This book is printed on minimum impact paper. The production of this paper, which contains a large percentage of post-consumer waste, uses less water and fewer chemicals than the production of most other recycled papers. The wastepaper is not deinked or bleached, so the clays and inks are not discharged into the environment and are incorporated into the new paper.

Abbreviations

ABS	acrilonitryle-butadiene-styrene
API	American Paper Institute
B.O.D.	biological oxygen demand
EPA	Environmental Protection Agency
EPRI	Electric Power Research Institute
GNP	gross national product
GPI	Glass Packaging Institute
GRI	Gas Research Institute
HDPE	high density polyethylene
ILSR	Institute for Local Self-Reliance
IPC	intermediate processing center
ISRI	Institute for Scrap Recycling Industries
kWh	kilowatt hour
lb	pound
LDPE	low density poloyethylene
MMBtu	million British Thermal Units
MRF	Materials Recycling Facility
O&M	operating and maintenance
PET	polyethylene terephthalate
PP	polypropylene
PPI	producer price index
PS	polystyrene
PVC	polyvinyl chloride
RCS	rigid container stock
SPI	Society for the Plastics Industry
TPD	tons per day
TPY	tons per year
UBC	used beverage container

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We would like to reassure all those mentioned above that the responsibility for the book is only ours.

BEYOND COLLECTION

INTRODUCTION

Every year Americans throw out more than 100 million tons of nonperishable trash, most of which is buried in landfills. Yet that trash contains at least 78 million tons of recyclable materials: 50 million tons of paper, 12 million tons of glass, 11 million tons of plastics, and 5 million tons of aluminum. Recycling these materials could reduce our consumption of energy and virgin resources, reduce our environmental pollution, create new sources of government revenue, and expand local employment in many communities.

Using a hypothetical American city of one million people, this report presents a detailed analysis of the costs and benefits of recycling the mountains of trash that we throw away each year.

Recycling is no longer an afterthought in waste management. Cities and states that only a short while ago predicted that they could recycle 10-20 percent of their municipal solid waste (MSW) have now set goals of 25, 30, and even 50 percent, and are striving higher. Such high materials recovery goals lead inevitably to the question: "What can one do with these materials?" Today they are shipped abroad. The single largest export from the Port Authority of New York is scrap paper, and the second is scrap steel. This practice means that American cities and towns depend on foreign markets to dispose of their recyclable waste. Reduced waste exports create crises for collection programs in the United States. Cities must burn or put in landfills materials that could be recycled.

When America's cities ship their waste overseas, they deny themselves the benefits of processing abundant locally available materials. They become classic colonies, exporting their raw materials and importing finished goods. Processing adds value to a material. It also adds jobs and income to the local economy. Today, these benefits accrue not to the cities that generate the materials, but to the countries that import the waste. For example, a ton of loose waste office paper can be sold for $30. Bale the paper and the market price rises to $150. Pulp the paper and the price reaches $570. Convert the pulp into writing paper and the price can climb to $920 per ton.

Of course, some of the finished products' value is attributable to invested capital. A glass processing machine that turns old bottles into a substitute for virgin material costs half a million dollars and contributes $50-70 per ton to the value of the reprocessed product. The glass plant that turns the old bottles into new bottles costs $10-12 million dollars and adds more than $250 per ton.

Each stage of processing increases the economic benefits of recycling. Large capital investment in plant and equipment often means that the highly skilled workers who operate the plant will receive high wages. A worker in a paper mill earns more than a recycler collecting office paper. The paper mill buys more supplies such as electricity or accounting services than does the intermediate processor or initial gatherer of materials, and these purchases in turn create further jobs in the local economy. Manufacturers may also have a research and development budget, especially in such a rapidly evolving field as scrap processing. This means hiring engineers and scientists and developing patentable knowledge which itself adds value to the local economy. Italian and West German recycling manufacturers, encouraged to innovate by tax incentives and abbreviated paperwork, now export technology licenses to the United States.

The benefits aren't exclusively economic. Using secondary materials for production increases efficiency at a global level by reducing mining and manufacturing waste, diminishing air and water pollution, and conserving energy and natural resources. Scrap-based industries also help to reduce the need for expensive and dangerous forms of disposal.

The local manufacturer with access to plentiful supplies of low-cost raw materials gains a competitive advantage in the same way that a manufacturer with access to low-cost labor or low taxes does. The advantage is compounded by the manufacturers' proximity to both materials and markets, reducing transportation costs to a smaller fraction of the final cost of the goods. This makes scrap-based industries strong economic competitors. Production based on the variety of materials contained in waste diversifies local economies, lessening the effects of economic swings in a particular manufacturing sector.

One reason cities and regions have not yet fully investigated the possibilities of scrap-based manufacturing is that they have not been recovering large volumes of materials. Minnesota's Twin Cities, for example, with 2.2 million people, generated about 2.5 million tons of garbage in 1985 and recovered only 250,000 tons of a possible 2 million tons of usable materials. These materials would be sufficient to support local processing and manufacturing plants. But until cities actually recover their waste, manufacturers will be unlikely to establish plants that use these materials. Dozens of companies that process waste into usable materials established facilities in Pennsylvania and New Jersey after recycling became mandatory in these states.

THE APPROACH

We focus on a hypothetical city of one million, and assume that this city will sort as much of its waste as possible for recycling. How can this city maximize the value of its waste materials? Which of its material needs can this city meet by recycling its waste?

We examine four different industries to answer this question. Which products are now made of recycled materials? Could the waste of a city of one million sustain production of these goods?

In three of the four industries we studied, the city's factories would be smaller than typical recycling facilities. In these industries, the city's extensive recycling would therefore create a new manufacturing structure. In the final section of the book we examine what this structure might look like.

In order to effectively provide a city's materials through recycling, entrepreneurs would have to establish recycling facilities. For each industry, we recommend factory characteristics that fall into three different categories determined by raw materials and end products. The different categories are determined by how close the factory would come to closing the loop.

In Table 1, Recycling Categories, we explore the different levels of recycling and their impact on reducing the need for virgin raw materials.

In the first category, waste materials are re-manufactured into the same materials, reducing the need for imports of virgin materials. Every ton of recycled glass replaces a ton of virgin glass. Approximately 80 percent of paper, 95 percent of glass, less than 1 percent of plastics, and 95 percent of aluminum can be recycled into their original form. At

In most cases, we recommend that the city implement a recycling program that separates materials at the source of generation. This source separation will help ensure that the materials gathered are as free as possible of contamination.

Our appendices include background information on the manufacturing processes that are discussed in the main chapters. This information is meant to supplement the reader's knowledge of the technologies necessary for recycling.

RECYCLING AS WASTE DIVERSION

If a city of one million were to collect all of the paper, plastics, glass, and aluminum in the waste stream it would reduce its solid waste by 50 percent and generate 347,500 tons of raw materials for manufacturing each year. Table 2, Total Solid Waste Generated by a City of One Million in 1987, combines estimates of MSW with estimates of waste materials normally excluded from municipal calculations, such as components of cars, airplanes, and buildings. Materials available for the city are derived from national averages. Recycling all of the materials included in this study would consume 55 percent of the weight of solid waste. Total recycling of wastepaper alone would reduce solid waste by almost 40 percent.

Judging the composition of MSW is an inexact science and there is some controversy as to the total amount of MSW generated and as to the breakdown of that waste; these issues are discussed in Appendix 1. General conclusions about the benefits of recycling can, however, be drawn from available estimates of solid waste composition.

Table 2:

Tons of Solid Waste Generated by City of One Million in 1987

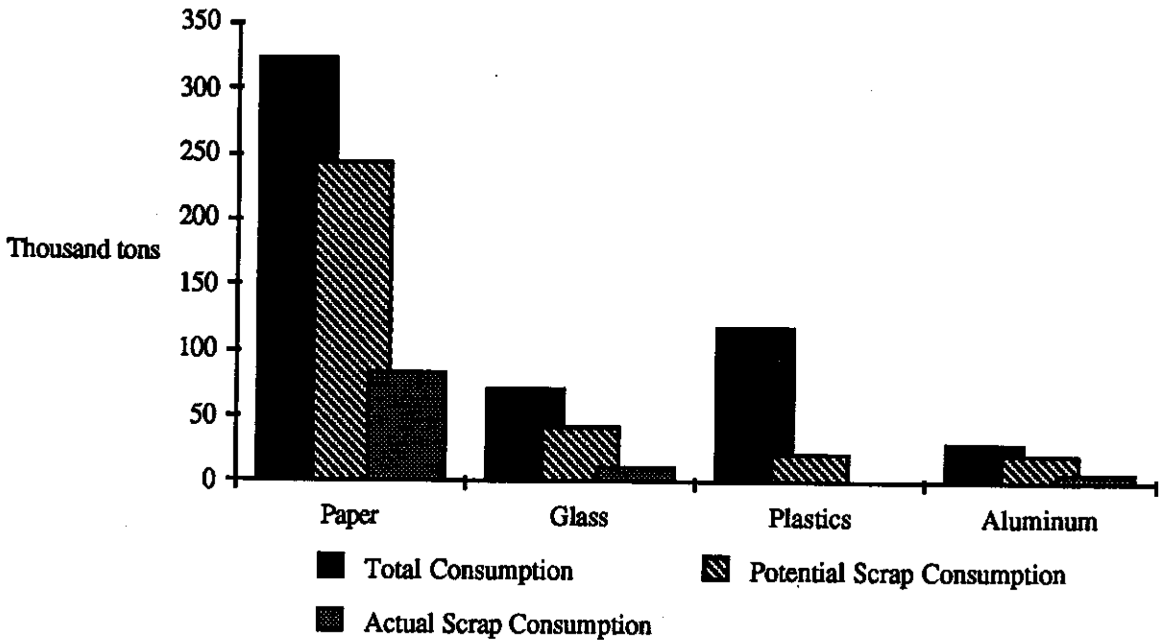
	City	Percent
Paper	245,000	35.8
Yard Waste	170,000	24.8
Ferrous	83,000	12.1
Other	65,000	9.5
Glass	54,000	7.8
Plastics	46,000	6.7
Aluminum	22,810	3.3
TOTAL:	686,300	100.0

Source: Franklin Associates, Characterization of Municipal Solid Waste, and figures from different materials chapters on how much waste is available.

With the exception of plastics, slightly more than 20 percent of these materials are presently recycled. The potential for recycling is obviously much higher. More than 70 percent of the paper, glass, and aluminum consumed in this country could be made from secondary (recycled) materials. Figure 1, Scrap and Virgin Inputs for City's Consumption, compares the actual and potential levels of recycling to the total consumption of materials in a city of one million inhabitants. The difference between the city's consumption of finished goods and the scrap that is potentially available for recycling is made up by virgin supply.

Figure 1:

Recycling for a City of One Million



The demand for materials limits the level of recycling. When the demand drops, U.S. recycling suffers. The amount of wastepaper collected has risen sharply over the last 10 years, yet domestic remanufacturing has not kept pace. Now, cities and states export more and more of their wastepaper. American recyclers depend on export markets to absorb increased waste materials. But these markets are limited.

RECYCLING AS MORE THAN WASTE DIVERSION

These foreign markets also benefit from the value added to the materials in processing. In order for the city itself to capture this value, it needs local manufacturers to process the materials into finished goods. Because transportation adds to the cost of scrap materials, local production can optimize the benefits of recycling. Table 3, Benefits of Local Production, charts the number of plants that could be supported by our hypothetical city and the benefits that would result directly from their establishment. Information for the table is drawn from the estimates made in each of the chapters. These plants would divert 50 percent of the waste destined for disposal. Their operation would provide for almost

1,500 jobs. Sales of the products from these plants could add more than $250 million to the local economy each year.

Table 3:
Benefits of Local Production

Product	Number of Plants	Tons Waste Diverted	Percent Waste Diverted	Number of Jobs	Value Added
Paper:					
Printing and Writing paper	1	60,000	9	170	$81,487,000
Tissue	1	50,000	7		
Newspaper *	1	50,000	7	170	$38,264,000
Paperboard	3	85,000	12	270	$45,426,000
Glass					
Containers *	1	51,000	7	100	$24,707,000
Plastics:					
Granulate	28			250	
Pellet	11			240	
Molded goods	12			240	
Subtotal:	51	33,000	5	730	$65,885,000
Aluminum:					
Cans	1	5,500	1	15	$27,452,000
Siding	2	13,000	2	20	
Total:	**61**	**347,500**	**50**	**1,475**	**$256,936,000**

*These plants operate on 50 percent scrap materials.

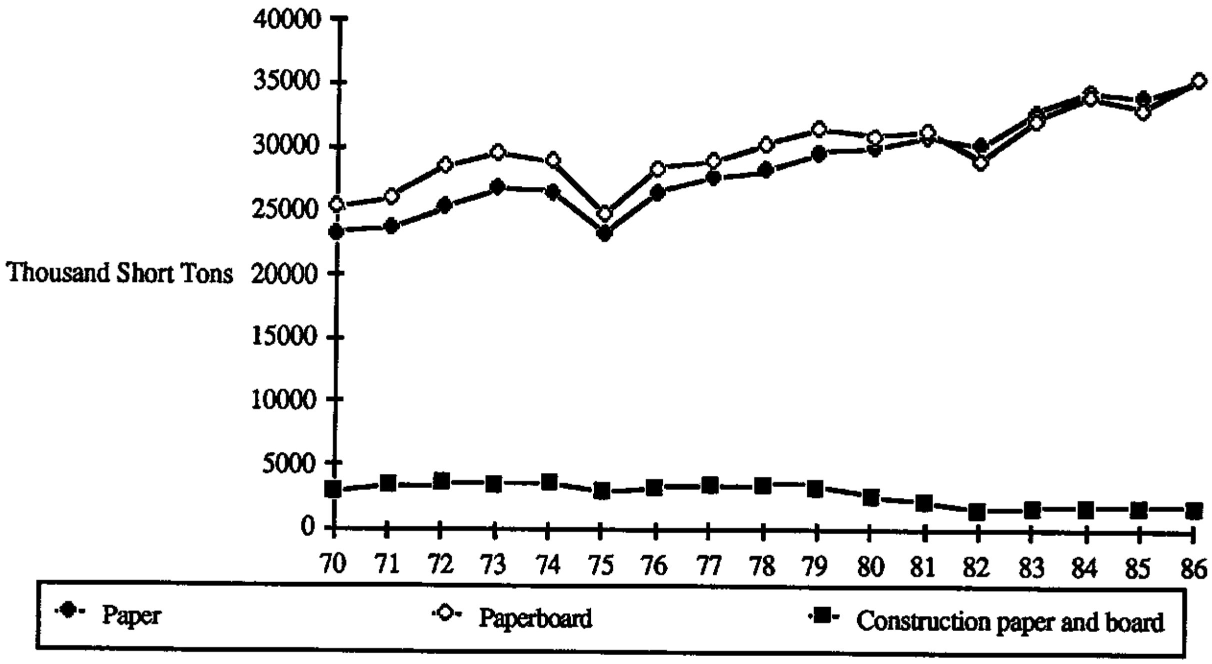
PAPER

INTRODUCTION

There are more than 70 different subcategories of paper, defined as a mesh of vegetable fibers. It can be grouped into seven major end uses: printing and writing papers, newsprint, tissue, packaging papers, containerboard, boxboard, and construction paper and board.

Recent trends in paper consumption are shown in Figure 2, Consumption of Paper Products. The following section focuses on the segments of the paper industry that are expanding. Overall, domestic demand for paper products is expected to climb by 2.5 percent annually over the next 5 years.[1] This growth rate holds for both paper, which is thin and mostly used for communication, and paperboard, which is somewhat thicker and more commonly used for packaging. The only segment of the paper industry that is shrinking is construction paper and board, and it is therefore not analyzed in this section.

Figure 2:
Consumption of Paper Products
1970-1986



Source: American Paper Institute

The markets for most paper products depend on those of other products. For example, the market for newsprint depends on the demand for advertising, which is directly related to the strength of the economy. Advertising accounts for anywhere from 60 to 80 percent of a newspaper's revenue.[2] When people buy goods and services, retailers and employers advertise in newspapers, newspapers carry more pages, and newsprint mills run at capacity.

Establishing small-scale recycled paper mills that consume locally available wastepaper will lessen the city's dependence on distant markets for its wastepaper. In addition, in some cases, recycled paper production costs less than production based on wood pulp. Unfortunately, despite increased collection, wastepaper continues to provide only a quarter of the fiber used by the domestic paper industry. In the past the use of wastepaper fiber in the paper industry has been limited by fluctuations in the quantity and quality of the collected wastepaper.

This limitation can be largely overcome by source separation of wastepaper. Grades that are separated are easier to recycle because they have similar characteristics. At the least, our hypothetical city can collect printing and writing paper, newspaper, and cardboard.

Table 4, Tons of Secondary Paper Available for a City of One Million in 1987, compares the tons of secondary paper available to the total consumption of the selected grades. If all the secondary paper in a city of one million were collected and recycled it would provide approximately 72 percent of the fiber consumed by the city's inhabitants. Consumers discard newspapers shortly after reading. Discarded newspapers could therefore provide almost all of the fiber needed to produce new newspapers for the city. The paper industry classifies magazines, books, and junk mail, as well as stationery and business forms, as printing and writing paper. Consumers discard some grades of this paper directly after use. Other grades are archived or made into books. Discarded printing and writing paper accounts for approximately 75 percent of the fiber the city would need to make more printing and writing paper. Industrial scrap, waste created in the production process, would provide approximately 5 percent or 17,000 tons of the necessary fiber for paper for a city of one million.

Table 4:
Tons of Secondary Paper Available
for a City of One Million in 1987

	Tons available	Percent of consumption
Newspaper	57,110	95%
Printing and writing paper	82,310	73%
Paperboard	89,070	62%
Industrial scrap	17,000	5%
Total:	**245,490**	**72%**

Source: Based on Paper, Paperboard & Wood Pulp Monthly Statistical Summary, vol. 66, No. 10, American Paper Institute, October 1988; Generation of Recyclable Paper.

This wastepaper would provide enough raw materials to establish six separate mills:

- A 150-ton-per-day newsprint mill consuming old newspapers
- A 200-ton-per-day printing and writing paper mill consuming 50 tons per day of pre-consumer waste and 150 tons per day of post-consumer printing and writing paper
- A 100-ton-per-day tissue mill consuming post-consumer printing and writing paper
- A 100-ton-per-day corrugating medium mill consuming paperboard
- A 100-ton-per-day linerboard mill consuming paperboard
- A 85-ton-per-day containerboard (for example, cereal boxes and notebook backing) mill consuming 20 tons of newspapers and 65 tons of paperboard.

Each of these mills is dependent on further markets for its materials. For example, the newsprint mill must find a newspaper publisher that is willing to print on its product. The printing and writing paper must be bought by printers and offices.

Estimates of the capital cost per rated daily ton for recycled paper mills range between $275,000 and $675,000. A rough estimate for the combined capital costs for the city's mills therefore ranges between $200 and $500 million.

INCREASED COLLECTION AND EXPORTS

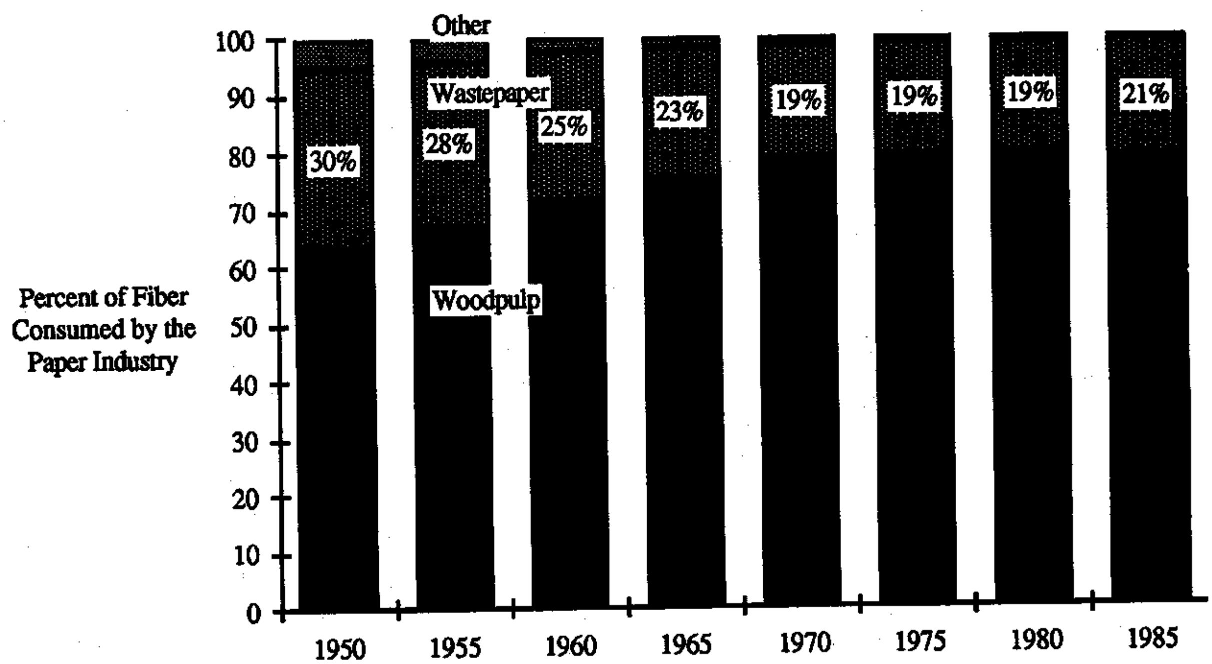
In an effort to reduce their waste streams, a growing number of states and cities now mandate collection of recyclable materials. Estimates of paper's contribution to waste range from 30 to 50 percent; diversion of paper can significantly reduce discards. At least five states have enacted recycling legislation that mandates collection of newspapers and cardboard, and three states also encourage the collection of high-grade office paper.[3] This expansion of collection has already glutted the market for recyclable newspapers in some areas of the country.[4]

This glut is also in part a consequence of a relatively low wastepaper utilization rate, which measures mills' consumption of wastepaper as a percentage of total production.

Wastepaper utilization has declined significantly since the 1950s (see Figure 3, Fiber Sources for U.S. Paper Production). Just a little more than 25 percent of the paper that is currently made in the United States is made of recycled fiber. Wastepaper utilization rates for paper and paperboard are 13 and 32 percent respectively. The overall global wastepaper utilization rate is slightly higher than 30 percent. Compare this to Denmark, where 77 percent of the fiber used in the paper industry comes from wastepaper. Or compare this to Spain and the United Kingdom, both of which produce paper made of more than 50 percent recycled content. Or to Taiwan, which had a wastepaper utilization rate of more than 80 percent in 1987. These figures indicate that higher utilization rates can be achieved.

Figure 3:

Wastepaper Consumption in the Domestic Paper Industry



Source: Based on Alice Ulrich, U.S. Timber Production, Trade, Consumption, and Price Statistics 1950-86, U.S. Forest Service, Washington, D.C., June 1988.

Wastepaper, like other secondary materials, is divided into pre- and post-consumer components. Pre-consumer or new scrap consists of deinking grades, or pulp substitutes. These are the preferred grades because they contain a lower proportion of contaminants be combined with any other kind of paper from magazines to tissue boxes. Because of the relatively high quality of office paper, it is most commonly recycled into tissue and writing paper products. Relatively few printing and writing paper mills in the United States are equipped to utilize secondary paper of any kind, except for pulp substitutes. Only eight of the more than 170 mills that produce writing paper have the deinking equipment that is necessary to recycle waste office paper into new office paper.[6] Most of this post-consumer grade is recycled into tissue products.

Table 5:
Wastepaper consumption in Printing and Writing Paper and Tissue Production in 1986

Type of wastepaper	Printing and writing paper		Tissue	
	1,000 tons	Percent	1,000 tons	Percent
Wastepaper consumed				
Mixed Paper	0	0	77	1
Newspapers	0	0	190	3
Corrugated	15	0	222	4
Deinking	306	2	946	19
Pulp Subs	688	3	641	14
Total	1,009		2,076	
Total Production	19,668		5,095	
Wastepaper as % production		**5**		**41**

Source: Based on U.S. Environmental Protection Agency, "Minimum Recovered Materials Content in Paper and Paper Products Procured by the Federal Government," updated with API statistics.

Secondary paper plays a much more significant role in the production of tissue paper than it does in printing and writing paper. Post-consumer wastepaper represents less than 2 percent of the fiber consumed in printing and writing paper production. Objections to the use of post-consumer paper in printing and writing paper center around the need to control the quality of incoming fibers. Post-consumer office paper may be included with inappropriate grades of paper or types of ink and glue, not to mention cigarette butts and banana peels. Recycled tissue mills, however, are more willing to use post-consumer grades such as office paper and computer printouts.[7] Post-consumer paper represents as much as 28 percent of the fiber used in recycled tissue mills.

It has been has been estimated that in 1987 more than 7 million tons of high-grade office paper were generated and were at least theoretically available for recycling in either mixed paper or deinking grades.[8] Yet U.S. mills used less than one fifth of this potentially valuable resource. The hypothetical city might target this portion of its waste and this kind of mill as a means of increasing its ability to recycle.

WHY RECYCLE?

If these materials were retained in the local community the value added by processing would benefit the community. Table 6, Prices of Wastepaper at Various Stages of Production, represents the prices that were offered at the various stages of production for some common grades of wastepaper and their end products in the fall of 1988. At each stage value is added that translates into increased employment and purchases. Profitable recycling operations encourage the establishment of ancillary businesses to attend to the needs of the workers as well as of the business itself. This impact can be roughly measured by the difference in value between the stages.

Table 6:

Prices of Wastepaper at Various Stages of Production

	Waste	Scrap	End product	Converted
Mixed Paper	nominal	$10-15		
Corrugated	$5-10	$50-60	$440-460	
Newspapers	$0-5	$0-50	$545-555	
White Ledger	$30-40	$180-185	$920	$1700

Source: Based on prices from Fibre Market News, Pulp and Paper Week, and Conservatree Paper Company.

So far we have evaluated the paper industry's utilization of wastepaper as a disposal strategy, looking at the available wastepaper and at the value that may be added to a material that was previously considered a cost to the community. What happens when we look at recycling as a strategy for production? How, in fact, does waste-based paper compare with virgin paper? We find that selected cost variables are in some cases lower for recycled paper products, while they are somewhat higher in other cases, most notably in the printing and writing paper grades.

Table 7, Operating Costs for Virgin and Recycled Paper Production, presents an analysis of the cost of producing recycled paper must take into consideration the operating costs. Of these the most significant is the cost of the raw material. The estimates in this study are based on the following assumptions:

- A mill consumes either wastepaper or pulp wood
- Pulp wood costs $45 per ton
- Wastepaper prices vary according to the paper used
- Labor costs reflect industry averages for the paper and paperboard industries
- Natural gas provides the needed energy at a cost of $3.75 per MMBtu
- Energy use reflects engineering estimates used in Franklin Associates, Proposed Recycling Targets.

These estimates are necessarily limited by lack of information about certain important costs. For example, purchases of chemicals and other additives contribute significantly to final costs. The costs of these purchases are difficult to calculate because each mill uses different mixes of chemicals and additives depending on the final product and whether or not the process uses an acidic or alkaline water. In some cases, the addition of recycled fiber reduces the cost because less labor is required for secondary fiber processing than for virgin pulping.[9] Many printing and writing paper mills don't pulp their own wood and some pulps sell for more than $800 per ton.[10] Therefore, the raw material costs for virgin writing paper may be much higher than the estimate below. Recycled paper's generally higher fuel costs reflect the cost of purchasing energy. However, as outlined in Appendix 2, Paper Processing, recycled paper production can save as much as half the energy required to produce paper from wood. In addition, in many cases recycling reduces raw material needs by almost 75 percent.

Table 7:
Operating Costs for Recycled and Virgin Paper Production

	Linerboard		Writing paper	
	Virgin	Recycled	Virgin	Recycled
Operating Costs				
Raw material	$176.40	$148.20	$171.90	$187.20
Labor	$61.39	$61.39	$154.29	$154.29
Fuel	$25.61	$60.00	$53.44	$68.51
Total	$263.40	$269.59	$379.63	$410.00

In fact, paper industry data indicate that the amount paid for all materials used in the manufacture of paper is approximately 41 percent of the value of the final product. This suggests that other materials such as sizing, clay, and other additives introduced in the paper manufacturing process are a significant expense. The 41 percent figure includes transportation costs. Aggregate industry figures show that chemicals and transportation each represent approximately 12 percent of the total value of shipments.

The city benefits from having a local recycling capacity. Such facilities ensure markets and increase employment. In some cases these facilities face higher costs than facilities that produce virgin paper. Some cities and states have recognized these costs and encourage the establishment of recycling facilities through tax incentives and sharing the funds saved in reduced waste disposal costs. Other localities have established programs that favor recycled over virgin paper by taxing consumers and manufacturers of virgin paper or by procuring recycled paper even though it may be more expensive than virgin paper.

WHY SMALL-SCALE?

As shown in Table 8, Distribution of Production between Small and Large Scale Mills, in the last 10 years the role of the small mill producing under 300 tons per day has shrunk. Such mills, which accounted for almost a quarter of United States production in 1976, today account for less than a fifth of domestic production. This segment of the industry contains the bulk of the recycling mills.

Table 8:
Small and Large Scale Paper Mills

Mill Size	Annual Capacity			
	1976		1984	
TPD	1,000 tons	Percent	1,000 tons	Percent
0-300	15,736	24	14,429	19
301-1,000	27,534	42	26,580	35
Over 1,000	22,404	34	34,934	46
	65,674		75,943	

Source: The U.S. Pulp and Paper Industry: An Energy Perspective

The major factors influencing small-scale paper making are access to and the price of materials, water, energy, and labor. Benefits of small-scale recycled mills are:

- More people employed
- Less pollution
- Easier access to raw materials
- Reduced dependence on foreign markets
- Greater flexibility of production.

Small mills are handicapped because paper industry equipment is typically designed for large mills, thus raising capital costs for smaller mills which must choose either to operate below capacity, to have specially made equipment, or to buy used equipment that is in some cases inferior to new equipment. In addition, increased employment can be a disadvantage where labor costs are high. It is reasonable to suppose that these costs would contribute to a capital cost per ton of output that would put a smaller mill at a disadvantage. Since 1976, the industry structure has changed in favor of the larger mills, those over 350,000 tons per year, which now account for almost half of the industry's output. This is an obstacle to the establishment of smaller-scale mills that has nothing to do with other obstacles to recycled paper production.

Costs per ton for small-scale paper mills are often significantly higher than for larger mills. Smaller mills generally employ more workers per unit of output, leading to higher operating costs. For developing nations with high unemployment and low labor costs, this is not generally a problem. However, in the United States, where labor costs are relatively high, this is an obstacle to establishing small mills. Small-scale manufacturing allows more flexibility than large-scale manufacturing in the kinds of positions that employees hold in the mills. The ratio of administrative to production workers is similar no matter what the mill's size. However, workers can perform a number of different functions.[11]

Table 9, Capital Costs for Recycled Paper and Paperboard Mills, shows capital costs for several standard-sized recycled paper mills constructed as greenfield installations. The information comes from various engineering firms and equipment manufacturers. The capacities quoted are the sizes that industry sources have told ILSR are appropriate for the different finished products.

Table 9:
Capital Costs for Recycled Paper and Paperboard Mills
in the U.S.

Capital Costs

Mill	Capacity (Tons per day)	Total Capital Cost	Capital cost/ton
Writing	400	$270 million	$675,000
Newsprint	550	$325 million	$591,000
Linerboard	550	$160 million	$291,000

Source: RUST Engineering, BE & K Engineering, and CRS Sirinne Engineering.

These estimates assume that the mills are greenfield installations, built where no mill has previously existed. One industry source notes that a mill could be constructed with its paper machinery located in an old textile plant or similar building to reduce costs. A recycled linerboard mill will be opening soon in an abandoned glass mill in Muskogee, Oklahoma.[12]

Higher capital costs for smaller mills represent an economic penalty paid by manufacturers attempting to establish local recycling facilities. Obviously, in the paper industry, most mills have capacities of several hundred tons per day. As a factory increases in size the capital cost increases as well, but at a diminishing rate. The capital cost per rated ton of capacity is therefore much higher for smaller mills. Ask anyone in the paper business about the economic penalty paid by manufacturers operating small-scale paper mills and they will reply that the capital cost is somewhere in the neighborhood of three times that of the larger mills, which benefit from economies of scale. Yet, this kind of estimate doesn't account for the small-scale firms' abilities to benefit from non-integration and the use of wastepaper as a resource. Another factor that adds to the economic viability of smaller scale paper mills is the availability of used equipment, often small-scale, discarded by larger mills in favor of larger machines.

According to estimates from United States paper industry analysts, paper manufacturers that invest in mills producing wood-based paper pay higher capital costs per ton of capacity than do manufacturers that choose to establish mills that consume wastepaper. The per-daily-ton cost for a complete virgin-based paper mill is estimated at approximately $1 million.[13] Recycled paper mills, on the other hand, are estimated to cost from $275,000 to $675,000 per daily ton of capacity.[14] These estimates reflect the complete cost of the mills, including buildings, effluent control systems, and storage areas. The estimates do not include land or, for the wood-based mill, estimates of the cost of owning or harvesting timberland. The estimates assume new construction from the ground up of facilities that consume raw materials and produce rolls of paper. With the exception of the molded pulp mill, the mills produce from 400 to 550 tons per day. These preliminary estimates indicate that in the United States recycled paper mills can cost substantially less per ton than wood-based paper mills.

As stated, however, capital costs within the recycling equipment industry favor larger mills. A crucial element of a recycled paper mill is the repulping/deinking section. Here, wastepaper is mixed with water and chemicals to make a solution that will be spread across a wire screen or wire-encased cylinder and formed into paper. The deinking section of a recycled paper mill represents 5 to 6 percent of the initial cost. The estimates set out in Table 10, Relative Capital Costs for Deinking Systems, reveal the penalty paid by the small-scale recycled paper producer in the purchase of a complete deinking system.

Table 10:
Relative Capital Costs for Deinking Systems

Rated Capacity (Tons per day)	Total Capital Cost	Cost Per Ton
20	$4 million	$200,000
50	$6 million	$120,000
100	$8 million	$80,000
300	$12 million	$40,000
500	$17 million	$34,000

Source: Beloit Corporation.

Deinking equipment for the 20 TPD mill is estimated to cost almost six times as much per ton of rated capacity as for the 500 TPD mill. But there are some cost advantages enjoyed by small mills that would lead to a reduction in the total cost difference between small- and large-scale mills.

Estimates for used equipment help to diminish this cost difference. A 40 TPD Hydrapulper, a machine that breaks wastepaper apart in water, costs approximately $140,000.[15] A used machine of the same capacity costs $22,500.[16] For small-scale paper recycling, new equipment can cost approximately six times as much as used equipment. The economic penalty paid by small-scale papermakers for equipment can be practically offset by the purchase used machinery. Equipment tends to last a long time; some equipment installed in mills around the turn of the century is still in operation.[17] Many mills wait to rebuild and replace their machinery for as long as 50 years.

CONCLUSION

Paper products represent a large disposal problem for municipalities. In an effort to alleviate this problem, many policymakers have established mandatory recycling programs. However, they have ignored the next step in recycling: the establishment of markets for the materials. Such markets, recycling mills, are economically feasible. If these mills were to be located close to consumers, the probability of their success and the success of recycling as a whole would be enhanced.

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GLASS

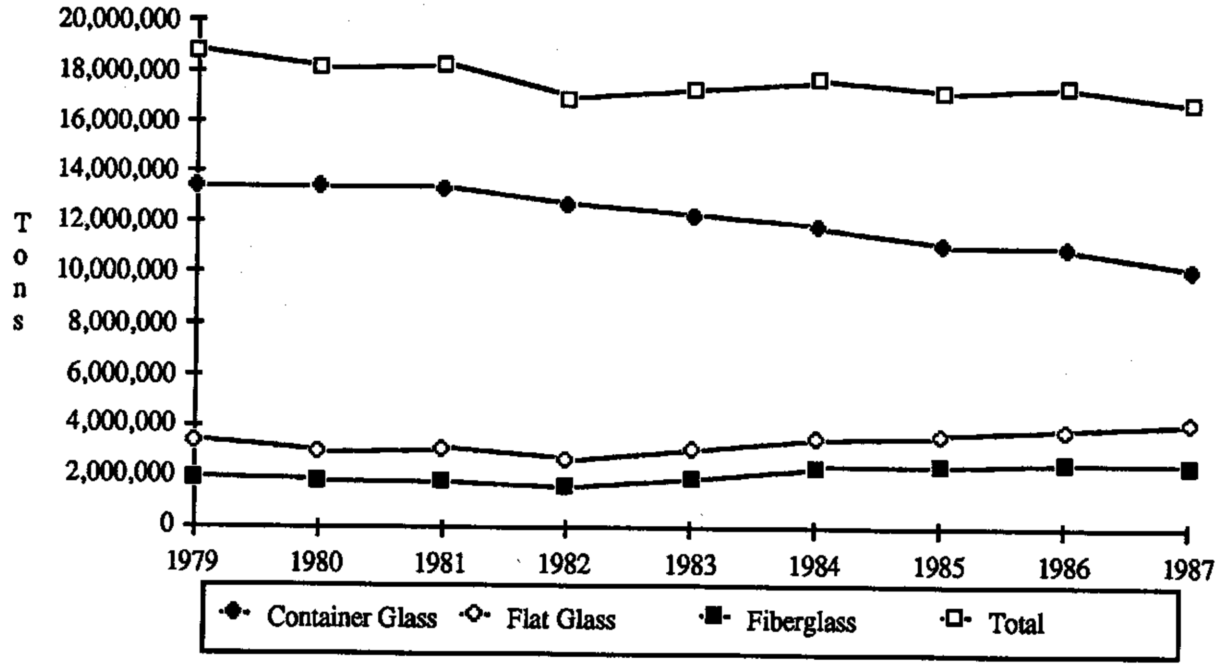
INTRODUCTION

While glass is used in windows, computer screens, and varied other applications, most of the glass used and, more importantly, discarded is packaging. Glass is heavy, and consequently makes up a disproportionate share of the waste stream by weight--8.4 percent (disproportionate relative to the number of glass containers sold, compared to aluminum and plastics containers). Glass' great advantage lies in its ready recyclability: not only is glass recyclable, but some secondary glass must be used to make glass from virgin materials. (Secondary glass used in making new glass is called cullet.)

The advantages to using secondary glass have been well documented at the plant and local levels. Primary among those advantages is reduced energy consumption (up to 30 percent); glass making is an energy-intensive process. Further benefits from using secondary glass are reduced wear on the glass melting furnace (the single largest capital expense in a glass manufacturing plant), reduced capital costs, reduction of emissions, and ultimately, cheaper production.

An understanding of the factors affecting demand for glass products is useful for gauging longer-term trends in consumption and disposal of glass products. Total glass consumption in the United States is projected to stay even at about 19 million tons per year for the near future.[1] Consumption has been more or less level for the past 5 years since the decline in number of containers used was arrested and advances in lightweighting slowed. However, as Figure 5, U.S. Glass Consumption, shows, there is no one glass industry--instead there are four discrete industries, three of which are illustrated: container, flat, fiberglass, and pressed-and-blown ware. Each segment is influenced by different forces, as outlined in the next section. Figure 5 shows trends for the glass industry as a whole as well as for its component industries. (This study does not cover the pressed-and-blown segment of the industry, which manufactures decorative items, optical products, and electric bulbs, because it accounts for a small part of total glass tonnage and because it does not use secondary glass as a component.)

Figure 5:
United States Glass Consumption



Source: U.S. Department of Commerce

WHAT IS GLASS?

More than 90 percent of the glass produced in the United States is soda-lime glass. While the precise combination of ingredients varies from product to product, this glass is made up primarily of sand, soda ash, and limestone, and is used to manufacture glass containers, flat glass, pressed-and-blown ware, and lighting products. It is possible to manufacture a container out of old window glass, window glass out of old containers, and fiberglass out of either. Because the primary glass markets are container glass, flat glass, and fiberglass, the demand certainly exists for scrap glass. The container glass market is twice the size of the flat and fiberglass markets combined. This is of primary importance to this study because the container glass market produces and absorbs the greatest quantity of post-consumer glass.

The future of container glass is dictated by trends in the packaging market as a whole and by competition from substitutes such as plastic and aluminum. Future markets for flat glass and fiberglass will be dictated more by trends in the end-market applications, especially construction and automotive applications, than by competition from substitutes. The construction industry is heavily dependent upon tax policies and interest rates, while the automobile industry is dependent upon interest rates and the price of oil. Fiberglass, in its insulating applications, is also heavily dependent upon the price of oil. Markets for glass are, except in the case of oil imports, relatively impervious to changes in the value of the dollar in international trade, unlike the markets for plastics and aluminum. All three glass industries are commodity industries: they manufacture basic products intended not for consumers but rather for fabricators which convert the product into consumer goods. In the flat glass market, for instance, the basic glass manufacturer sells enormous sheets of glass. Fabricators then cut, coat, shape, and etch the glass to turn it into auto windows, shower stalls, etc.; this is the work that adds the most value to the original materials.

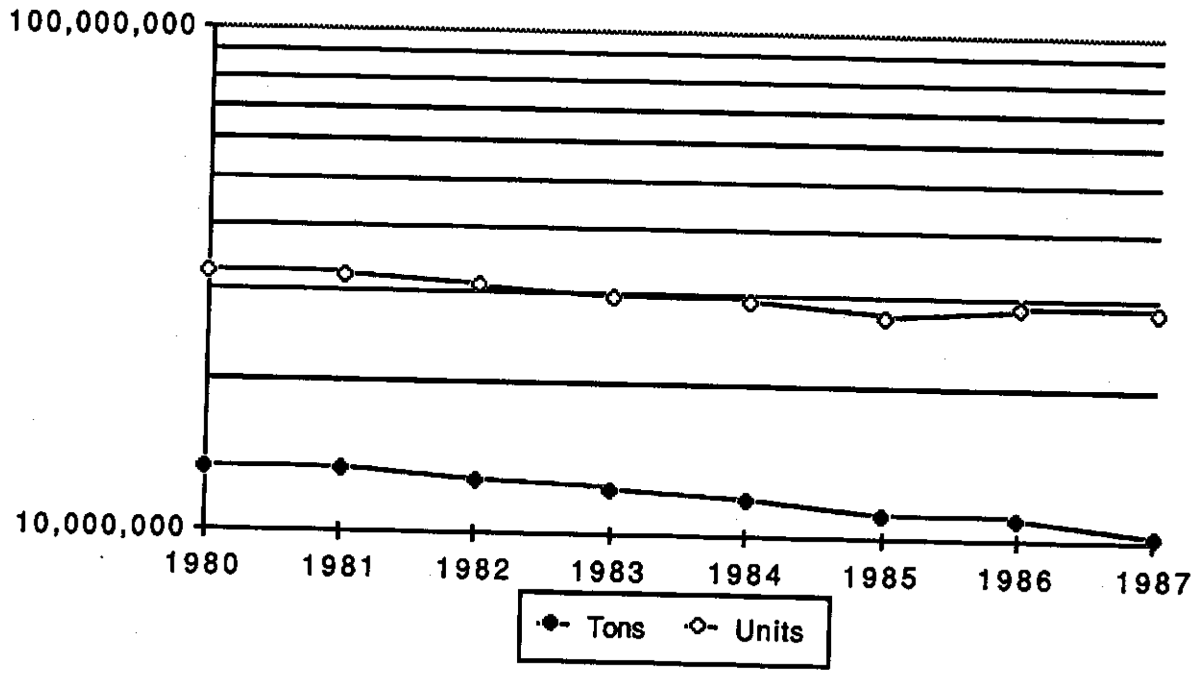
Container Glass

The container glass industry is easily twice as large as the two other markets combined in terms of tonnage. However, it is facing great competition from aluminum, paper, steel, and plastics. As a result, growth in unit shipments is expected to continue to decrease at a rate of 1 percent a year for the next year at least. To show how fierce competition from other materials has become, just a year and a half ago glass container shipments were expected to increase at a rate of 3 percent a year over the next 5 years.[2] Advances in reducing the weight of glass products are decreasing the amount of glass used per bottle and therefore are reducing the quantity of raw materials used by the industry. Figure 6, Container Tonnage vs Number of Units, shows the significant decline in glass tonnage production against the moderate decline in unit shipments.

Figure 6:

Container Tonnage vs. Units

(Semi-log scale)



Source: Department of Commerce

Tracking trends in the packaging market is made difficult by the fact that trends in its constituent markets are widely divergent. Take, for example, the rigid container market. Within the glass segment alone the divisions are: food, beverage, beer, liquor, medicinal, chemical, and toiletry. Each segment is subject to different market forces. Thus while more and more glass food containers have been sold each year, beer bottles have come and gone and come back again, just in the past 3 years. Currently food, soda, beer, wine and liquor containers have been holding their own and even growing, while medicinal, chemical, and cosmetic containers have shifted increasingly to plastics.

Interestingly, the glass market benefits from Yuppie tastes in premium beers, wines and "natural" foods--all of which are predominantly packaged in glass. Furthermore, though generally impervious to the strength of the dollar (glass is too heavy to be shipped overseas), the container glass market does benefit indirectly from the low dollar as imported premium beers and bottled waters become increasingly expensive, thus stimulating demand for local specialty beers and waters and the domestically produced glass containers they're packaged in. However, demand for container glass is more closely linked to demand for its substitutes, aluminum and plastics. The beer industry's decision to turn from glass to aluminum resulted in a decrease in demand of 5 billion containers between 1980 and 1985. This accounted for 85 percent of the total decrease in container shipments in that period. The glass industry, in an effort to keep its market share, lowered container prices until they were below cost, a development which led to plant closings and a realignment of capacity and demand. This has halted construction of new glass plants since1982.[3] The container glass industry sees glass' recyclability as a strong competitive advantage and has consequently committed itself to recycling every container it produces. This renders it at once the most logical and the largest market for post-consumer glass.

Flat Glass

As Figure 5 showed, flat glass consumption has increased, and is expected by the industry to continue to do so, though debate on the futures of the construction and automotive industries has led to projections ranging from slight declines to significant increases.[4] Capacity is also increasing to meet demand expected from new glass-dependent technologies (electric windshields, liquid crystal displays, insulating glass). The fabricated glass market is growing at the fastest rate, which suggests that the siting of a flat glass plant would attract numerous other plants to coat, cut, laminate, and otherwise process the flat glass. As a result, the greatest economic development might be recognized through the establishment of small-scale flat glass plants that would attract numerous fabricators to further process the glass into commercial products.

The flat glass market is heavily dependent upon the construction and automotive industries, both of which are heavily dependent upon oil prices and interest rates. Approximately 57 percent of all flat glass shipments goes to the construction market, while 25 percent goes to the automotive industry. The remainder is specialty products such as aquarium glass, mirrors and solar panels. As in the container glass market, advances in weight reduction have decreased the virgin inputs in glass, even as consumption of the finished product has increased. Since 1900, glass industry demand trends have paralleled trends in the gross national product.[5] However, care must be taken in using GNP as a predictor of demand in the short term because issues of capacity, substitute materials, and imports can have more immediate effects on the market.

The tremendous expense associated with shipping extremely fragile products such as windows has led to the development of a flat glass minimill that runs efficiently at a small-scale and can thus be built near attractive markets. This emphasis on market proximity, which requires smaller-scale plants, bodes well for this closed-loop model in which a city provides its own markets for its products.

Fiberglass

Insulation is the dominant fiberglass market. It is twice the size of the textile market and uses large proportions of cullet in production. Total production of glass fibers has increased dramatically in the past 10 years. Fiberglass for insulation applications is, like flat glass, closely linked to construction and oil prices. Production slipped in 1987, as would be expected given this market's construction links, but is expected to follow the same trends in the construction market that apply to flat glass. The fiberglass insulation business is also facing competition from plastics (especially foam insulation) and cellulose insulation. Nevertheless, fiberglass has almost 80 percent of the market (as measured in board feet). Plastics' flammability will deter further growth in the plastics insulation market, thus assuring fiberglass a continued high market share. This is important because fiberglass is a large consumer of post-consumer cullet. Currently about 50 percent of the material inputs for fiberglass are post-consumer glass.

Other Markets

Further markets exist to absorb secondary glass: glassphalt, roadbed aggregate, clay bricks, masonry block, glass beads, glass-polymer composites, and foamglass. The only markets aside from glass containers and fiberglass which use appreciable quantities of secondary glass are glass beads and glass marbles. Glass beads are generally manufactured from 100 percent post-consumer cullet and waste glass (such as the scrap from flat glass fabricating operations) and are used to reinforce plastics. The American Glass Review estimates that demand for glass beads is over 50,000 tons per year. A similar product used by the fiberglass industry to reduce the plant size necessary for economical operation is glass marbles that are remelted to form fiberglass.

MAXIMIZING VALUE FROM DIVERTED WASTE

The manufacturing process has historically created enough cullet to constitute as much as 20 percent of the manufacturing input materials. Malformed containers, trim scrap from glass sheets, and glass found unsuitable for the intended applications, are all sources of cullet. Trends in the automation of production lines, quality control and batch weighing, combined with improved technologies for coloring smaller batches of glass, have decreased the amount of glass available in-house as cullet. As a consequence, firms need secondary glass.

Using cullet rather than unfused batch materials produces documented savings in energy, furnace wear, capital costs, and pollution control equipment. Capital costs are reduced because batching facilities and pollution control equipment are no longer needed.[6] The energy reduction, by an industry rule-of-thumb, is 3 percent for each 10 percent increase in the use of cullet, and perhaps greater since there is no need to run scrubbers to catch particulate matter and sulfur oxides.[7] According to one source, it takes approximately 1.3 million Btus/ton to melt cullet, and 1.9 million Btus/ton to melt raw materials.[8] Furnaces in glass manufacturing plants generally last 5 or 6 years using batch (sand, limestone, etc) but may last twice as long using high levels of cullet. Because refurbishing a furnace costs over $2 million, an increase in furnace life can substantially decrease the costs of glass production.[9] Finally, using 100 percent cullet eliminates the need for pollution control equipment by eliminating the volatilization which occurs in the highly turbulent and dusty batch melting process, and which can add $700,000 to the capital costs of a 200 TPD plant. High cullet use also eliminates the 20-40 percent loss of raw materials through volatilization (these materials are both the byproducts of the chemical reaction that fuses the silica sand and other ingredients, and particulate matter swept up the flue by the turbulent gasses).

Table 11, Costs per Ton Production of Virgin-Materials-based vs. Cullet-based Production, assesses all pollution control costs against capital expenses, and puts the savings: in perspective.

Table 11:

Costs per Ton Produced of Virgin-Materials Based vs. Cullet-Based Production

Source of Cost	Virgin[1]	Cullet[2]
Materials	$50.00	$50.00
Energy	18.00	12.60
Labor & Overhead	2.58	2.58
Capital Investment	20.36	11.21
Total:	**$90.94**	**$76.39**

Source: Based on EPA, as quoted in Roles of Electricity in Glassmaking, EPRI 1986. The title of the original chart was : Variable and Fixed Cost Relationships for Glass Melting with Natural Gas with All Pollution Control Costs Assessed Against Capital-Related Expenses

1 Materials: Westra, Donaldson and Hnat, 1987, p. 246; Energy: @ gas=3c/MBtu and 6 MBtu/Ton; O&L: based on PPI, U.S. Statistical Abstract; Capital: estimated from PPI for Machines & Equipment.

2 Materials: average price of cullet in the Northeast, Summer '88; Energy: estimated given 3% reduction in energy use for each 10 percent increase in cullet; Capital: regular capital costs minus cost for pollution control equipment.

Most glass manufacturers recognize both the economic and the public relations benefits of using secondary materials and currently buy and often process post-consumer glass from recycling programs and individual consumers. At present, demand exceeds supply of both post-consumer glass and cullet.[10] This has driven up the price of cullet. Firms have been known to pay over $70 a ton for unprocessed bottles.

Of course, recycling is beneficial not only to the manufacturer but also to the community. The benefits accrued locally include the avoided disposal costs, the revenue received for the glass, and, if the plant is local, an increase in employment and secondary economic activity. Benefits to the community, if the plant is locally owned and run, can be measured in terms of the value added to the glass through production, since the value added is the sum of the variable and fixed costs plus profits associated with production.

Table 12:

Value at Each Stage of Production ($/Ton)

Product	Garbage	Buy-back	Cullet	End product	Total Value Added/Ton
16 oz Bottle:					
Clear	-70	40	55	450	520
Green	-70	40	43	384	454
Flat Glass:					
1/4" Window	-70	40	55	1300	1370
Architectural	-70	40	55	7500	7570

A third force is driving glass recycling at the moment. The recycling push tends to come not so much from the producer or the bottler as from the manufacturer of the contents whose brand name is intimately associated in the consumer's mind with the container in question. Thus, Coca-Cola and Procter & Gamble are working hard to make sure that they are associated not with the solid waste problem but with the solution.

However, the producers too are a force in recycling. Container manufacturers don't want to see refillable containers regain popularity because of public environmental and solid waste concerns, a development that would cut deeply into the disposable container market. They feel that recycling can alleviate environmental concerns without diminishing the market for disposables. Further impetus is provided by the packaging materials competition which depends not only upon cost and consumer preference, but also on recyclability.[11] Legislation banning unrecyclable packaging is increasingly common throughout the country, and is spurring industries to establish the recycling networks that will enable their packaging to survive.

HOW MUCH CAN BE RECYCLED?

Given the tremendous benefits recognized through using recycled glass it is worthwhile to determine both how much glass is available to be recycled and whether glass plants can run on exclusively secondary glass (and if so, why this isn't being done on a large scale already).

Using materials data, shipping figures, and information on average lifespans, Franklin Associates (a solid waste consulting firm) has estimated that 11.8 million tons of glass were discarded in 1986, of which only 8 percent was nonpackaging glass. Production figures indicate that 17.4 million tons of glass were produced in 1986. The discrepancy between production and disposal figures is a function of both the life of the product and of the definition of MSW. While it is assumed that glass bottles and jars have a lifespan of less than a year, windows can be expected to last virtually forever. The 8 percent non-container glass comes from light bulbs, cookware, and miscellaneous other glass products. Many of these are not recyclable because they may contain additives detrimental to soda-glass production. That means that 90 percent of the glass in the waste stream is thoroughly recyclable container glass.

Fortunately, both container glass and insulating fiberglass plants can run on 100 percent post-consumer cullet. Container glass plants have been known to do this for extended periods of time, the only limiting factor being the supply of secondary glass available. For a flat glass plant 100 percent cullet use is less desirable because even slight imperfections are more readily visible in flat glass than they are in containers. The loss of one container diminishes production very little, but the loss of long lengths of flat glass can seriously affect a plant's economic viability. Since current technology doesn't favor using high quantities of cullet, much research would need to be done to ascertain how much post-consumer cullet could safely be absorbed in flat glass manufacture.

For the purposes of our model, the most efficient and thus most elegant form of recycling turns secondary materials into their antecedent forms, bypassing the waste stream altogether. Clearly container glass could form a closed-loop system whereby a container becomes a container becomes a container. However, there are losses in consumption and in manufacturing which limit the amount of secondary glass actually available.

External Losses

It is impossible to estimate with any accuracy the amount of glass lost to consumers. Jars are saved to store nails. Bottles are saved for aesthetic reasons. Containers are broken and discarded with more general waste. As a guide, then, one can use the return rates recognized in "bottle-bill" states, which average 93 percent. Alternatively we can look at the results in other countries where recycling has had a longer history. In some European nations, return rates for all glass containers have exceeded 53 percent without deposits, without easy access to glass recyclers and without other tangible incentives to recycle.

We are thus estimating that in a city of a million in which every resident has an incentive to recycle, and in which recycling is facilitated through use of intermediate processing centers, 90 percent of all container glass can be recovered.

Recycling Losses

Glass has highest value when color sorted and decontaminated (a full discussion of this process can be found in the Appendix). Technologically, it can be color separated at any stage before melting. However, economical sorting, whether manual or photo-optical, proceeds most efficiently in terms of both time and quality with whole bottles--it takes less time to sort bottles than shards, and the process loses (or lowers the grade of) less glass.

If bottles arrive whole at a processing center, processing losses total 3-5 percent by weight. This includes not only glass, but also aluminum caps, paper and plastic labels, and extraneous items such as cups. This remainder is used as aggregate--low-value bulk filler for cement, except for the aluminum that may be usefully separated out. Thus, while not lost to the system, the unsortable, heavily contaminated glass is lost to container manufacturers.

We have shown how just over 85 percent of the waste glass can usefully be recovered for glass container manufacture. Losses in the manufacture of glass are negligible. While standard processing volatilizes 20-40 percent of the inputs (which escape up the flue), secondary glass does not volatilize, and the losses are estimated at 1/10 of one percent. Since defective containers are immediately returned to the feedstock mix, one ton of inputs renders one ton of outputs. This relationship holds for flat and fiberglass also.

A recovery rate of 85 percent is possible. However, the availability of post-consumer glass depends heavily upon legislation mandating recycling or container deposits. Most of the glass companies in the United States buy post-consumer glass, and many of them have invested in beneficiation machines that process incoming bottles into a usable substitute for raw materials. It is estimated that by 1990 more than half the companies in the industry will have their own beneficiation systems[12], while another third will be sharing systems.[13] It should be noted that under "bottle-bills," which have achieved seemingly high return rates of up to and sometimes over 95 percent, only targeted containers are returned. Thus a large proportion of glass consumed is not recycled: peanut butter and pickle jars, medicine and cosmetic bottles, liquor bottles, etc.

WHY ISN'T EVERYBODY RECYCLING?

This leads us to, and partially answers, the question of why secondary glass-based production isn't more widespread. Use of post-consumer cullet is very recent, only approaching significant quantities since the market takeover by disposables in the 1970s. While recycling then began as a moral issue and was used primarily to fund Boy Scout troops and other charitable causes, the sharp rise in the costs of landfill disposal in the 1980s prompted many municipalities to collect materials for recycling rather than dump them. Even where incineration was the preferred form of waste disposal, glass' obvious inability to burn made it a good candidate for recycling. Estimates suggest that industry-wide, post-consumer cullet consumption is approaching 30 percent of container glass batch ingredients. Thus, both the absolute volume and the relative proportion of post-consumer cullet to total raw ingredients are increasing.

This seems to hold true for the fiberglass industry as well. Owens-Corning regularly uses 50 percent post-consumer cullet in the manufacture of fiberglass insulation.

Adding to the problem of insufficient collection in the early 1970s was the sporadic supply. With increased (and mandated) collection, supply chains and long-term contracts are being set up that guarantee a producer a given quantity of materials. Furthermore, quite a few municipalities and entrepreneurs have set up materials recovery facilities (MRFs) or intermediate processing facilities (IPCs) that process mixed recyclables (aluminum cans, glass bottles, plastic bottles, steel cans, and paper) into manufacturing-grade feedstock materials.

But secondary materials have one more battle to overcome--and that is the conservative nature of the manufacturers and the deep resistance with which they tend to regard secondary materials. Although the industry has had thousands of years to work out problems in the delicate glass manufacturing process, hardly a decade has been spent studying post-consumer glass recycling. The problems which come of using post-consumer cullet are neither mysterious nor insoluble. The problems can be analyzed, explained, and then overcome through what become routine adjustments.[14] (A more detailed discussion of the risks associated with using secondary glass can be found in the Appendix on glass manufacture and recycling.)

The primary concerns are contamination with other materials such as aluminum and ceramics, insufficient processing capabilities to release air bubbles trapped in the secondary glass, and the variable composition of the secondary materials, both within each batch and over many loads. The contamination problem is being successfully handled by glass processors. New and developing technologies are coping with the processing problems, and while there are slight differences in composition between flat glass and various bottle glasses, the range of compositions is no broader than that in standard production.[15] This has been borne out empirically by various firms which have run on 100 percent cullet, and even 100 percent flat glass cullet, without production problems.[16]

For the purpose of this study, we are making certain assumptions about consumption. Thus, for glass containers, we assume:

- Per capita annual consumption is 150 lbs. of which 100 lbs. is packaging;
- Packaging glass enters the waste-stream within a year of production
- 90 percent is recoverable for glass container manufacture
- 5 percent is lost in the recycling process and cannot be used for container manufacture, though it can serve as aggregate in glassphalt, bricks, etc.
- 85 lbs per person are thus available for manufacture
- 140 tons per day (TPD) for a city of a million.

In fact, much of the broken and supposedly "lost" glass can be recovered through various separation techniques for mixed waste, and then used in low-grade, durable applications. Nevertheless, for the time being we will concentrate on the 140 TPD available for use in glass manufacture in a city of a million.

Is this enough to sustain production? In fact, it is.

Glass plants around the world vary widely in size and technological sophistication, from manually operated pot furnaces to the continuous tank furnaces used by most United State glass manufacturers. While the stained glass industry in the United States continues to use pot furnaces in which small batches of ingredients are melted and worked by hand, the container, fiberglass, and flat glass industries have grown very large in both company and plant size. The smallest flat glass and container glass plants in the United States produce between 150 and 175 tons per day. This is in contrast to medium-size plants which produce approximately 700 tons per day, and large operations which produce over 1,000.

A city of a million would produce glass sufficient for one 135 TPD furnace after accounting for losses. Furnaces are built as small as 50 TPD, but there is little reason to believe that a plant could produce economically at that size under current practices. Energy makes up 18-20 percent of a modern plant's running cost.[17] A small-scale furnace can cost over $5 million, and will need to be rebuilt every 5-6 years at a cost of $2 million.[18] Thus, capital, operating, and interest expenses on the furnace alone form a major part of the costs of running a plant.

Table 13, Capital Costs for Glass Plants, compares the capital costs for various manufacturing plants at the smallest scale:

Table 13:

Capital Costs for Glass Plants

	Capacity (TPD)	Capital cost/ton	Total Capital Cost
Container	135	$89,000	$11,000,000
Flat	100	200,000	20,000,000
Fiberglass	100	47,000	4,700,000

The data in Table 13 are gross estimates, and reflect the fact that manufacturing practices have emphasized economic concentration, mass production, and perceived economies of scale rather than more specialized and flexible forms of manufacturing. Thus, the estimates above are based on underutilization of equipment that could process much more glass. Were more glass melted, the costs per ton of product would of course decrease.

However, this emphasis may well be changing. As noted above, the flat glass plant which runs currently at 200-250 TPD is one-fourth the size of the more traditional 1,000 TPD plant. A new glass melting technology that favors the use of cullet, can be economically operated to run as few as 10 TPD. Both these innovations allow for small-scale and highly flexible production with lower capital costs, reduced energy requirements, and reduced land needs. If the other economic factors are favorable, they can therefore be profitably set up in or near cities--an impossibility with plants that currently take up four or five acres.

The emphasis on flexibility that both these technologies exhibit has further implications for glass production. At present, glass companies are in large part warehouses. The large container companies produce and often label bottles for major bottling concerns under nationwide contracts. For this reason, a glass plant might produce a year's worth of bottles and store them in a warehouse, only shipping out routinely the quantities demanded. The low value/high weight ratio of glass containers renders it uneconomic to ship empty bottles very far. As a consequence, container manufacturers prefer to set up near bottlers, and bottlers near their markets and/or their product source; that is, if they bottle mineral water they will set up near the spring, whereas if they bottle soft drink syrup they will set up near their market. Small-scale flexible glass manufacturers could produce much shorter runs and save themselves the expense and space involved in shipping and storing by locating in the heart of their markets. Only the local situation can determine whether the costs of storing the bottles is greater than the value of the forgone production due to downtime changing molds. The greatest downtime comes not from mold changes, however, but from color changes. Small-scale producers can flush their systems of the unwanted color faster than can large producers. Only the local situation can determine whether or not these various costs and savings offset one another.

Small-scale producers have a significant role to play, even in today's highly consolidated markets, not only because they defuse charges of antitrust violations in glass producing industries. The major bottling concerns are averse to being tied into exclusive contracts and generally seek secondary suppliers. Local suppliers might well offset their scale disadvantage through their transportation and warehouse savings. Similarly, small consumers who cannot get contracts or preferred status with large manufacturers can find competitive suppliers in locally-based manufacturers. Furthermore, anybody with a need for a specialized run would be well served by a small-scale flexible producer.

These advantages apply not only to the container market but to the flat glass manufacturing market as well. This flexibility is enhanced by the mini-flat glass plant's ability to produce both flat and patterned glass in one facility.[19] This technology has the potential to change the economic concentration in the glass industry by allowing for many smaller producers of basic glass to enter the field. Whether or not the mini-flat plants can follow the lead of the steel and aluminum minimills in penetrating traditional markets remains to be seen, but the technology is now available to make this happen.

Container Glass

Table 14, Capital Costs for a Glass Manufacturing Plant, shows approximate rock-bottom costs for a glass-container manufacturing plant with two container producing lines:

Table 14:

Capital Costs for Glass Container Manufacturing Plant

Beneficiation machine	$500,000
Batch plant	300,000
Furnace (including furnace building)	4,000,000
Forehearth (Furnace to I-S machine)	300,000
Eight-section bottlemaking machine	1,900,000
Conveyor and lehr system	400,000
Quality-control inspection machinery	300,000
Box forming operations	200,000
Baghouse	700,000
Compressors and cooling fans	100,000
Mold shop	200,000
Land and bldg ($25 per sq. ft.)	2,000,000
Container	
Total	**$10,900,000**

Source: Emhart Glass Machinery Corp.

*(Terms are explained in the glass processing appendix)

Table 14 does not include the costs of engineering, construction, settling ponds, permits, etc. If those costs were added in, the total would be considerably closer to $12 million. Costs per rated daily ton would therefore be approximately $89,000 under traditional forms of manufacture. However, if the glass melting technologies currently under development prove successful, it may well be possible to reduce capital costs by 15 percent. In fact, annualized cost savings from the new technologies are estimated to be as much as $57 and $75 per ton or 20 percent of the products' final value.[20] Furthermore, batching facilities may be substantially simplified and fewer sections of the glass forming machines may need to be installed. With the lower capital and operating costs the plant might well run efficiently at a considerably smaller scale. However, there might also be a penalty for being smaller. Fixed costs (engineering, permitting, etc.) are not diminished on a smaller scale plant, energy is relatively more expensive, and some new technology parts might well cost more because they are not being mass produced.

While in some industries--most notably the plastics and paper industries--modernization has created a large secondary market for smaller scale machinery, the supply of secondary machinery for glass manufacture is slim. There is no secondary market for furnaces, though there may be for some glass forming machines. However, these machines have been designed to be upgraded, and are thus not readily available for purchase on the secondary market. There are no smaller scale technologies currently in efficient operation. Developing countries tend to build plants that use the technologies and scale used in the United States, but to use them under capacity. Where labor is low-cost it is substituted for much of the automation possible in glass manufacture, but such substitution is uneconomic in the United States. Manual work in a glass factory is extremely hot, noisy, and dangerous, and has been eliminated in the United States at least in part because of occupational safety and health laws.

Flat Glass

A minimill technology has been developed for flat glass plants which has successfully decreased the efficient scale of production from 500 TPD to 200 TPD. No such small plants are actually running in the United States. A 200 TPD demonstration/pilot plant is run by AFG Technologies in Kingsport, Tennessee but this does not prove viability for a plant independent of a large corporation. The estimated costs per rated daily ton capacity are $200,000, though this may actually underestimate the true costs as there may be a penalty for going smaller than the 250 TPD plants upon which this estimate was based.[21]

Fiberglass

An analysis of the fiberglass industry done for EPA in 1976 indicated that four firms then dominated the fiberglass market, with the larger two accounting for more than 80 percent of production; there were only 23 fiberglass plants in production. According to the Glass Industry Directory there are currently 35 glass fiber insulation plants in the United States. Economical production of glass fibers can only be achieved at large volumes--that is, over many plants. As a consequence, there are no small fiberglass producers though there are small-scale plants.[22] Again, shipping fiberglass any distance is uneconomic because of the high volume-to-weight ratio. It is preferable, therefore, to produce fiberglass locally in small production plants.

Whereas the volumes of production may be great, the actual tonnages of fiberglass produced in an average plant are on the order of 50-150 tons per day. Advances in glass melting slated to be introduced in the fiberglass industry may well diminish the scale at which a fiberglass insulation plant operates efficiently and allow for more localized production. The difficulty in breaking into so concentrated a market with such a low margin for profit requires cooperation between the municipality and the producer to keep costs of production low enough to compete.

Present modes of production and disposal imply material losses as described above. However, different institutional systems inspire both other forms of production and other means for returning materials such as the networks for refillable bottles. Were the costs of disposal reflected in the price of a disposable bottle, consumers might well find the convenience of disposable bottles not worth paying for. Until the late 1950s, refillable bottles were the most widely used containers, and were known to make as many as 30 trips apiece. Methods for ensuring their return were generally economic, as they are today in many developing countries where deposits, rather than running a nickel or a dime apiece, are often sufficient to double the cost of the contents. A return to refillables as the primary container source (a move which Sweden has successfully made) would diminish raw materials needs by 90 percent, thus providing sufficient secondary materials for several container generations, even with losses. Sweden, in addition to instituting mandatory deposit legislation nationwide, has standardized bottles to render refillables more economic.

In a refillable bottle system with standardized bottles the bottlers have no incentive to withdraw bottles from the system even if they are getting considerably scratched and weak. A system whereby the containers are returned to the manufacturer, either after a given number of trips or when they break, could overcome this problem and conserve the materials base. In order for this to work, manufacturers would need to ensure bottlers that all returned glass would be bought. Through guaranteed buy-back, or by leasing the containers, manufacturers could ensure their raw materials base while closing the manufacture-consumption-use-disposal-manufacture loop.

CONCLUSION

The easiest recycling model is the manufacture of glass containers: the market is known, the composition of the bottle is known, the waste stream is bypassed, and transportation is reduced enormously. Furthermore, as in any glass recycling, energy needs are substantially reduced, as is wear on the melting equipment. The smallest existing plants in the United States produce slightly more glass than our city of a million could produce feedstock for. On the other hand, due to the tremendous consolidation that has gone on in the industry over the past 8 years, most firms are paying off enormous debts and postponing repairs and maintenance on equipment.[23] While they have been able to cannibalize the plants they shut down in this consolidation, they are beginning to need new equipment, more downtime for maintenance, and a greater competitive edge to fight the inroads plastics are making. This edge could come from local scrap-based production.

There is little reason to believe that the flat glass industry is in a position to use secondary glass without a great deal more research and investment. There are no political reasons for the industry to use more secondary glass, because its product is generally higher value-added than the products of the container industry, because energy makes up a smaller proportion of the final price, and because the savings are thus less likely to make enough of a difference to encourage research.

The fiberglass industry can absorb a great deal of secondary glass, but it is unclear whether one small-scale plant could operate efficiently enough to run at a profit. However, the near elimination of shipping costs may well alter the economics sufficiently to render such plants feasible. Certainly the durable and forgiving product lends itself to providing a use for secondary materials.

A city could thus meet only about half its glass needs through recycling, unless window glass, auto glass, and the like could be collected and decontaminated successfully. Since both auto and architectural glasses are increasingly being coated with metal films, layered with plastics, and used to encase liquid crystals and other unrecyclable high-tech products, this is highly unlikely.[24]

In meeeting half its needs through recycling, though, the city also diverts 8.5 percent of its waste stream from the landfill and provides approximately 100 jobs directly (and more through ancillary businesses). Furthermore, the city ceases to export its raw materials (glass scrap) to others, only to import them back later as finished goods. Thus, it initiates a material independence--the first step towards self-reliance.

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PLASTICS

INTRODUCTION

Plastics, first used widely during World War II and widely commercialized shortly thereafter, came fully into their own in 1979 when the volume of their production exceeded that of steel for the first time. Needless to say plastics are produced to be consumed and inevitably discarded, with the result that plastics now form the fastest growing portion of the waste stream. This has drawn (in large part unwanted) attention to plastics from the public and thence legislators, and has precipitated interest in plastics recycling. This interest has been encouraged by entrepreneurs who have found in secondary plastics inexpensive, high-quality substitutes for increasingly expensive resins.

While initially limited to several commodity resins, plastics now number in the thousands with compositions tailored to specific design applications. Increasingly, plastics are being layered with one another, alloyed with other plastics, blended with other fibers, and otherwise modified into forms that are often unrecyclable. In these new incarnations, they are competing with and substituting for traditional materials such as steel and aluminum in applications in the aerospace, automotive, and packaging industries. Not only have plastics penetrated markets formerly reserved for other materials, they have also created markets: lightweight phones, coolers, plastic wrap, wire insulation, and housings for electronics, among many others.

Plastics are increasing as a percentage of the waste stream by weight and, more significantly, by volume. This growing presence renders them both more of a burden in the landfill and more attractive to recycle from the municipal perspective. Since even commodity plastics are increasing in both value and demand they are proving to be lucrative to recycle from a commercial standpoint as well. However, the sheer variety of other plastics and their relatively small proportions in the waste stream makes a large part of the plastics waste stream extremely difficult to recycle.

Because of their high volume-to-weight ratios plastics are best processed in the city that generates them rather than being shipped long distances at great cost. Because even small cities generate enough plastics waste to provide feedstock for numerous manufacturers, plastics recycling can prove a sound strategy for both the private and public sectors. We will examine the plastics that are most readily recyclable, discuss the limitations to recycling the others, and explore the options and benefits available to a city that seeks to capture the value added in processing materials locally.

WHAT ARE PLASTICS?

Plastics make up as broad a family as metals, and, like metals, can be alloyed to create materials with particularly desirable properties. Unlike metals, however, plastics are "unnatural" in that they do not manifest themselves in nature, but need to be manufactured in a series of chemical processes which link atoms into nearly indestructible, high-molecular weight chains of molecules. While thousands of plastics have been designed, six so-called commodity plastics are most prevalent in municipal waste, and can be easily sorted from other materials and plastics. These plastics are:

Plastic	Acronym	Example of Use
High density polyethylene	HDPE	milk jugs
Low density polyethylene	LDPE	plastic bags
Polystyrene	PS	brittle yogurt container
Polypropylene	PP	bottle caps
Polyethylene terephthalate	PET	soda bottles
Polyvinyl chloride	PVC	pipe, bluish bottles

The commodity plastics make up the first level of a four-level hierarchy in which plastics are differentiated by increasingly higher performance characteristics. The four levels of the hierarchy are commodity, intermediate, engineering, and advanced, and the differences can be illustrated by the following example: whereas a trash bag carries a fairly light load only once and is made of a commodity resin, slings for loading ships must be enormously strong, and are now made of an engineering-grade nylon that has a tensile strength greater than steel. Telephone casings that must have a greater strength-to-weight ratio than soda bottles and a much longer life are made of intermediate plastics. Teflon, which has to bear up under intermittent intense heat over a long life, is an advanced resin.

Plastics can be categorized both by composition and by end product. Demand for each plastic varies considerably due to the success of its various applications. The life of these applications in turn affects the quantity and availability of each plastic in the waste stream. We will therefore break down our analysis by plastics (the major commodity resins) and major end-uses.

In the past 10 years consumption of plastics has nearly doubled to 27 million tons per year and has been steadily growing. Demand for plastics is expected to continue rising by approximately 10 percent per year. See Table 15, Production of Major Commodity Resins in the United States The commodity resins made up almost three-fourths of total plastics production in 1988.

Table 15:

Production of Major Commodity Resins in the U.S. ('000 Tons)

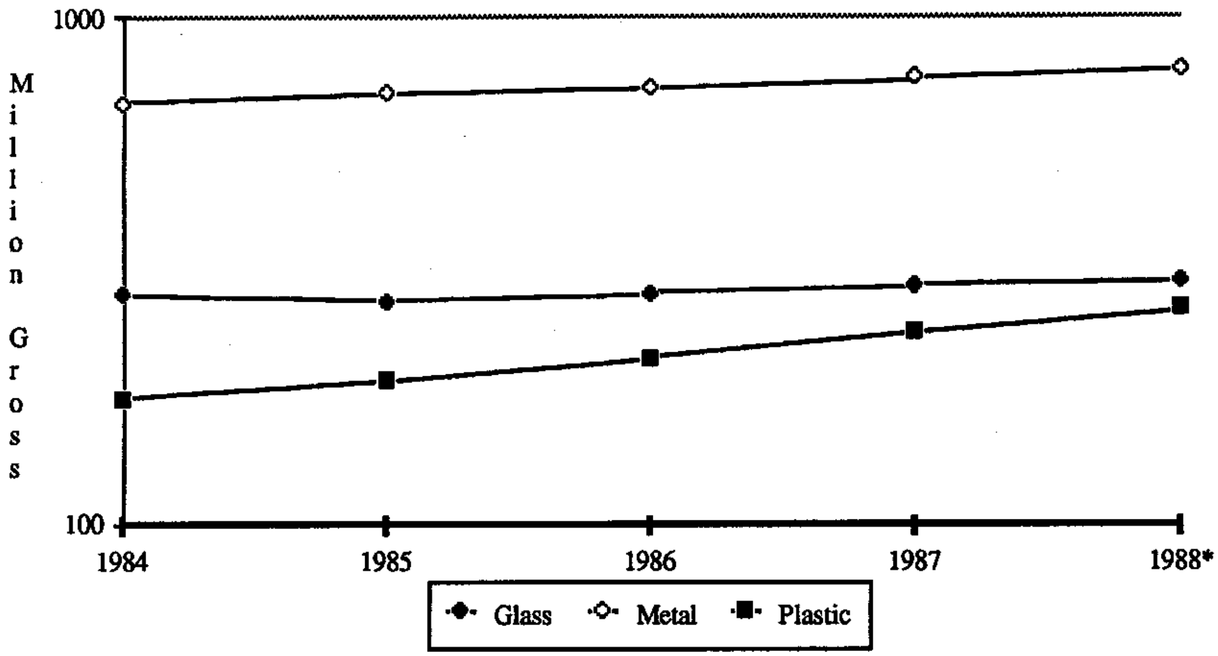
	1976	1988	% Increase
HDPE	1,563	3,813	144%
LDPE	2,882	4,863	69%
PP	1,269	3,068	142%
PS	1,942	2,516	30%
PVC	2,353	3,994	70%
PET	15	1,000	6,567%

Source: Modern Plastics, January 1977 and January 1989

The demand for the commodity resins is expected to grow at an even rate, except for PET (technically an engineering resin, though used in commodity applications) which is expected to gain a progressively larger share of the total plastics market.

Over the past 20 years, relative as well as absolute consumption of plastics has increased. Thus, in rigid containers plastics,which had been unheard of in 1960, now account for 18 percent of the market. Figure 7, United States Container Shipments, shows the relative increase of plastic consumption compared to aluminum and glass.

Figure 7:
United States Container Shipments



A recent survey of food company packaging executives suggests that this trend towards plastics is continuing: of the two-thirds who were switching packaging materials, all were moving to plastics. [1] The Society of Plastics Industries (SPI) estimates that by the year 2000, plastics production will increase to 38 million tons per year, more than 2.5 times 1976 production.

Markets

Packaging is the largest component of both the plastics market and the plastics waste stream. Within the packaging category, containers and film (primarily plastic bags) account for 86 percent of the plastic used, with closures and coatings making up the remainder. Plastics in packaging increased 10 percent by weight in 1987 to an average of nearly 53 pounds per person, all of which is classified as "one-trip" packaging, and can therefore be expected to reach the waste stream almost immediately. Plastics have increasingly taken the place of more traditional materials such as glass, aluminum, and steel. This is most clearly visible in the case of PET: whereas the overall beverage container market has grown slowly since PET's inception in 1979, the PET soda bottle has grown at an annual rate of 30 percent in container applications. It is predicted that PET use in the food and drink industries could top 500 million pounds (250,000 tons) by 1992 -- 100 times its use in 1982.[2] In fact, if plastics' growth trends continue, plastics will replace glass as the second most common container material.

The second largest market for plastics, building components, is highly sensitive to trends in construction and housing starts. Thus high growth rates in construction imply a strong demand for secondary plastics as a substitute for virgin plastics. However, this market holds relatively little importance in terms of the municipal waste stream: building components are generally not allowed in municipal landfills (and are thus not classified as municipal wastes) and they generally take so long to reach the waste stream (conservative estimates suggest 20 years or more) that they fail to contribute a significant amount of plastic to the waste stream.

Other important plastics markets are transportation, electronics, appliances, toys, and furniture. In each of these applications, plastics are increasingly being used to replace heavier and/or more costly materials. For example, plastics have increased 37 percent by weight in cars since 1976, and could make up almost every part of a new car in the foreseeable future: several car companies have developed cars made exclusively of plastics (engines as well as bodies) which are at once lighter, easier to fabricate, easier to assemble, and more energy-efficient than current automotive designs. These markets are important both in terms of their contributions to the waste stream and in terms of their ability to absorb secondary plastics.

The breakdown of plastics production by markets is shown in Table 16, Major Markets Ranked by Size.

Table 16:

Major Markets Ranked by Size

Markets	('000 Tons)	% of Market
Packaging	6,352	41%
Building	5,324	34%
Electronics	977	6%
Transportation	801	5%
Housewares	635	4%
Appliances	540	3%
Furniture	481	3%
Toys	351	2%
Total:	**15,432**	**100%**

Source: Modern Plastics, January 1989

Markets for Secondary Materials

As demand for plastics has outgrown the resin producers' ability to meet it, converters (manufacturers who turn resins into goods) have been eyeing secondary plastics as virgin resin substitutes. The simultaneous trend toward mandatory recycling (and legislation banning non-recyclable packaging) has encouraged manufacturers to find ways to separate, clean, and reuse the collected plastics. This has led to innovations on two fronts: 1) separating and cleaning the plastics, and 2) using the contaminated mixed plastics as one material. In the first case, secondary plastics can be used to replace resins otherwise used for manufacture, but in the second case, the plastics are competing in low-grade applications with wood and cement--materials that are considerably cheaper.

Current post-consumer plastics recycling has centered on PET and HDPE. PET is being recycled into the broadest range of goods: fiberfill, strapping, pallets, engineering plastics, and various combinations of its chemical components. HDPE is used primarily for pipe and flowerpots, as is PVC. No post-consumer plastic film (which is primarily LDPE) is being recycled in the United States (such film as is being collected is sent to Asia or Europe for recycling), though film recycling is widespread in Europe.

Current technology can clean most of the contaminants that accompany plastics in the waste stream, but it cannot get all of them. As a consequence, there is a strong belief among plastics producers and recyclers that the Food and Drug Administration, which must approve all packaging that comes into contact with food, would not approve secondary plastics for food-contact purposes (packaging, microwave trays, etc). Since gaining approval is expensive no one has sought to enter this market. The result is that plastics' largest market (and largest contributor to the waste stream) cannot absorb secondary plastics.

This leaves leaves the markets displayed in Table 17, Estimated Markets for Secondary Plastics. The largest single market for post-consumer plastics is pipe: drainage, plumbing, agricultural, etc., for which the primary feedstocks are HDPE and PVC. The transportation industry is beginning to absorb secondary plastics in applications as diverse as floor mats, fenders, and dashboards. The most traditional market for secondary plastics has been nursery supplies: flowerpots, pallets, plastic edging, etc., but recycled plastic is also making inroads in markets as diverse as battery cases and tricycle tires. A sample of markets by end product, plastic, type and size is shown in Table 17:

Table 17:

Estimated Markets for Secondary Plastics ('000 Tons)

	Markets						
	Pipe	Non-Food Pkging.	Electr.	Transport	Toys	Misc.	**Total**
LDPE	59	452	185	0	82	400	**1,177**
PVC	1,720	0	256	111	17	600	**2,703**
HDPE	271	1,100	58	43	85	350	**1,907**
PP	20	0	23	187	20	1,150	**1,400**
PS	11	40	205	0	119	225	**600**
PET	72	23	27	100	0	1,000	**1,221**
TOTAL	**2,151**	**1,615**	**754**	**441**	**322**	**3,725**	**9,006**

Source: ILSR

It is estimated that almost 10.5 million tons of plastics are discarded each year in MSW [3]. Waste plastics from autos (not included in estimates of the plastics available in MSW) are predicted to reach a million tons annually by 1990[4]. Thus, the supply of plastic scrap exceeds the markets able to absorb it by several million tons--even more if one takes into account unrecycled scrap from packaging operations. Furthermore, several of the plastics in the packaging market alone provide more secondary plastic per year than their markets can absorb: both LDPE and HDPE are present in quantities exceeding their markets by several thousand tons. This would suggest that one needs to look at non-plastics markets to ensure the expansion of recycling.

This is precisely what the developers of the mixed plastics waste technology did in developing a wood substitute. These products are especially suited to use as docks, piers, horse stalls, and other applications where wood is subject to rapid environmental decay. This market is especially useful for absorbing mixed plastic tailings--the plastics which remain in the waste stream when high-value, easily separable and recyclable resins have been removed. These lumber substitutes are also useful in applications where splinters and wear pose problems. However, it is unclear how large the market for this "lumber" is since plastic lumber costs twice as much as treated lumber This could change as advances in the technology enable faster, more cost-effective production. However, the multiplicity of plastics in everyday goods is already rendering it more difficult to separate one plastic from another either visually or mechanically, thus condemning enormous quantities of these plastics to the mixed waste technology (see Table 19).

Large resin manufacturing firms are beginning to involve themselves in plastics recycling--a sector otherwise composed entirely of very small entrepreneurial firms. If the aluminum industry is any indication, the participation of the larger corporations can lead to more recyclable design, increased technology, and a greater emphasis on using secondary materials. The aluminum industry'w experience is discussed in the following chapter.

WHY RECYCLE?

Firms and municipalities large and small are recycling because plastics recycling is the means to a host of ends: from both the municipal and the manufacturing perspective, plastics recycling can be adopted as an economic strategy, a disposal strategy, a political strategy, and an environmental strategy.

At the firm level, plastic scrap's inexpensiveness (it sells for approximately half the price of virgin resins) and good quality make it an excellent substitute for virgin resins. A considerable part of the cost of a resin lies in the additives with which it is compounded to make it easier to work with (by broadening the range over which it melts, for example) or longer-lived. Those additives are already present in the secondary resin, and thus make it a considerable bargain to manufacturers.

There are recurrent disjunctions between demand and capacity that drive up the prices of resins and tighten up the supply to the extent that only large, "preferred" customers are sold the resins. Polyethylene prices have risen 158 percent in the past 18 months, for example. However short-term, these supply shortages and price increases are recurrent, and harmful to small producers, especially those with relatively low value added products. The low value-added markets are thus best off using secondary plastics that are inexpensive and in constant supply. At times like the present when demand far outpaces supply and capacity increases won't come on line for years, secondary materials-based manufacturers can develop market niches and relationships that they can carry on through times of overcapacity and low resin prices.

Furthermore, business opportunities exist in processing secondary plastics to render them successful substitutes for resins. Already machinery, additives, and products are being developed to facilitate plastics recycling, and numerous developers are making money licensing technologies rather than recycling the plastics. Mixed plastics waste processing has created markets for a product which didn't exist before, precisely because the conditions for economic operation could not be met with virgin plastics.

The municipality can also look at plastics recycling as an economic opportunity: the relative scale is small, the products much in demand, and the ancillary businesses good for employment. While many plastics recyling firms are highly automated, they nevertheless tend to hire several workers per ton of capacity. In the course of operations, job duties tend to become very flexible and linked closely to problem-solving rather than to strict job descriptions. This leads to a more highly skilled work force, a more dynamic economic environment, and a broader tax base.

The greatest measurable benefits accrue to both processor and municipality through adding valueto the materials and adding to the diversity of economic life within a city. Table 18, Value at Each Stage of Production, gives a sense of the products into which plastics can be recycled, and the benefits accruing to the community of so doing:

Table 18:

Value of Plastics at Each Stage of Production

($/Ton)

Value

Product	Baled	Granulated	Pelletized	End Product
Plastics				
HDPE to pipe	360	440	600	1200
LDPE to trash bag	200	340	600	
PET to fiberfill	120	500	600	1750
Mixed	40	60		1200

Notes: These numbers are averages of numbers collected in mid-autumn 1988. Because prices in the first three categories vary widely, they are used to describe relative differences in price, rather than absolute prices. The prices of finished goods vary much less, so total value added remains more constant.
Source: ILSR

Disposal is a problem for both firms and municipalities. Rising landfill costs have encouraged firms to either recycle their scrap plastics themselves or send them to someone who does. Numerous "tolling" operations have sprung up to take mislabelled, malformed, or otherwise unsuitable plastic, clean and grind it, and sell it back to the manufacturer.

Municipalities are also faced with rising landfill costs and, perhap more pressing, with overfilled landfills. While plastics contribute 8 percent of the waste stream by weight, they are thought to represent between 20-30 percent by volume in the landfill. As a consequence, the municipality saves the avoided cost of landfilling the plastic and realizes the greater benefit of increasing landfill life. Setting in place the networks for having plastics recycled is also beneficial because the 10 percent growth per year in production will increase the volume going to the landfill at an increasing rate and will increase the revenue (direct and in terms of avoided costs) from the sales of the plastics at an equivalent rate.

The plastics industry recognizes that recyclability is looming larger in the public mind and that this concern is being translated into legislation banning many plastics products. Even without laws, pressure is being brought on the industry to come up with mechanisms to reuse or recycle what it produces. This pressure can play no small part in the success or failure of a container. The Petainer Corporation developed a plastic can which was deemed recyclable (and was being recycled in Massachusetts) but which required extremely careful sorting: the can, which had a plastic body and aluminum ends, was often confused with aluminum cans and sent to aluminum smelters where it burst into flame and caused furnace fires. This degree of sorting would have required additional equipment--a demand considered onerous enough that bottlers ceased to use the cans, and U.S. production was halted, although not before legislation banning the can was enacted in several states, contributing to lackluster sales and high marginal costs of production.

At the same time, various designs have been marketed which render recycling substantially easier, and thus the likelihood of plastics being recycled much greater: the petaloid bottle, manufactured exclusively from PET, needs no stabilizing base cup (almost always made of HDPE) and thus requires no second separating step in the recycling process. A disposable soda syphon has been developed in California with recyclability in mind: the entire bottle, valve mechanism and all, is manufactured of PET. Even so, recycling programs and bottle bills are presently recovering only 1 percent of the plastics discards (though bottle bills have been successful in recovering 93 percent of their targeted containers).[5]

This is evidence that pressure for recycling does in fact change industry's perceptions of the costs that have to be accounted for in determining the benefits of the introduction or continued use of certain products, and suggests that more pressure would bring greater changes. The large firms' decisions to recycle are in large part political moves to pre-empt further antiplastics legislation[6].

Plastics have proven an issue for politicians too. Unlike glass and paper, plastics have little likelihood of disappearing into the environment through decay or pulverization. As a consequence, plastics are not easy to ignore as a source of litter. In fact, plastics' very popularity is being used against them, as the public finds them a convenient scapegoat for litter and disposal ills. Many cities and counties are banning some plastics packaging products or legislating the rates at which a material must be recycled in order to be called recyclable. Still, this very durability renders plastic recyclable time and again. Politicians, aware that recycling evokes feelings of virtuousness in participants while incineration elicits fear, are parlaying calls for recycling into votes.

Finally, with all the talk surrounding the environment, the greenhouse effect, and scarce energy supplies, plastics recycling is good for the environment. At the national level, the energy savings inherent in using the embodied energy of waste plastic (DOE has estimated that a product using secondary plastics uses one-third the energy needed to create that product from raw materials such as natural gas or oil) and reducing demand for the non-renewable feedstock can diminish dependence upon foreign sources of inputs. The environmental benefits lie primarily in the avoided production of resins: production of virgin resins is a highly polluting and hazardous process, involving six of the 10 most dangerous chemicals on the EPA's list. Further environmental benefits are recognized in the extension of landfill life and in the reduction of noxious incinerator emisions thought to be caused by plastics burning.

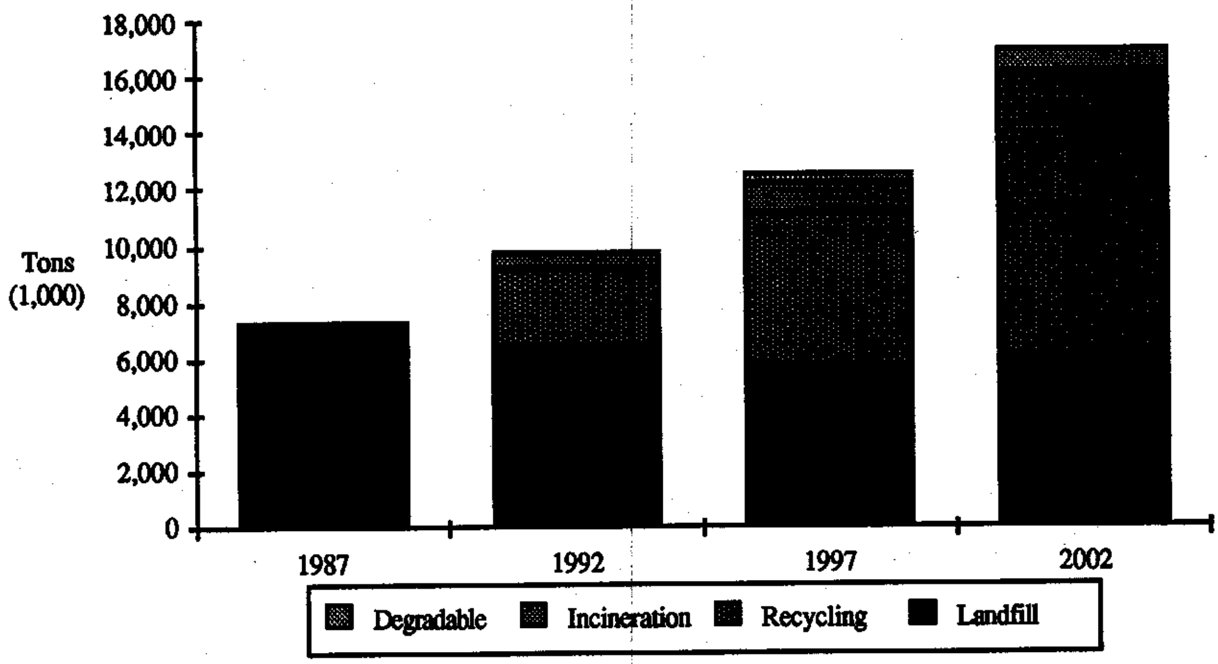
HOW MUCH CAN BE RECYCLED?

The plastics industry generally recognizes four categories of plastics recycling: primary, secondary, tertiary, and quaternary. Primary recycling converts a resin to a product with properties similar to those of its physical antecedent. Secondary recycling converts waste plastics into goods with properties other than those of the original resin (either because of contamination, or, in the case of thermosets, because they can be used solely as fillers). Tertiary recycling converts the waste plastics into basic chemicals and fuels, and quaternary recycling converts plastics into heat through incineration.[7] This study examines exclusively primary and secondary recycling because tertiary and quaternary recycling waste the embodied process energy in a material, and fail to retain the primary properties embodied in the processed good. This is in keeping with the recycling hierarchy developed in the first chapter of this book.

While only 150 million pounds out of over 20 billion pounds[8] of post-consumer plastics packaging scrap is currently being recycled, it is technologically possible to recycle virtually all of this plastic. In fact, it is estimated that about 5 billion pounds will be recycled annually by the year 2000--40 percent of the expected supply of plastic container scrap.[9] The limiting factors are collection and markets, not technology. As mandatory recycling and therefore collection increases, the disposition of plastic waste is expected to change as shown in Figure 8, Disposition of Plastic Container Scrap:

Figure 8:

Disposition of Plastic Container Scrap



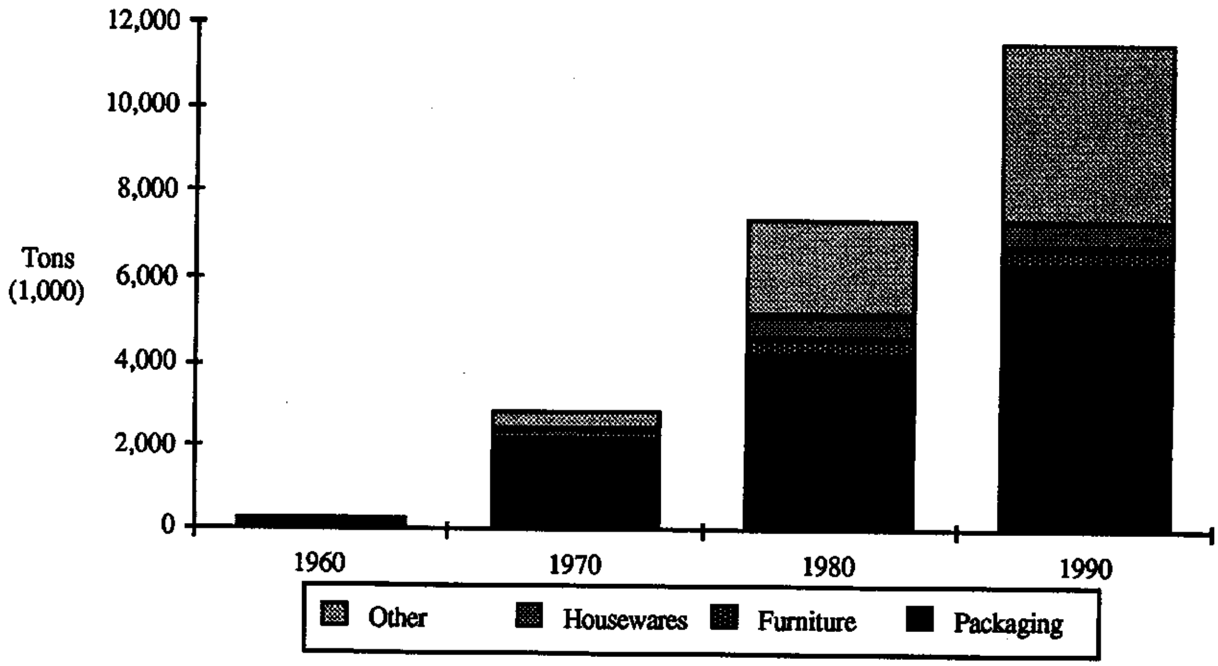
Source: Business Communications Company[10]

This predicted increased in the use of secondary plastics is both demand- and supply-led. The increase in multi-material collection spurred by landfill closings and public fear of incinerator emissions has led to greater supply, while rising prices for virgin materials has led to increased demand. Increases in tipping (dumping) fees are spurring mandatory recycling legislation, which may mean that plastics may soon be collected widely enough to serve as a large and dependable source of raw materials. Furthermore, increased demand for recycling can spur technological innovations creating inexpensive resins with broad-based properties that are readily recyclable--both technologically and economically.

WHAT PLASTICS ARE IN THE WASTE STREAM?

Plastics are used interchangeably in a wide variety of end products with different lifespans. As a consequence, it is extremely difficult to gauge with any accuracy precisely what plastics are in the waste stream and in what proportion. However, the plastics mix in packaging is known, as is the fact that plastics packaging makes its way into the waste stream within a year and accounts for 55 percent of the plastics waste stream, the rest being made up of a mix of disposable, nondurable, and durable goods (like housewares, toys, luggage and furniture), as shown in Figure 9, Plastics Discards:

Figure 9:
Plastics Discards 1960-1990



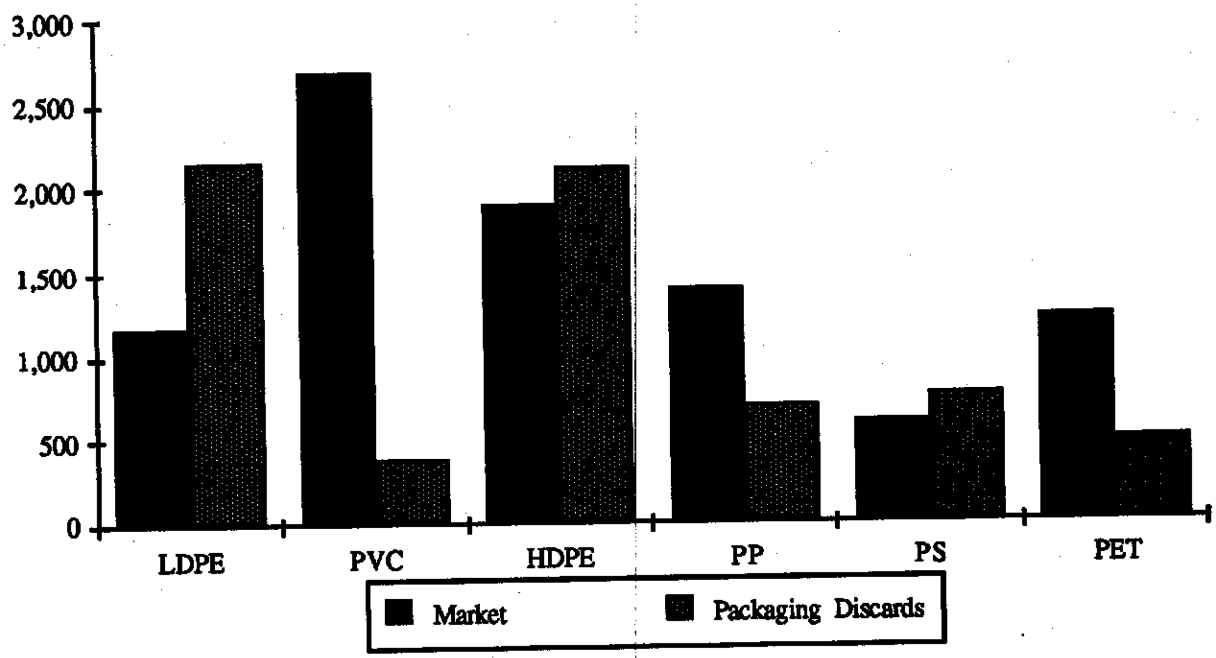
Source: Franklin Associates, 1988

Packaging Plastics

The six major commodity plastics make up 95 percent of the packaging market. Since these are the plastics most likely to be collected and easiest to sort they are at present the only plastics that will find well-defined markets. In order to fill demand for plastics in the potential markets with scrap, a realignment of plastics and their markets would have to occur. Unfortunately, each plastic has characteristics which render it particularly useful for one or another application. Thus while some intraplastics substitution may take place, supply and demand is likely to continue out of alignment. In Figure 10, Comparison of Packaging Scrap and Markets, we compare each plastics' presence in the waste stream with the extant markets to absorb them.

Figure 10:

Comparison of Packaging Scrap and Markets



Source: ILSR.

Since plastics don't decay and disappear into the environment, a very high percentage of the packaging plastic can be recaptured, though its inability to withstand extreme heat (fire, for example) certainly accounts for some loss (and total disappearance) as do the various uses consumers may find for used containers. For example, empty milk jugs with lids are used as floats for rafts, markers for swimming areas, holders for bags, etc. To allow for these losses, we will assume that 90 percent of packaging is recoverable.

However, not all packaging plastic is in a discrete and recoverable form: plastics are used as coatings on other plastics, glass, and paper and as closures for glass and plastic containers. Coatings make up 9 percent of all packaging plastic, and are lost in the recycling process. Closures make up 5 percent of all plastic packaging, and often cannot be separated without mixed plastics separation technology. While closures can, if collected, be recycled at the very least into mixed plastics waste products, coatings probably cannot, and we must therefore assume that 9 percent of packaging is unrecoverable. A further small amount of layered plastics is discarded from products like squeezable plastics bottles, and lined orange juice jugs. This leaves us with essentially 80 percent of the packaging plastic.

Nonpackaging plastics

The remaining plastics are evenly divided between plastics in durable applications such as appliances, bowls, and mugs and plastics in nondurable applications such as disposable diapers, apparel, and plastic cutlery. While these plastics are technically recyclable into something, they are composed of a much wider range of plastics, many of them thermosets and composites which are much more difficult to separate. We will therefore assume that only 50 percent of these plastics are recoverable, and that they are all destined for the mixed-plastics waste technologies. This adds 2.5 million tons of mixed plastics to our recycling feedstock.

If we therefore assume that 80 percent of the packaging plastic is recoverable, we can outline two scenarios for recovery. In one, manual separation limits high-grading to the 60 percent recognizable at sight and therefore readily separable. The second scenario assumes that the plastics are collected together and granulated before being separated in suspension. This would allow recycling of each plastic independently, and would therefore bring in the greatest returns while demanding a much greater investment. Table 19, Burden on the Mixed Plastics Market, suggest the plastic available for processing in either of the two scenarios, and the resultant load on the mixed plasics lumber market.

Table 19:
Burden on the Mixed Plastics Market
Tons For a City of a Million

	Highgrade Plastics	Mixed Plastics Market
60% High-graded	13,200	19,800
90% High-graded	19,800	13,200

What does this mean to our city? Under the first scenario, in which only 60 percent of the packaging plastics are highgraded, the amount of plastic lumber generated by a city would produce 780,000 virtually indestructible park benches per year. Under the other scenario, in which 95 percent of the packaging plastics are highgraded, over 500,000 park benches could be produced at 51 pounds per park bench. Neither of these scenarios suggests adequate long-term markets for the plastics currently in the waste stream. The better solutiowould be the recycling of plastics into their antecedent forms.

There is a discrepancy between production and disposal figures that can be accounted for by the length of time between production and disposal that is dependent upon the applications into which the various plastics go. Plastics have taken the place of numerous other materials in cars, furniture, appliances, and packaging, to name just a few products. This has been happening at an accelerating rate. Therefore, plastics in durable applications are only beginning to make themselves felt in the waste stream. This should change rapidly as products with a higher proportion of plastics enter the waste stream. Table 20, Typical Life Cycles of Plastic Products, lists some plastic products lifespans measured from production to entry into the waste stream.

Table 20:

Typical Life Cycles of Plastic Products

Product	Estimated life (years)
Packaging	1
Disposable diapers	1
Pens, lighters, razors	1
Footwear	2
Apparel	4
Toys	5
Housewares	5
Sporting goods	7
Luggage	10
Furniture	10
Wire & cable	15
Construction material	20

Source: Milgrom, Franklin, and Brewer (from Brewer, 1988)

Separation

In order to derive the maximum valuefrom secondary plastics they must be separated into usable and differentiated components by both color and type. Traditionally this has been done by hand either at the household level or by workers at a processing center. However, in order to recycle large quantities of plastics, mechanical sorting is necessary. Techniques for mechanically sorting mixed ground plastics by their density have already been developed as have other techniques for separating whole bottles by color and composition. Although these techniques would enable high levels of plastics recovery while simultaneously guaranteeing the highest quality, they require numerous stages of machinery, large quantities of liquid solutions, and solvent baths. They have been uneconomical to run because they are expensive, they function too slowly, and there are insufficient markets for the final products. There is reason to believe that the already high rate of innovation in plastics recycling will continue and such problems will be overcome in a fairly brief period of time.

Evidence that these problems are already being overcome can be found in the 1988 Plastic Bottle Recycling Directory that lists over 60 companies that reprocess post-consumer plastic containers, almost twice the number in the 1986 directory. In fact, long established virgin-resin users have found it economical to switch completely to secondary resins: with virgin HDPE costing about 43 ¢/lb and secondary resins commanding only 18-25 ¢/lb, there exists a strong incentive to use secondary resins in as many applications as possible. The economics are even more favorable for engineering thermoplastics: a $2.00/Lb virgin resin can be replaced by a 50 ¢/lb secondary resin. This has led to resins designed for recyclability and to alloys derived from secondary resins.[11,12]

On the basis of production and life span statistics ILSR has calculated the amounts of each plastic available for processing as shown in Table 21, Available Separable Scrap:

Table 21:
Available Separable Scrap ('000 Tons/yr)

	U.S.	City of a Million
LDPE	1,725	7.19
PVC	304	1.27
HDPE	1,704	7.10
PP	568	2.37
PS	618	2.58
PET	396	1.65
Total	**5,315**	**22.16**

Add to this 2.2 million tons of mixed plastics, and there are 7.5 million tons of scrap plastic for processing--31,300 tons per year for a city of a million.

WHY SMALL-SCALE?

Several industry factors inhibit large-scale plastics recycling. Most importantly the large converters recognize economies of scale in buying: while virgin PET is sold to them at $.60/lb, smaller converters have to pay more than twice as much--$1.40/Lb. At the lower price the virgin materials are worth twice as much as scrap PET, but the scrap PET is not as pure, and can entail more work--changing screens, etc. As a consequence, the larger firms may find the virgin material's premium price worth the savings in labor and convenience. This explains why recycling is driven primarily by small firms.

Second, collection systems are not yet widespread, and a large firm may not be able to get sufficient quantities easily. There are no long-term markets for plastic scrap, which is consequently sold either on spot markets (which vary widely in price due to fluctuations in the availability of both virgin and secondary materials) or through direct contracts between buyers and sellers.[13]

WHAT DOES IT TAKE?

As explained above, smaller operators benefit most from using secondary materials. This is for two reasons: 1) they recognize greater unit savings than the larger producers and 2) they require smaller amounts of materials and therefore fewer contracts. For small manufacturers the costs of doing business with secondary materials producers is the same as the costs of doing business with virgin materials producers, but these costs are much greater for large manufacturers: relatively small collectors can provide a small manufacturer with sufficient plastic, whereas a large company would need many more contracts in order to get a sufficient supply of materials, thus substantially increasing transaction costs. Furthermore, small-scale operations benefit much more from the lower transportation costs that accompany the siting of a plant near both inputs and markets. This study therefore focuses on the smaller-scale rather than larger-scale operations.

As explained in the Plastics appendix to this report, recycled plastics must be sorted by plastic type and, if possible, by color. Once sorted, they are ground into 3/8" squares (called regrind or flake), cleaned into clean flake and often, though not necessarily, remelted and formed into tiny pellets. At this stage they are, not surprisingly, referred to as pellet.

The smallest extant United States regrinding operation has an output of 400,000 lbs/yr, or 0.59 TPD, and processes primarily HDPE. Larger operations process several plastics. The smallest remanufacturers operate at about 1 TPD and manufacture a variety of products ranging from flower pots to plastic mats. Pelletizers tend to be larger as they achieve a small profit margin and have relatively expensive equipment. The smallest pelletizer we found ran at about 6 TPD, though it should be possible to run at about half that size. Very small-scale fabricators by industry standards produce under 500 tons per year (TPY)[14] or 2 TPD. However, even firms producing 70 TPD consider themselves small-scale.

The scale of molding and forming operations ranges from 2 TPY to 225,000 TPY with an average plant producing 12,000 TPY.[15] This average-sized plant would need twice as much of any given plastic as a city of a million could be expected to generate. While the smallest plants tend to produce high-value added products (rather than commodity products), manufacturers of plastic pipe (a commodity product) are known to work exclusively with secondary plastics, producing less than 5,000 TPY. Manufacturers of flower pots, plastic lumber, and auto mats work profitably at a third of that scale using secondary plastics.

Thus a city of a million could support numerous granulators, cleaners, and pelletizers producing virgin resin substitute at per-plant rates of under 2,000 TPY. Each step could be processed independently or various combinations of steps could be performed within a plant. Small-scale compounders (under 500 TPY) can be set up to upgrade the plastics with additives before they are taken by the molders for use in fabricating specific products.

Table 22, Capital Costs for Selected Plastics Processors, compares the capital costs, including engineering, building, etc., for the erection of greenfield facilities for various plastics processors.

Table 22:

Capital Costs for Selected Plastics Processes

	TPD Capacity	Capital cost/ton	Total Capital Cost
Regrind	3.0	$250,000	$750,000
Clean Flake:			
PET	22.0	110,000	2,500,000
Other	2-5.0	90-150,000.	300-450,000
Pelletizer	2.4	500,000	1,190,000
Mixed Plastic	3.4	220,000	770,000

These processes, in cleaning the plastic, add a maximum of $600 but typically only about $400 per ton of input materials. However, were the city or, rather, its entrepreneurs to process this plastic into final products the valueof the materials could increase to over $4,000 per ton depending on the application. The same benefits that accrue to the city accrue also to the entrepreneur: profitably adding $400/ton necessitates a greater volume than adding $4,000. The costs for these operations, as well as the scale, are more difficult to quantify because the operational costs vary enormously depending upon the application, and the returns depend upon the specialization in the product. For examples, plastic pipe can be manufactured and sold at $1,200 per ton, truckbed liners at $4,000, and flooring tiles for $4-5,000.

Cost Breakdowns

The equipment cost for a PET granulate recycling operation is approximately $150,000 including both the grinding and the cleaning operations. Multiplying by the Center for Plastics Recycling Research (CPRR) factor of 5, one gets total costs for the operation (construction, engineering, building, but not land) of $750,000, or $250,000 per rated daily ton capacity.[16]

The PET bottle recycling technology developed by CPRR is estimated to cost $2.5 million dollars for equipment, installation, land and building, and produces clean polyethylene and polyester granulate. At its 22 TPD break-even capacity, the plant costs approximately $110,000 per ton.

The PET washing and high-grading system which St. Jude Polymer uses costs approximately $2 million--$280,000 per daily rated ton capacity. This includes a quality control laboratory, in-line storage, water recycling units, and a cyclone (see plastics appendix for a description).

However, the cleaning technologies for other plastics (generally invented by each producer and hence proprietary) are estimated to cost between $100,000 and $250,000 for the equipment and another $200,000 for the building--$90,000 to $150,00 per rated ton daily capacity at 2-5 TPD--a much lower break-even point.

The mixed plastics lumber equipment costs $295,000 for outputs of 400 pounds per hour--3.4 TPD. Adding $250,000 for the building, $200,000 for granulators, conveyors, and the like, and another $250,000 for installation, the capital costs per rated daily ton capacity are approximately $290,000.[17] Another recently developed technology which produces plastic lumber can process the plastic almost three times as fast as existing processes, and may thus change the economics and/or scale of production. However, it is not yet beyond the pilot-plant stage, and the economics are therefore uncertain.[18]

For a system which takes in a specific plastic and pelletizes it, costs break down as shown in Table 23, Capital Costs for a Standard Pelletizing Operation:

Table 23:

Capital Costs for a Standard Pelletizing Operation

Granulator & Shredder	$200,000
Washing System	$100,000
Extruder & Water Bath	$113,000
Pelletizer	$ 27,000
Building	$250,000
Installation & startup	$500,000
Total:	**$1,190,000**

The capital costs per rated daily ton at 2.4 TPD (one shift) are $500,000. If production expands to three shifts per day, the capital costs per daily rated ton become $170,000 with the same equipment.[19]

So, a city of a million could set up the plants shown in Table 24, Potential Number of Processors Sustained by Waste Scrap, to process each plastic into a virgin materials substitute:

Table 24:

Potential Number of Processors Sustained by Waste Scrap

	City (TPD)	# Granulators	Pelletizer	Molder
LDPE	27.64	9	4	1
PVC	4.87	2	-	
HDPE	27.31	9	4	1
PP	9.10	3	1	
PS	9.91	3	1	
PET	6.35	2	1	
Mixed	35.00			10
Total	**120.18**	**28**	**11**	**12**

However, to really recognize the value of local production, the plastics must be further processed into goods. This step of production can be added onto any of the processes listed above, or set up independently. In either case, the plastic must be remelted, mixed with additives if necessary to endow it with the requisite properties, re-extruded, and then molded. The molding machines and molds vary considerably in price depending upon the final product. This is due to the size of the final product, the amount of tooling required, the force with which the product must be molded and the type of molding machinery used: plastic goods can be blow-molded, vacuum-formed, compression-molded and injection-molded. Container forming operations give a good indication of the variation in price for a set of molds: costs for a set of bottle-forming molds can vary by a factor five depending upon the neck finish alone.[20]

The following numbers are presented to give a sense of the costs involved: A set of molds for continuous manufacturing of plastic pipe can cost $55,000 for each size of pipe (a plant would want to manufacture a dozen sizes), while molds for coat hangers might cost $30,000 per set. An injection molding machine that would process about half the HDPE available in the city per day would cost just over $500,000.[21] This machine could, with the addition of various molds, process a variety of goods from coat-hangers to traffic cones. A blow molding machine could cost $750,000 but could produce all kinds of containers.

How close does this come to closing the loop? In gross numbers, this level of recycling would fill 20 percent of a city's current demand for plastics. This seems rather low for so vigorous an effort, but this is due to the nature of plastics recycling, which disallows the greater portion of recycling into the antecedent processed form and therefore stresses continual downgrading until a final home is found as a lumber substitute.

Precisely because this is not a very sunny scenario, work is being done on upgrading secondary plastics into engineering-grade applications for durable products such as auto parts and industrial equipment. Additives are being developed to overcome the problems specific to recycling: heat and light degradation in the original polymer, difficulties in mechanical separation, and successful use of colorants. These operations should be no more capital-intensive than those outlined above, and, while adding to the raw materials cost, can upgrade a $600 per ton scrap plastic to a $2-3,000 per ton resin.

CONCLUSION

By setting in place collection systems and recycling networks, a city can not only reduce the current volume of plastic going to the landfill, but can preclude rapidly increasing quantities of plastics from making their way into the waste stream. Furthermore, the city can meet a large portion of its plastics and plastic product needs through recycling of secondary plastics, thereby reducing its dependence upon foreign sources of materials, increasing its economic life, and creating numerous jobs. This form of manufacturing not only benefits the city, but also benefits the business that can substitute this locally abundant, inexpensive supply of raw materials for expensive resins.

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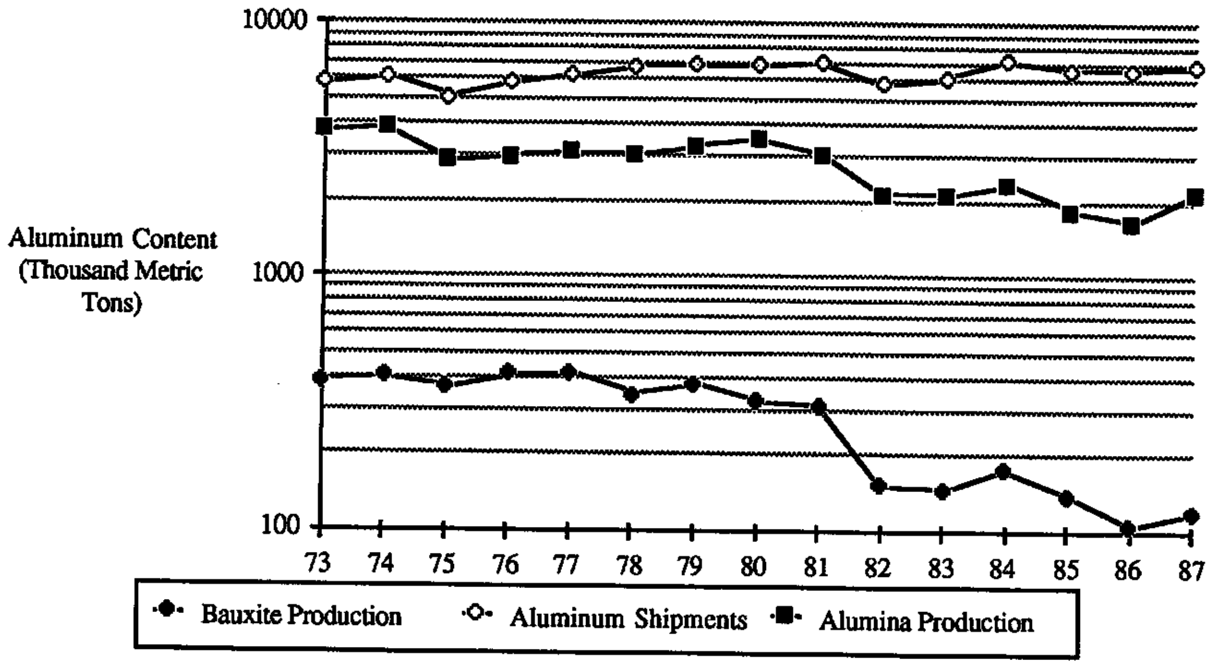
ALUMINUM

INTRODUCTION

Primary producers manufacture aluminum by refining bauxite ore into alumina and then smelting the alumina into aluminum (for a more complete discussion of this process please turn to Appendix 5, Aluminum Processing). They mine the ore primarily in equatorial zones. The United States aluminum industry is largely dependent for raw materials on the nations in which bauxite is found, many of which are developing nations. The ability to exploit scrap materials is therefore especially important in this industry. Since 1973, United States bauxite production has decreased (see Figure 11, United States Aluminum Production and Shipments). Imports and recycling have kept American aluminum production volumes relatively stable.

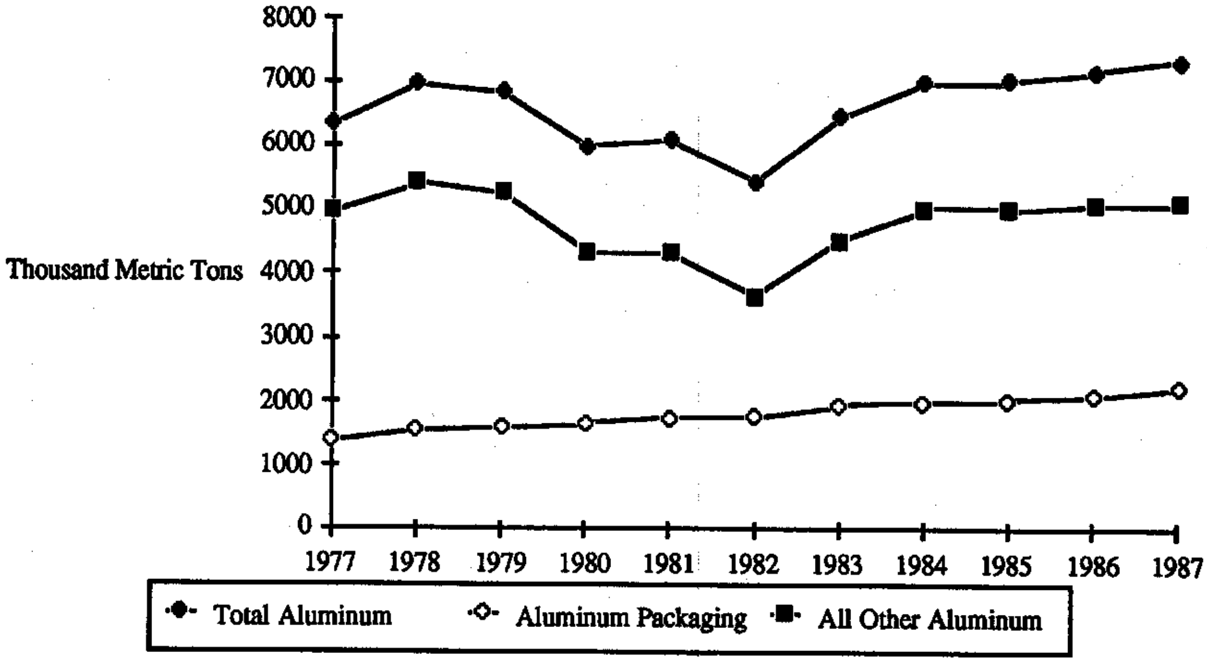
Figure 11:
Trends in United States Aluminum Production and Shipments
1973-1987
(semi-log scale)



Source: Bureau of Mines and Aluminum Association

Between 1974 and 1984 demand for aluminum end-products in the United States rose approximately 1 percent annually, on average. Aluminum cans and aluminum in passenger cars accounted for most of the growth, while other types of consumption remained stable or even shrank, (see Figure 12, Relative Growth of Aluminum Packaging and All Other Aluminum Products). Both cans and cars are significant consumers of secondary aluminum. Secondary aluminum has long been recast into car parts, while discarded aluminum beverage cans are increasingly recycled into new cans.[1] Growth in demand for aluminum in the United States between now and the year 2000 is predicted to be about 2 percent a year.[2]

Figure 12:
Relative Growth of Consumption of Aluminum Packaging and All Other Aluminum Products
1977-1987



Source: The Aluminum Association.

ALUMINUM FOR THE CITY

As Table 25, Tons of Aluminum Scrap Available, demonstrates, if our hypothetical city of one million inhabitants were to recycle all of its aluminum it would have approximately 75 percent of the aluminum necessary for production for the city. Different products that contain aluminum have different life cycles. An aluminum can is discarded shortly after use, while aluminum in cars becomes available approximately 10 years after it has been fabricated. Aluminum machinery has an average useful life of 20 years. In 1987, machinery made in 1967 would become available for recycling. These different life cycles indicate different levels of utilization. If all of the aluminum available from construction uses which had been installed 35 years ago were to be recycled, this would represent approximately 17 percent of the construction aluminum that was shipped in 1987.

For aluminum recycling the city will have to rely on a combination of source separation and mixed aluminum processing. The success of aluminum can recycling is due to its easy identification and separation from other materials. Thus, aluminum cans can be sorted out by the consumer and then our hypothetical city will have a valuable source of materials. The rest of the materials are more difficult to sort and must be processed during resmelting in order to achieve a uniform supply.

Table 25:
Tons of Aluminum Scrap Available
for a City of One Million in 1987

Market	Life cycle	Year of interest	Scrap available	% of total	% 1987 Shipments
Packaging	1	1986	8,850	39%	94%
Transportation	10	1977	6,070	27%	94%
Consumer Durables	10	1977	2,250	10%	85%
Construction	35	1952	1,090 (est.)	4%	17%
Machinery	20	1967	1,290	6%	70%
Other	10	1977	3,260	14%	75%
Total old scrap available			22,810	100%	73%

Source: Based on Aluminum Recycling Casebook, Aluminum statistical review for 1987, and Aluminum Association.

If the city were to separate and collect all of its waste aluminum, it could establish two manufacturing facilities:

- A resmelter to consume 5,500 tons per year of used beverage containers
- A resmelter to consume 4,000 tons per year of car scrap
- A minimill to consume 9,000 tons per year of mixed aluminum sheet

These three facilities would consume approximately 80 percent of the aluminum discarded by the city in 1987. Their production would reduce but not eliminate the dependence of the city on outside manufacturing and sources of materials. The resmelters would ship recycled aluminum to a manufacturing facility to be rolled into rigid container stock (RCS) or car parts. This RCS would then be manufactured into cans to be filled and shipped back to the city for consumption. The RCS from the city would, of course, provide almost as much stock as would be needed for the city. The car scrap could be recycled into grades that could be used in cars and airplanes. The remaining aluminum would provide less sheet than would necessarily be consumed and the city would still need additional aluminum from the outside.

For certain processes, the capital costs for producing aluminum from bauxite are significantly higher per ton than they are for producing from scrap (see Table 26, Capital Costs for Primary and Secondary Aluminum Processing). This is due to the significant costs of establishing separate mining, refining, and smelting operations. Minimills' lower capital investment has allowed secondary minimills to achieve limited success in siding and guttering, which are relatively low-value-added products (the derivation of these numbers is explained in Appendix 5, Aluminum Processing).

Table 26:

Capital Costs for Primary and Secondary Aluminum Processing

Bauxite	$	470/ton
Alumina	$	2,000/ton
Aluminum	$	3,500/ton
Total (virgin)	$	5,970/ton
Total (recycled)	<$	1,240/ton

Source: Based on Mineral Facts and Problems, 1985 Edition, and Hunter Engineering.

The minimills, with their recycled feedstock, are not in direct competition with primary producers. Primary producers have a higher-value-added output because they are better able to control the surface characteristics of the aluminum they produce: aluminum used on the sides of cans must be significantly smoother than the aluminum used for gutters and siding. Thus the capital cost savings are not a competitive benefit to recyclers. However, researchers from the primary producers continue to work toward adapting minimill technology for higher-grade applications.[3]

With aluminum, access to inexpensive resources and the low price of minimill technology are advantages that favor small-scale production. Small-scale aluminum entrepreneurs operate in the lower value segment of the market and thus do not threaten the profits of the larger companies. Most commonly they are kept in business by their very close relationships with their suppliers and customers.

WHY RECYCLE?

Processing waste aluminum adds value. Table 27, Value Added to Aluminum Scrap, shows the value added to Used Beverage Containers (UBCs) and mixed aluminum at each stage of processing. The estimated value added to the most commonly recycled grades of scrap is based on published prices. It was assumed that UBCs would be recycled into aluminum to be remanufactured into beverage containers. The mixed aluminum collected from scrapped cars and demolished buildings was assumed to be baled for processing into siding.

Table 27:
Value Added to Aluminum Scrap

	garbage	buy back	baled	end product	total value added/ton
UBCs	($0)	$600	$1,230	$2,300	$2,30
Old sheet	($0)		$1,240		$1,240

Source: Based on data collected by Pat Plunkert, U.S. Bureau of Mines.

Not only does the processing of scrap into finished products add value to materials that were once considered waste, but it produces significant savings in energy costs. For example, in 1985 the cost of energy represented 33 percent of the value of shipments in the primary aluminum industry, while in the secondary nonferrous metals industries the cost of energy was less than 4 percent of the value of shipments.[4]

The primary production of aluminum requires significantly more energy than does recycling aluminum. Aluminum recycling eliminates the need for refining and original smelting. The most energy is saved in the bypassing of the smelting process. When aluminum is smelted from alumina it requires 1,000 times as much electricity as when scrap aluminum is resmelted. In total, secondary processing consumes approximately 7 percent of the energy used in primary processing.

In addition to saving energy, aluminum recycling saves materials. Moreover, the alumina refining process pollutes air, land, and water. For each ton of alumina refined from bauxite, a red mud slurry containing one or more tons of solids is discharged into ponds where the solid material settles out after a few years. Sulfur dioxide and dust from the bauxite, alumina, and other materials must be filtered. Aluminum manufacturers use eight tons of materials, including the ore and materials used in the furnace, for every ton of finished aluminum. Aluminum recycling reduces this consumption of materials.

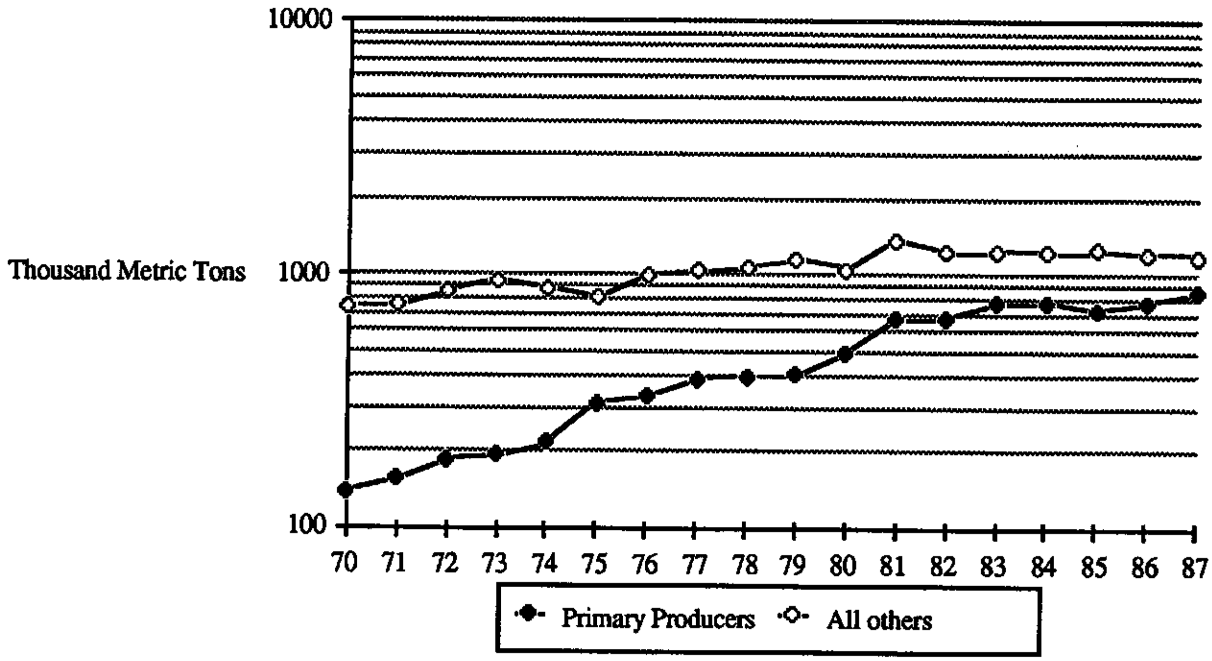
In 1984, more than 900,000 tons of aluminum, almost 40 percent of the amount discarded, were recycled.[5] The remaining 60 percent of aluminum discards, one-and-a-half million tons each year, is not recycled and is discarded into the municipal waste stream. The Bureau of Mines projects that unused discards will rise above two million tons by the year 2000.[6] If all available aluminum were recycled it would account for slightly less than three-fourths of the aluminum needed. Yet in 1987 old scrap consumption represented only 28 percent of the metal shipped by the industry.[7]

There are three important consumers of aluminum-scrap: primary producers, secondary smelters, and minimills. Primary producers are so named because they produce finished aluminum from bauxite. In most cases they use scrap as a supplement to virgin materials. However, in their production of can stock, they have moved significantly toward secondary sources. Secondary smelters have traditionally remelted scrap and produced ingots for use in foundries. In general they do not produce end products. Minimills, on the other hand, consume only aluminum scrap and produce finished products. At this writing there are no minimills producing can body stock, though Coors Brewing Co. operates a mill that produces can end stock. Figure 13, Consumption of Aluminum Scrap by Producer, shows demand for aluminum scrap.

Figure 13:

Consumption of Aluminum Scrap by Producer

(semi-log scale)

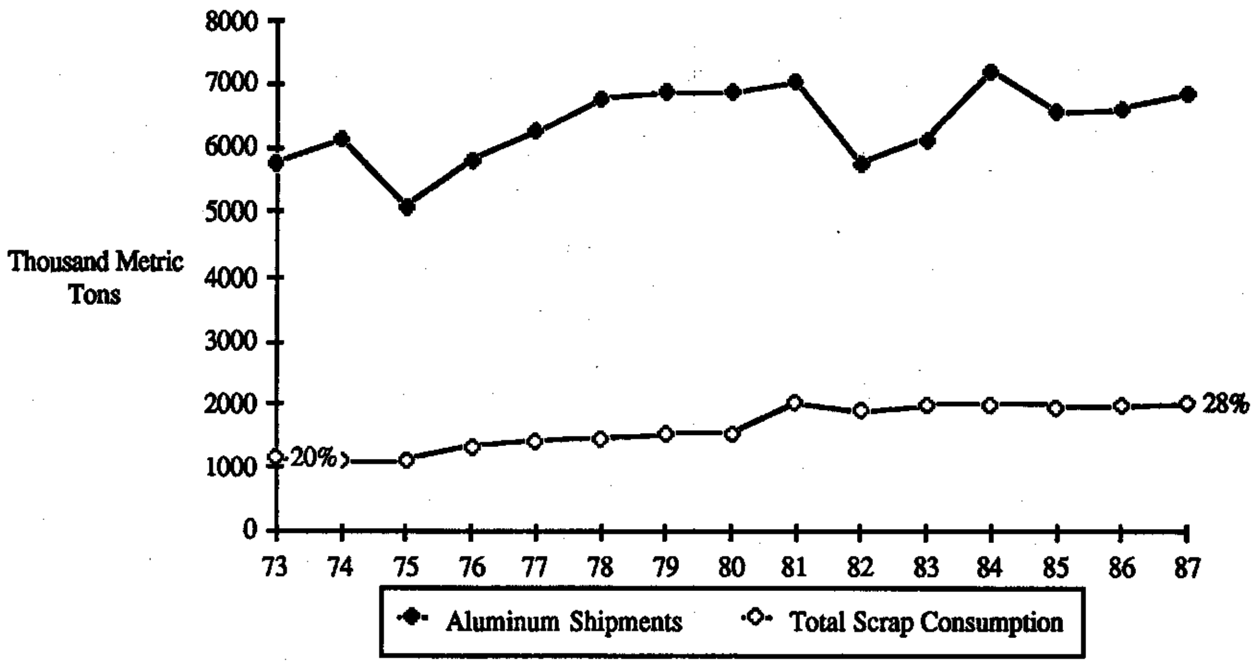


Source: The Aluminum Association, Aluminum Statistical Review for 1987, p. 31.

The two largest sources of old scrap are transportation uses, and packaging. Transportation uses, such as airplanes and cars, provide approximately 27 percent of all old aluminum scrap. Containers and packaging make up slightly less than 40 percent of old aluminum scrap. Of these two large sources of aluminum, it is estimated that the most accessible source is cars and other transportation uses, because of their size and relatively high proportion of aluminum content.

The other large source of old scrap is aluminum cans or used beverage containers (UBCs), which in 1987 accounted for 1,322,000 tons or 16 percent of aluminum shipped. Because of the quick turnaround (metal from an aluminum can may return to a recycling center within three months after the can is fabricated) much attention is paid to the level of UBC recycling.[8] In 1987, UBC recycling represented approximately half of new aluminum can production.[9] This indicates a dramatic increase from 1979, when UBC recycling represented 25 percent of new can production.[10]

Figure 14:
Aluminum Shipments and Recycling



Source: U.S.Bureau of Mines and the Aluminum Association

There are two kinds of aluminum mills: primary and secondary. The primary mills, which refine bauxite into aluminum, range in size from 81,000 to 298,000 tons per year.[11] They produce both wrought and cast aluminum. Companies with primary mills, such as Alcoa and Reynolds, possess a high degree of vertical integration and diversity of operations. Reynolds Metals Company owns bauxite mines in Australia, Brazil, Guinea, and Jamaica; manufactures a full range of aluminum products from cans to building parts; and operates approximately 88 recycling plants and service centers.[12] Secondary mills, sometimes called minimills, each produce anywhere from 10,000 to 100,000 tons per year. Larger mills are generally not interested in buying scrap directly from communities. In general, they buy from resmelters who prefer to buy from scrap dealers who are able to amass a quantity of metal large enough to warrant transportation to the resmelting operation. Minimills have the lower capital and raw materials requirements that make it possible for them to locate in a particular community. Existing minimills distribute their goods regionally and sometimes nationally. These size and capital advantages make the minimill technology appropriate for our hypothetical city.

WHAT LIMITS RECYCLING?

The potential for aluminum recycling is limited by the presence of contaminants in post-consumer waste. For example, plastics mixed with aluminum are difficult to detect. Many of the more commonly recycled alloys contain a high percentage of magnesium, and therefore must be treated before being recycled into alloys requiring lower magnesium. Paint, oil, plastic, and rubber can burn during resmelting, raising the cost of air pollution control. Another obstacle to the use of scrap aluminum is the lack of uses for mixed alloys. Thus, aluminum must be sorted into alloys for different applications. This is not always economically feasible with small supplies of mixed aluminum. These factors could be overcome through progress in developing sorting technology.

The logistics of aluminum supply also limit recycling. Producers must be assured of a continuous supply to justify expenditures for recycling equipment, but it is often difficult to accurately gauge the potential supply. Some aluminum is embedded in products, such as cans, with short life cycles. Aluminum scrap from these sources will generally become available for consumption within one year of production. Aluminum is also used in the production of buildings, cars, and airplanes. Though there are general estimates available for the various time periods in which these sources of scrap will become available, their availability cannot be guaranteed. The small amount of aluminum contained in a particular application may make recovery not worth the cost. In buildings aluminum scrap is usually found entangled with other materials, which, if mixed with the aluminum during resmelting, may cause pollution problems.[13]

In addition, the established scrapping process has become more environmentally sensitive in recent years. Some aluminum-bearing items, such as refrigerators, can become potentially hazardous when scrapped. Due to increasingly stringent regulation scrap dealers will no longer accept these items, which are landfilled instead. In addition, some alloys are very specialized and cannot be effectively separated from more general scrap; their superior properties are lost for further processing.

When cars and other large durable goods are recycled there is always the possibility that they are being recycled for materials other than aluminum even though they may also contain aluminum. Some separation techniques yield a remainder that is not easily recyclable. However, this may become less of a problem as cars come to contain more aluminum than previously, making it more cost-effective to separate and recover the aluminum.

BENEFITS OF SMALL-SCALE MANUFACTURING

In 1987 the aluminum industry's consumption and secondary material supply was:

- 68 pounds per capita consumption
- 2 percent annual growth rate
- 20 percent of aluminum packaging difficult to recycle (foil and closures)
- 50 pounds of secondary aluminum available per capita
- 19 pounds of secondary aluminum recycled per capita.

For industry, siting small facilities near to cities makes sense, because it allows them to shorten the supply chain. This reduces transportation costs.

Processing UBCs for manufacturing into can stock provides a business opportunity in high-grading. In the spring of 1988, UBCs were bought from consumers at approximately $920 a ton. After processing, removal of lacquer, and resmelting, the aluminum was worth $1,420 a ton. Initially, UBCs are high-graded by removing anything that isn't aluminum: dirt, moisture, plastic, steel, iron, lead, and paper. Such contaminants reduce the usefulness of aluminum for recycling. Plastics burn during delacquering. Dense metals fly out of the shredder and can cause accidents or injuries. Aluminum contaminated with dirt and sand must be diluted with more expensive primary aluminum. These contaminants can clog a recycling plant's or mill's air filters. Contaminated UBCs must be sold for lower grade, lower price applications.[14]

Establishments that high-grade automobiles were primarily intended to procure steel. In the process of separating the shredded car three basic components are separated. Magnets pull out 1) the steel and blowers separate 2) the fluff, a mixture of plastics and other materials, leaving 3) a non-ferrous residue. This residue contains zinc, copper, and lead, which can be separated from aluminum through what is called a dense-media process.

Before establishing the recycling facilities suggested on page 82, our hypothetical city would have to identify the methods already being used to collect -waste stream materials and would have to attempt to have some UBCs directed to the new resmelter. Once resmelted the new aluminum stock could be shipped to a primary aluminum manufacturer such as Alcoa or Reynolds to be made into rigid container stock, the thinly rolled metal that forms the basis for aluminum beverage cans. This process, whereby a facility at one location is responsible for melting the metal while a facility at another location takes the metal a step further, is also already entrenched in the aluminum industry. Such operations require very little technological expertise; the most crucial aspect of the process is ensuring that scrap cans are free of combustible contaminants.[15] This means that the city must either have a well established collection program or have good relations with sources of collected aluminum.

CONCLUSION

Recycled aluminum saves energy and materials. Because of contamination, the aluminum industry still recycles less than half of the scrap metal available. Local scrap processing facilities make it possible for a city to benefit from recycling's low energy and capital costs while reducing dependence on foreign bauxite. The local recycling entrepreneur benefits from the opportunity to use scrap without incurring high transportation costs.

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TRUE ABUNDANCE

> For in the highly developed economies of the future, it is probable that cities will become huge, rich and diverse mines of raw materials. These mines will differ from any now to be found because they will become richer the more and the longer they are exploited. . . . The largest, most prosperous cities will be the richest, the most easily worked, and the most inexhaustible mines. . . . Just so, we may expect that the solving of pollution and other problems arising from wastes, while requiring many workers, will not be an economic burden upon the developing economies where such problems are, in fact, solved. On the contrary, all wealth extracted from recycled wastes, plus pure air and pure water, will represent increases in true abundance.
>
> Jane Jacobs,
> The Economy of Cities, 1969

A city maximizes the value inherent in waste materials by manufacturing them into goods that meet the material needs of its inhabitants. In so doing, it generates the jobs and incomes to purchase the goods. The benefits are not only those immediately obvious in the measurements in our charts. The secondary jobs and businesses created by growth in industries can multiply the number of jobs several times. The local economy is strengthened by increased diversity that makes it more resistant to economic disruption through either a collapse in prices for one commodity's price or dependence on one company or industry. But the greatest benefits come as a result of the long-term trends toward more efficient use of all resources: primary and waste materials, energy, land, air, and water.

Economic efficiency is improved when manufacturers must bear the production costs currently borne by society at large. Present modes of production allow manufacturers to escape the costs of disposal of the product, disposal of production wastes, use of nonrenewable resources, and depletion of renewable resources. When producers pay these costs, secondary materials become economically more attractive. Recycling leads to materials and energy efficiency. It retains the energy embodied in the original product, and reprocessing uses a fraction of the initial process energy.

The obvious benefits of these efficiencies will encourage innovation in mature basic industries. Minimills promoted the resurgence of the steel industry and enabled it to be competitive with producers in countries such as Japan and Korea despite unfavorable labor cost differentials. The low-cost local production made possible by such efficiency encourages ancillary industries to site themselves near sources of processed materials. Rubber Research Elastomerics (RRE), a tire recycling operation in Minnesota, manufactures a rubber-substitute product that it sells for half the price of virgin rubber. As a result, a second firm has set up near the RRE plant to use RRE rubber to manufacture industrial products such as gaskets.

The diversity created for each material by such developments buttresses the local economy against the shocks from cyclical fluctuations in any one industry. The oil shocks of the late 1970s prompted national recessions and the downturn in the auto industry in the early 1980s devastated parts of the Midwest. Economic diversity further diminishes the power any one company has over the economic fate of the community. Glass plants are often located in small towns where they are major employers. The closing of a glass plant can directly eliminate hundreds of jobs and, in the longer run, shrink the support sectors that provide goods and services to the plant and workers.

Much of the waste associated with manufacturing using only or primarily virgin raw materials occurs because the raw materials desired are contaminated with other elements. For every ton of aluminum produced four tons of materials are discarded. The production of glass volatilizes well over one-fourth of the batch ingredients, ingredients that are not desired but that are bound to the desirable elements and canonly be removed chemically in the melting process. Whatever their form, these waste materials become pollution and must be captured and disposed of. It is much cheaper, more environmentally benign, and more efficient to refrain from creating this waste in the first place. This can be ensured through the use of secondary materials.

A city's choice of end markets for waste materials must be determined by the availablility of raw materials. The supply and form of waste materials determines the possibilities for recycling. These can only be accurately gauged through waste stream composition studies. Many of the products people discard are products they consume over and over again such as soda, beer, medicine, and cosmetic bottles. What people throw away indicates what was consumed and points to viable end markets. It also indicates the form in which the materials arrive, and therefore the steps necessary to render them usable for processing into finished goods.

Existing capacity must also determine the recycling goals of a city. If a glass bottle plant is already located in the metropolitan area, it would be foolish to build another one. Greater returns can be recognized in fulfilling needs that are not already met through local manufacturing. A listing of those plants in the area that take or could take secondary materials should be made.

Because small-scale recycling enterprises can cost more the establish and operate than large-scale manufacturers, the city must make a financial commitment to recycling. The development of many of these plants is beyond the resources of the entrepreneurs a city would like to attract. Identifying funding sources for startups and risky businesses would allow a city to determine what additional financing will be needed to encourage the establishment of recycling businesses. The choice of technologies determines the range of goods produced by a given process and thus the extent to which local needs can be met using the local supply of secondary materials.

What a city can do:

- Ensure collection of recyclables so that the materials supply is guaranteed
- Refuse other forms of disposal so that materials flows are not jeopardized
- Set up separation plants, whether publicly or privately held, to guarantee sources of high quality materials
- Insist materials be fully recyclable into antecedent or equally high-graded form, so that benefits of value-added production are not forgone through dependence upon low-grade or easily saturated end markets
- Remove barriers to secondary materials' use in specifications
- Prohibit external costs to production such as pollution
- Set clear goals.

Even the partial realization of the model would lead to profound changes in forms of production, end products, and industry networks. These changes could well overcome the limits to achieving a perfectly closed loop.

Currently, for example, beverage companies work nationwide markets. To cut down overhead costs they set up nationwide contracts with just a couple of bottle manufacturers; these manufacturers set up plants in inexpensive labor and land markets and use nationwide transportation networks to distribute their containers to bottlers, who then fill them and distribute them locally. Such distribution networks make refillables almost unworkable--especially since the bottlers' customer are not the consumers but the retailers (who do not want to bear responsibility for storing and returning containers). A local firm would not suffer from such complicated supply chains, and could more easily establish refillables as an economic alternative if manufacturers of disposables to assume the responsibility for the cost of disposal.

Far-reaching supply chains necessitate long-life packaging, hence much of the innovation in composites and laminates. However, these packages, justified as protection from light, heat, air, and germs, are all but unrecyclable. This is most obvious in the case of orange juice containers. Because orange juice becomes bitter when slightly oxidized, it is packaged in containers with serial layers of plastics to reduce the risk of oxidation over a long shelf-life. Were the shelf-life reduced, the juice could be packaged in a single-plastic container, and that plastic could be readily recycled.

Local production, distribution, and consumption networks would also decrease the amount of materials needed for both primary and secondary packaging. The materials used in primary packaging, the packaging that the ultimate consumer sees, would be reduced because there would be fewer goods in transit and the turnaround time would be reduced. Materials in secondary packaging such as boxes, styrofoam "peanuts," and other materials, would also be reduced as there would be less in transit and in inventory if supply chains were local. Shorter trips would diminish wear, further encouraging reuse and diminishing the total demand for materials.

An economy structured around the reuse of materials would stimulate the production of materials that are more easily reused. Products would gradually be designed not only for the consumer but also with an eye toward limiting the contaminants that might make recycling difficult. Currently, some materials that are added to products during manufacturing end up as contaminants when recycled. Thus the different layers in a plastic ketchup bottle that provide its desirable properties make the same bottle difficult to recycle. Producers currently have little incentive to manipulate their specifications for increased recyclability. However, some examples of such changes are already visible: firms are "leasing" their materials rather than selling them, (that is, they are guaranteeing to buy the products back when they fail) or committing to buy back materials collected by their direct customers (the aluminum manufacturers pay a "toll" to bottlers who collect aluminum and return it to the producers).

In today's national economy, products and commodities are differentiated in subtle ways. For example, some newspaper publishers have recently begun to purchase newsprint that adheres to higher brightness levels than the paper purchased by the rest of the newspaper industry. Recycled newsprint mills cannot economically achieve this level of brightness. The decision to differentiate this product on the basis of such subtle differences ignores the environmental costs of using extra bleach or making paper from trees. A commitment to recycling and the establishment of pollution taxes would encourage consumers to make the environmentally sound choice.

Furthermore, innovation is more quickly implemented among smaller companies, than among large ones. Plastics recycling, still quite new, was developed not by the large manufacturers and converters like Dow and Mobil, but rather by tiny firms experimenting in garages and basements. Only when the technologies and markets were proven did the large chemical manufacturing companies get involved. A small-scale economy can be expected to be more innovative and flexible since it is less bound up in mass production and more focussed on customers' needs. In fact, small-scale manufacturing facilities can retool and change production much more readily than larger facilities. A good example of this is glass manufacture in which a color change forces the loss of several days' production. Since the production is lost due to the quantity of glass which is unevenly colored during the transition period, it stands to reason that smaller quantities would entail shorter waits. Small-scale production would provide greater responsiveness to conditions in the local market.

Finally, materials networks would be redefined and the driving forces behind the use of secondary materials change. One can see examples of this already. Manufacturers are approaching cities to request secondary materials, especially plastics, which up to now haven't been collected in sufficient supply. Such demand-driven collection could render collection free for the city as haulers collect materials for resale to manufacturers. The use of secondary materials would build as supply was guaranteed, in turn encouraging investment in scrap-based technologies.

As Glenn T. Seaborg has said, we are working toward a society in which "the present materials situation is literally reversed; all waste and scrap - what are now called secondary materials - become our major resources, and out natural, untapped resources become our backup supplies." When recycling is so common that materials are no longer wasted our cities will begin to use their most plentiful resource to invigorate their economies. The task of waste diversion will have ceased to be a problem and will have become an opportunity.

APPENDIX 1: MUNICIPAL SOLID WASTE

Communities intent upon finding alternatives to landfilling often try to estimate the total amount and composition of their municipal solid waste (MSW) to determine what materials are available for either reprocessing or incineration and in what quantities.. In so doing they often hire consultants who measure the waste stream using one of three techniques:

1) Sorting and counting at the landfill;
2) Estimating consumption, life of products, and consequent disposal (generally from national figures);
3) A combination of the two.

The breakdown of materials in the study depends upon the rationale for the study. Thus a composition analysis for a combustion plant will separate the components into combustible and noncombustible, and then into various "high Btu" categories to determine the size of the necessary plant and the mix it will have to burn. A study done for an intermediate processing center, on the other hand, will focus on the separate materials and try to determine quantities and revenues for its recycling programs. Furthermore, different landfills will accept different mixes of goods. As a consequence, both the definition and measurement of municipal solid waste are matters of some debate.

Municipal solid waste is defined by Franklin Associates as residential, commercial, and institutional wastes, and by the Community Environmental Council as "nonhazardous, nonagricultural waste generated by residences, businesses and institutions." While some studies includes the following in their calculations and descriptions of municipal solid waste, other studies explicitly exclude them:

•Industrial process waste
•Demolition/construction wastes
•Water/wastewater treatment residues (sludge)
•Trees and brush
•Street refuse
•Car bodies
•Incinerator residue
•Boiler residue (power plant ash).

Thus estimtaed per capita generation rates can vary widely depending upon who is measuring what, even when people are discarding precisely the same things.

Municipalities vary widely in their definitions.of MSW because of their varying restrictions on municipal waste collection. While some will haul white goods (large appliances such as stoves and refrigerators), others require that such collection be done by individuals or private contractors. Of those municipalities which collect white goods, some sell them for scrap and others landfill them. Landfills themselves may be owned publicly or privately, and differ in what they accept (including whom they accept MSW from) and what codes or restrictions apply. Some municipalities include light industrial waste, especially from industrial parks while others will not accept waste from apartment buildings and retail enterprises. How the waste is dealt with by independent contractors is another variable; bottle bills and the availability of recycling centers are others. These factors clearly influence MSW composition studies of landfill sites.

As a consequence, waste stream composition studies are often not comparable. We have included in this report a series of tables showing the wide diversity of generation rates and of compositions to highlight the ineffectiveness of depending upon another municipality's composition data for designing and placing plants in a specific locality.

Changing consumption and production patterns are best described by the Franklin Associates analysis of trends. Because these are national averages based on industrial production of goods, and estimated forecasts, their applicability to specific local circumstances is questionable. The most accurate and detailed studies of actual discards are being done by the University of Arizona Garbage Project, which combines studies of refuse with demographic analysis and landfill archaeology.

Determining Local MSW

While national averages may be of academic interest, they are not useful at the local level in determining the nature and amount of solid waste generated. To compensate for this deficiency we have examined a number of municipalities which display demographic and geographic characteristics that significantly shift the composition of their waste from the national average. Even these categories, however, can't be applied to specific local circumstances as the characteristics are not discrete.

They are broken down, in Tables 28 and 29, as follows:

- •Northern
- •Southern
- •Manufacturing
- •Administrative (high proportion of white collar workers)
- •Urban
- •Rural

Table 28:

Waste Stream Composition Data from Various Regions in the U.S., Pounds

Yearly Per Capita Generation Rates

	Northern Ann Arbor/1	Southern Fresno/2	Administrative Essex Co./3	Manufacturing Detroit/4	Urban Seattle /5	Rural N.E. Michigan/6	1984 Nat'l average/7
Population	108,000	328,000	851,000	1,194,004	491,400	115,779	236,974,593
Total paper:	598	1,070	401	398	1,427	687	418
Newsprint	93	103	103	N/A	275	80	76
Corrugated	118	217	298	N/A	359	172	100
Mixed paper	387	669	N/A	398	793	435	241
Total Plastic	91	131	101	14	118	141	42
Total Metal	97	170	110	91	187	121	31
Ferrous Cans	4	N/A	N/A	N/A	70	101	22
Misc. Ferrous	81	90	90	N/A	43	N/A	2
Aluminum Cans	0	N/A	N/A	N/A	11	12	5
Misc. aluminum	11	N/A	19	N/A	N/A	N/A	3
Other non-ferrous	N/A	42	N/A	N/A	N/A	8	N/A
Total glass	49	129	117	93	234	81	100
Total organics	398	558	720	390	794	339	309
Yard Waste	171	229	N/A	390	N/A	63	201
Food Waste	64	N/A	N/A	N/A	N/A	176	91
Wood	85	N/A	67	N/A	N/A	54	17
Misc. organics	79	329	653	N/A	794	46	N/A
Total inorganics NEI	206	26			236	100	20
Textiles	101	64				64	22
All else NEI	36		269	125	51		181
Total	1,576	2,148	1,718	1,112	3,046	1,533	1,123

Source:
1. Ferrand & Scheinberg Associates, p. 28 (Pop: Statistical Abstract 1984, 1980 Pop. Table #29.) 2. Fresno-Clovis Metropolitan Solid Waste Commission, p. 40 (Pop: p.1) 3. Essex County Dept. of Planning & Economic Development, p.8 (Population: County Clerk's Office) 4. Weston Engineers, p. B-13, B-17 5. Seattle Engineering Department, p. 20 (Population: p. 14) 6. Ferrand & Scheinberg Associates, p. 29 (Population: N.E. Mich. Council of Governors) 7. Franklin Associates, Ltd., p. 1-12.

Note: NEI = Not Elsewhere Included

Table 29:

Waste Stream Composition Data from Various Regions in the U.S., Percentage

	Northern Ann Arbor/1	Southern Fresno/2	Administrative Essex Co./3	Manufacturing Detroit/4	Urban Seattle/5	Rural N.E. Michigan/6	1984 Nat'l average/7
Population	108,000	328,000	851,000	1,194,004	491,400	115,779	236,974,593
Total paper	37.95%	49.81%	23.33%	35.80%	46.85%	44.81%	37.19%
Newsprint	5.90%	4.78%	5.97%	N/A	9.02%	5.22%	6.76%
Corrugated	7.47%	10.09%	17.36%	N/A	11.79%	11.22%	8.94%
Mixed paper	24.58%	31.16%	N/A	35.80%	26.04%	28.38%	21.49%
Total Plastic	5.75%	6.11%	5.87%	1.30%	3.87%	9.20%	3.76%
Total Metal	6.16%	7.91%	6.38%	8.20%	6.15%	7.89%	2.78%
Ferrous Cans	0.27%	N/A	N/A	N/A	2.30%	6.59%	1.95%
Misc. Ferrous	5.16%	4.20%	5.25%	N/A	1.40%	N/A	0.15%
Aluminum Cans	0.03%	N/A	N/A	N/A	0.36%	0.78%	0.45%
Misc. aluminum	0.70%	N/A	1.13%	N/A	N/A	N/A	0.23%
Other non-ferrous	N/A	1.97%	N/A	N/A	N/A	0.52%	N/A
Total glass	3.08%	6.01%	6.83%	8.40%	7.68%	5.28%	8.87%
Total organics	25.27%	25.98%	41.93%	35.10%	26.05%	22.11%	27.50%
Yard Waste	10.84%	10.64%	N/A	35.10%	N/A	4.11%	17.88%
Food Waste	4.08%	N/A	N/A	N/A	N/A	11.48%	8.11%
Wood	5.36%	N/A	3.92%	N/A	N/A	3.52%	1.50%
Misc. organics	4.98%	15.34%	38.01%	N/A	26.05%	3.00%	N/A
Total inorganics NEI	13.10%	1.21%	N/A	N/A	7.74%	6.52%	1.80%
Textiles	6.40%	2.97%	N/A	N/A	N/A	4.17%	1.95%
All else NEI	2.30%	N/A	15.66%	11.20%	1.66%	N/A	16.15%
Total	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%

Source:
1. Ferrand & Scheinberg Associates, p. 28 (Pop: Statistical Abstract 1984, 1980 Pop. Table #29. 2. Fresno-Clovis Metropolitan Solid Waste Commission, p. 40 (Pop: p.1) 3. Essex County Dept. of Planning & Economic Development, p.8 (Population: County Clerk's Office) 4. Weston Engineers, p. B-13, B-17 5. Seattle Engineering Department, p. 20 (Population: p. 14) 6. Ferrand & Scheinberg Associates, p. 29 (Population: N.E. Mich. Council of Governors) 7. Franklin Associates, Ltd., p. 1-12.

Note: NEI = Not Elsewhere Included

In Table 30, Variations in Waste Stream Composition Attributed to Income, we have a comparison of income-related disposal in two cities--one Northern and one Southern. Table 31, Washington State Waste Stream Composition, presents one of the best available waste composition analyses, done by the Washington State Department of Ecology. And Table 32, Ideal Breakdown for a Waste Stream Composition Study, is an ideal breakdown for purposes of mining the waste stream for important materials.

Table 30:

Variations in Waste Stream Composition

Attributed to Income

(percent by weight)

	Fresno[1]	Milwaukee[2]	Fresno[1]	Milwaukee[2]
Newspaper	6	12.77	9.0	15.24
Corrugated	6	N/A	5.7	N/A
Mixed Paper	25	23.23	28.0	23.25
Plastic	7	5.91	6.0	7.11
Yard Waste	15	4.48	23.0	8.76
Glass	8	13.43	6.0	7.62
Ferrous	6	7.59	7.0	7.18
Nonferrous	2	1.92	1.6	1.3
Textiles	7	4.38	1.7	1.3
Organics	17	19.67	11.0	23.41
Inorganics	1	6.24	2.0	4.83
Total:	**100**	**99.62**	**101**	**100**

Source:
1. Fresno-Clovis Metropolitan Solid Waste Commission, p. 37. 2. Ferrand & Scheinberg Associates, p. 22, 23
(Percentages may not add to 100 due to rounding.)

Table 31:

Washington State Waste Stream Composition

Components	Percent
Nonrefillable beer bottles	0.93%
Refilable beer bottles	0.31%
Nonrefillable soft drink bottles	0.63%
Refillable soft drink bottles	0.10%
Container glass	4.11%
Aluminum cans	0.84%
Aluminum containers	0.22%
Tin cans	1.84%
Bi-metal cans	0.04%
Combination cans	0.26%
Ferrous metals	1.67%
Other metals	0.54%
Newspaper	5.62%
Corrugated paper	9.71%
Computer paper	1.27%
Office paper	1.69%
Mixed scrap paper	20.92%
PET bottles	0.25%
Plastic milk/juice containers	0.49%
N/R plastic packaging	6.93%
Hard plastic	1.29%
Rubber	0.30%
Food	12.26%
Yard and garden waste	22.88%
Wood	1.41%
Textiles	2.55%
Inert material	0.92%
Total	99.98%

Source: Washington State Recycling Survey, Department of Eclology, April, 1987

Table 32:

Ideal Breakdown for a Waste Stream Composition Study

Refillable Bottles:
- Flint (clear)
- Green
- Amber

Non-refillable bottles:
- Flint (clear)
- Green
- Amber
- Other container glass

Metal:
- Aluminum containers
- Bi-metal cans
- Ferrous metal
- Other metal n.e.i..

Paper:
- Newspaper
- Corrugated
- Computer paper
- Office paper
- Mixed paper
- Coated cartons

Plastic:
- PET bottles
- Clear HDPE (milk jugs)
- Colored HDPE (detergents, shampoo)
- Other plastic containers
- Plastic film (bags)
- Plastic goods (toys, bowls, etc.)

Rubber:
- Tires
- Misc. rubber

Organics:
- Food waste
- Yard waste
- Wood
- Miscellaneous organics

Textiles:
- Natural fabric
- Artificial fabric

Other:
- Inert material
- White goods
- Furniture
- Construction debris

Plastic laminates
Aluminum laminates
Disposable diapers

APPENDIX 2: PAPER PROCESSING

Paper derives its name from the Egyptian papyrus. One standard modern definition of paper is a mat of fibers, primarily vegetable, that have been suspended in water and placed on a screen for drying.

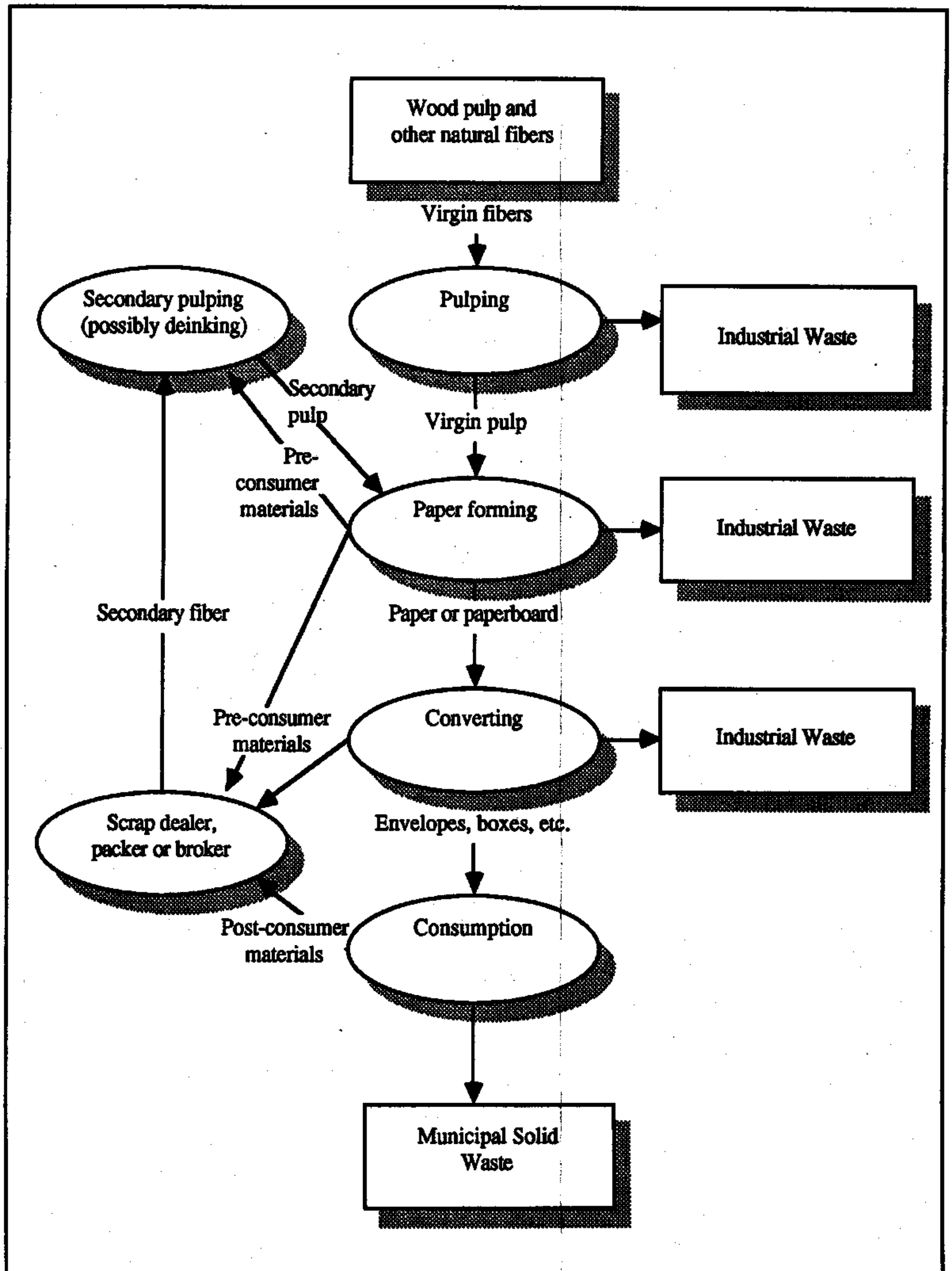
The paper that we buy in the store contains a number of other materials, chemical and physical, that impart special properties to the products that we use. Chlorine dioxide is used to bleach paper. Alum and other rosins are added for strength. Papers that contain foods are coated with wax and plastics. And some glossy papers, such as those used in magazines and direct mail inserts, are coated with clay.

American paper production began in 1690 at a mill near Philadelphia, nearly 1600 years after the invention of modern paper in China. Paper in 1690 consisted of recycled materials: cotton rags and wastepaper. The mill provided paper for the local newspaper, which was written by hand, tacked to a tree, and then returned to the mill to be recycled.[1] In 1719, a French scientist responding to a growing demand for paper and a shortage of rags, suggested that paper be made from wood. It wasn't until 1800, however, that the first European wood-based papermaking process was introduced in England. Matthias Kroops, the owner of the first wood-based mill, went bankrupt trying to market the paper. Later, in 1850, a mechanical process for grinding wood to produce pulp was introduced in both Canada and Germany. The first chemical process for manufacturing paper from wood was introduced in England a few years later.[2] Since then, various combinations of heat, chemicals, and grinding have been developed and implemented to enhance the pulping process.

Though paper was initially used primarily as a medium of communication, it now fulfills many other uses. Paperboard and tissue function as packaging. Paper products are found in buildings in the form of tar paper and roofing felt. Facial tissue and disposable diapers are two paper personal care items. Many of these products become part of the waste stream shortly after use.

As shown in Figure 15, Paper Materials Flow, the process of forming paper and making end products is the same whether the initial pulp is derived from wastepaper or wood. The difference between the processing treatment of these source materials lies in the way they are collected, prepared, and pulped.

Figure 15:
Paper Materials Flow



The mechanical and chemical processes for wood pulping both perform the same function: reducing raw materials to fibrous form for papermaking. All grades of paper are made from the same basic constituent: cellulose. The mechanical process removes very little of the extraneous lignin (which provides a plant's physical structure) and can have a yield of more than 90 percent of the original weight of the wood. Because lignin remains in the finished product and the grinding process shortens the cellulosic fibers, papers made from mechanical pulps tend to be weaker than chemical-pulp papers and to discolor easily. Mechanical pulps, which comprise approximately 10 percent of wood pulp production, are used primarily for newsprint and other products that don't require a long life. The chemical pulping process leaves the cellulosic fibers intact and dissolves the lignin, which is washed away. Though the resulting product is stronger than that made from mechanical pulp and, when bleached, retains its whiteness longer, these pulps can have yields as low as 40 percent compared to the original weight of the wood. Products made from chemical pulps, approximately 90 percent of virgin paper production, include cardboard, paper bags, tissue, and printing and writing papers.[3]

After pulping the materials can be bleached and thickened. A significant amount of today's paper is made at least partially from market pulp, which is produced to be sold to other processors rather than to be made into paper by the original processor. The pulp is sold dry and sent to paper or paperboard makers where it may be mixed with other types of pulp to provide the variety of characteristics required in different end products. Pulps take their names from the combination of factors used in their production, for example, semi-chemical, and chemi-thermo-mechanical pulp (CTMP).[4] CTMP pulps account for a little less than one percent of world market pulp production; they are, however, the fastest growing segment of market pulp, with production expected to double in the next four years. Kraft or sulfur-based pulps are the dominant grades, with more than 90 percent of the market. Kraft pulps are valued for their strength.

Wastepaper is repulped in a pulper, which combines water, the secondary material, and varying amounts of heat and chemicals. Deinking chemicals may be introduced during this phase of recycling. In a hydrapulper the solution can contain as little as two percent solids and as much as 15 percent. Repulping takes from 20 minutes to an hour. Following repulping the fibers go through a series of cleaning, screening, and refining stages that result in a pulp that can be formed into paper.

Mills that produce higher grades of recycled paper generally prefer pre-consumer wastepaper, such as clippings from envelope manufacturers and excess paper from printing houses. Though these grades are more expensive, they are generally more consistent in quality, fiber composition, and lack of contaminants.[5] For lower quality, less expensive grades, post-consumer wastepaper's inferior quality has traditionally been outweighed by its low price.

Wastepaper intended for tissue or for printing and writing paper production is subjected to further processing before paper forming. Begun in the repulping process, deinking continues up to the final stages of paper forming.

Secondary paper often contains a number of obstacles to effective reclamation, especially inks and glues. In some instances the ink can be incorporated into the finished product, but in other instances the paper will have to be deinked. Wastepaper that contains ink can be deinked in one or a combination of four ways: cleaning, screening, flotation, and washing. Most deinking is accomplished with the latter two methods. Traditionally, European mills rely on flotation deinking, while American mills have used mostly washing processes.

Flotation deinking relies on the cohesion of ink particles in pulped paper fibers. After pulping, air bubbles are blown into the slurry. The hydrophobic ink adheres to the bubbles and is then floated to the surface where it can be removed. This method relies on the size of the ink particles for its effectiveness. The larger the ink particles are the more easily they can be deinked through flotation. Flotation can remove laser "inks" that have caused deinking problems with other processes. Secondary pulps deinked through washing are treated with surfactants. This technology relies on time, heat, and chemicals to effectively disperse the ink particles. The smaller the particles the more effectively they will be deinked. Because laser inks tend not to disperse, they are difficult to wash out. Secondary pulps produced using flotation technology consume less water than the washing process in deinking. However, pulps deinked in this fashion are somewhat less bright than washed pulps. European papers adhere to lower standards for paper brightness than U.S. papers.[6]

After most of the ink particles have been removed using flotation or washing, or a combination of the two processes, the pulped slurry can be sent through forward and reverse cleaners that use centrifugal force to remove particles that have a different density than have the paper fibers.

The technological hurdles that recyclers must surmount fall into two main categories: diminished end product strength and contaminant removal. The underlying theme for both of these obstacles is the loss of fiber. Most paper products can be recycled. But, for more heavily treated papers, like magazines, much fiber is lost during the recycling/cleaning processes.

End product strength is an important criterion for most types of paper. Paper used for communication, as in books and newspapers, must be able to withstand the pressures of high-speed printing. Paperboard used for packaging must be able to successfully carry whatever is put in it. Recycled fibers are weaker than virgin fibers.[7] However, this problem has already been overcome to a large extent through new refining processes that allow the separation and filtering of shorter, weaker fibers.

The other major technological barrier to high-quality recycled paper is additives that are added to the cellulose fibers to make them stronger or whiter, or to the end-product, such as inks or glues. To remove the contaminants a mill must use a special process that often makes the fibers weaker.

Washing solvents, while they dissolve ink particles for removal, also dissolve adhesives, which are difficult to screen or clean for removal. When the adhesives reach the papermaking machine they agglomerate and stick to the equipment, necessitating premature replacement.

Loss of inks, additives, contaminants, and fiber cause the loss of approximately 15 percent of the incoming weight of the wastepaper. The fiber loss is a consequence of the cleaning processes.[8]

Paper mills that produce recycled paper have been accused of being more polluting than wood-based paper mills in two ways: dioxin byproducts and deinking waste. Despite these charges, recycled paper production significantly reduces total waste and pollution.

Dioxin is sometimes emitted during the recycling process, but it is created during the original wood pulping process. According to a recent EPA study, the interaction of lignin and chlorine in the bleaching of wood pulp creates dioxin. Concern about dioxin in the paper industry must be directed toward the wood-based mills that are its source. Recycled paper production, by decreasing the amount of paper produced from wood, reduces pollution.

The work comparing deinking waste in recycling to pollution from wood-based paper production took place during the mid-1970s, see Table 33, Pollution in Recycled and Virgin Paper Production. It was found that when secondary paper is repulped into a form analogous to unbleached virgin pulp, pollution is reduced. Recycled paper production consistently reduces air pollution and Biological Oxygen Demand (B.O.D.). However, when secondary fibers are repulped and bleached, more suspended solids are produced than when the pulp is made from wood.

Table 33:
Pollution in Recycled and Virgin Paper Production
(pounds per ton of finished paper)

	Unbleached/Undeinked		
	Virgin	Recycled	Percent Savings
Air Pollution	84	22	74%
Suspended Solids	16	12	25%
B.O.D.	30	18	40%
	Bleached/Deinked		
	Virgin	Recycled	Percent Savings
Air Pollution	98	40	59%
Suspended Solids	48	154	-221%
B.O.D.	46	40	13%

Source: Christine Thomas, Materials Gains.

At the time that these studies were done, deinking mills emitted as much as 30,000 gallons of water per ton of product. Today, these mills have developed effective water recycling systems; generally they emit no more than several hundred gallons per ton. Water effluent from such mills is clarified before release into the environment and the solids that used to cloud the water are now part of a dewatered sludge that is placed in landfills.

The sludge consists of paper fibers, coatings, and inks that were added to the paper when it was made into a magazine, newspaper, or report. The polluting effect of the sludge derives from these constituents, which would exist whatever the disposal strategy. Recycled newspaper, for example, produces little waste other than fiber and a small amount of ink. If the paper were simply placed in landfills, the ink, coatings, and all of the paper would simply add to the growing volume of solid waste. If the paper were incinerated, any pollutants would become part of the bottom ash or airborne particulate. As a disposal strategy, incineration leads to a weight reduction of less than 80 percent, while recycling paper leads to reductions of 75 to 90 percent .

Paper recycling mills can prevent the emission of the pollutants that have been added to the paper after production. More than half of the paper that is recycled by the paper industry is not deinked. Thus the potential pollutants are retained in the finished product. One writing paper mill has developed a solution to the problem of deinking waste by producing a paper that incorporates inks and other additives. The resultant paper, on which this book was printed, is not as white as wood-based or deinked papers, yet it serves its purpose and has other desirable properties, such as increased opacity. It also uses less water and fewer chemicals than other recycling processes.

There are two basic types of papermaking machines: the fourdrinier and the cylinder. In the late 1960s and early 1970s the fourdrinier benefitted from the introduction of a twin-wire process. Prior to the development of the twin-wire fourdrinier, pulp was processed by spreading it between a wired screen and a layer of felt. The resultant paper took longer to dry and the bonds developed were not as strong in recycled paper. With the introduction of the twin wire, more recycled fiber could be added.[9]

Though most mills cogenerate (create electrical or mechanical power and heat from the same fuel source), the energy intensiveness of papermaking leads to high fuel and electricity bills. In 1985, paper manufacturers' purchases of energy (fuels and electricity) totalled $4.8 billion, or approximately 14 percent of the industry's operating and maintenance costs (O & M), such as employment, materials, and energy. Each ton of paper produced contained approximately $94 worth of purchased energy. And paper mills generated 36 percent of the energy that they consumed. Paperboard mills, in contrast, spend 16.6 percent of O & M costs on energy. Each ton of paperboard consumed $42 worth of purchased energy. These mills generated 55% of the energy they consumed.[10]

Table 34, Material and Energy Savings from Paper Recycling, demonstrates the reduction in necessary Btus and raw materials through the use of wastepaper in three grades of paper. Though use of secondary fibers decreases the energy needed in paper production, virgin paper mills depend to a large extent on cogeneration and waste fuels to reduce their energy expenditures.[11] The use of secondary fibers in papermaking often leads to substantial savings of energy. A study has examined the fossil fuel equivalents required to manufacture five different grades of paper and paperboard from both virgin and secondary materials. Recycled tissue production requires half as many Btus per ton as does tissue production from virgin materials. Overall, recycled paper production requires one-third to one half as much energy than virgin paper production. For the paperboard grades, however, the energy savings are somewhat smaller than for the paper grades, ranging from 4 to 12 percent savings in Btu/ton. Recycling can result in decreased energy expenditures in two cases: production of newsprint and of tissue.[12]

Table 34:
Material and Energy Savings from Paper Recycling
per ton of Finished Paper

	100% Virgin	Recycled	% Savings
		Tissue	
Btus	30.15	14.03	53
Tons materials	4.66	1.22	74
		Newsprint	
Btus	23.02	15.85	31
Tons materials	2.90	1.25	57
		Printing and Writing	
Btus	27.56	18.27	34
Tons materials	3.82	1.04	73

Source: Franklin Associates, Proposed Recovered Materials Utilization Targets.

It is possible that recycled mills may be able to follow the lead of integrated paper mills by converting waste into energy to decrease energy expenditures. These mills might convert the unrecyclable portion of wastepaper into refuse derived fuel (RDF). A variation on this might be the adoption of cellulose-to-ethanol technology for recycled paper mill sludge. Several virgin mills around the country are successfully converting their sludge into ethanol. It is unclear whether the conversion would be successful in recycled paper mills given the variation in the contaminants found in recycled paper sludge.[13] However, as yet, the technology has not been tested in recycled mills.

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APPENDIX 3:
GLASS PROCESSING

Glass is an inorganic, non-crystalline, rigid substance solidified from a molten state. Obsidian and pumice, products of volcanic processes, are examples of naturally created glass. If cooled quickly enough, various plastics, metals, and organic liquids will also become rigid without forming orderly long-range crystal lattices. However, common usage narrows the definition of glass to substances which display certain characteristics of translucence, hardness, and chemistry.

This study concentrates on soda-lime glass, which accounts for over 90 percent of all the glass produced in the United States and is used to produce flat glass, container glass, pressed and blown ware, and glass fiber. While the actual composition varies more than the name suggests, representative compositions for flat and container glasses, excluding additives are shown in Table 35, Representative Compositions for Flat and Container Glass:

Table 35:
Representative Compositions for Flat and Container Glass

	Flat Glass	Container Glass
Sand	59%	56%
Soda Ash	18%	18%
Dolomite	14%	0%
Limestone	5%	18%
Feldspar	0%	7%

Source: Flat Glass: Franklin Williams
Container Glass: C.C. Burwell

HISTORY

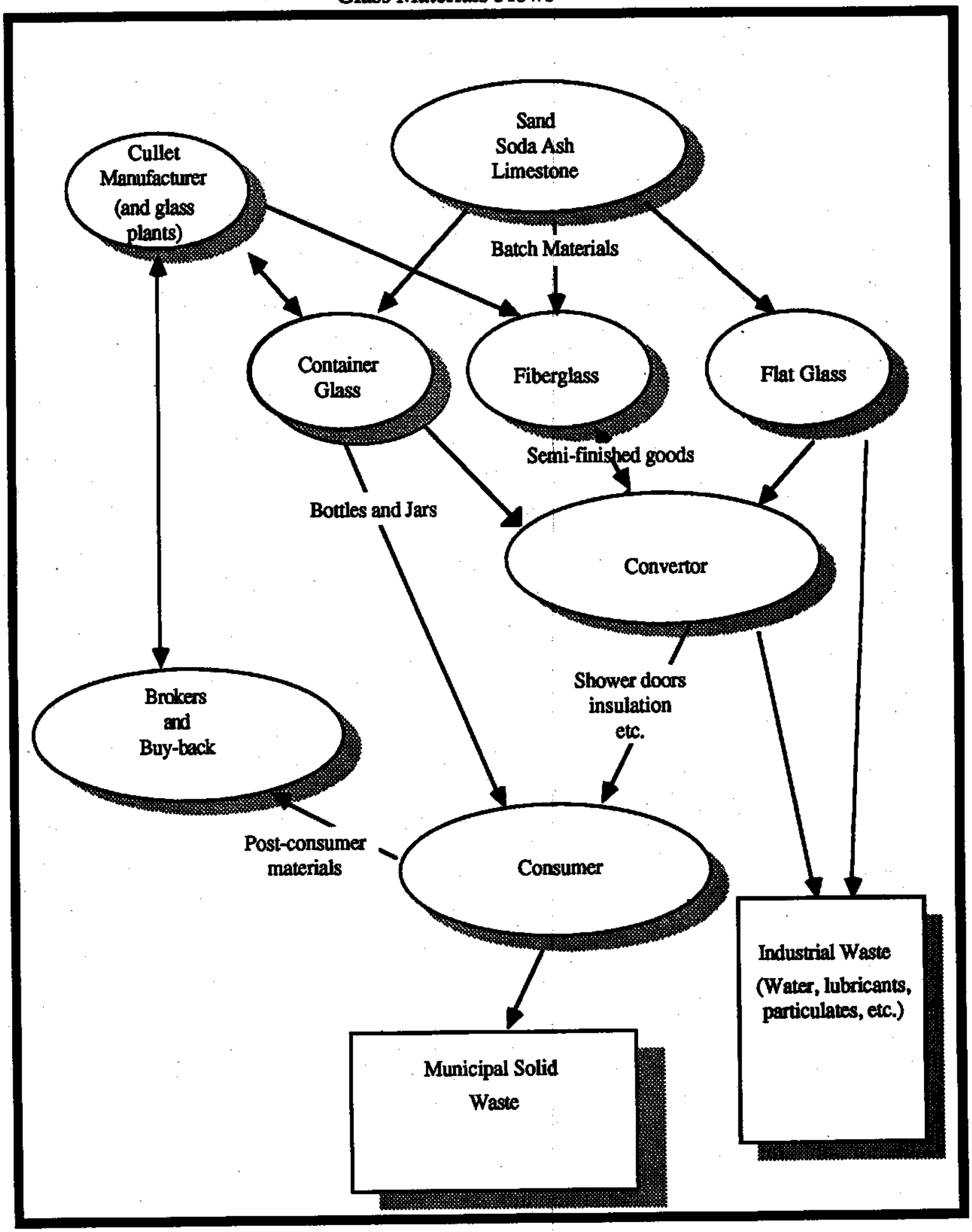
Glassmaking, first recorded in Egypt, was transformed from an operation for coating ceramic vessels to an operation for forming blown vessels by the first century B.C.. The Romans refined the technique sufficiently to establish glassmaking as an industry, thus rendering glass containers common household goods. The materials for glass--sand, limestone, and salt--were put into a pot and heated until fully melted. This melting technique is used to this day in stained glass manufacture and other uses where small amounts of glass are produced manually.

Today, flat, container, and fiber glasses are produced on a continuous basis: the raw materials flow continually into a furnace, melt and flow to the forming operations, and then, still moving, are cooled slowly and packaged. The entire process is usually fully automated: computers run each step of the operation from batch preparation through packaging. This has rendered working conditions considerably more healthy than they once were, while speeding up production and ensuring greater accuracy.

The history of post-consumer glass use in the United States is shrouded in secrecy, as is the current rate of use. An industry spokesman, on the condition of secrecy, suggested that post-consumer glass collected amounted to 1,500,000 tons in 1987.[1] Owens-Illinois began using recycled glass in the late 1970s in part to co-opt attempts at deposit legislation, and currently runs its plants at a plant average level of 54 percent post-consumer cullet. Anchor-Glass has installed permanent post-consumer glass processing machines in six of its 20 plants, and runs at an average of 35 percent post-consumer glass. While these efforts are commendable, they nevertheless fail to recover most of the glass in the waste stream. In fact, Franklin Associates estimates that only 9 percent of container glass produced in 1986 was recovered.

Figure 16, Glass Materials Flows, shows the structure of the glass industry.

Figure 16:
Glass Materials Flows



RECYCLING

One of the prime reasons for the low rate of glass recycling is that only reusable bottles are collected in significant quantities. Use of post-consumer glass has depended heavily on bottle bills and buy-back centers. While bottle bills attain high return rates for the targeted containers, they do not target 54 percent of all container glass.[2] Thus, the maximum recoverable is 40 percent of the container glass produced--less if refillable bottles are subtracted. Buy-back centers, of course, even when they pay hefty amounts for returned containers, only pay about 3.5 cents per pound. Because there are two average soda-bottles (16 oz capacity) to a pound, it seems unlikely that the one-and-a-half-cent per bottle return is a serious inducement to recycling, except among those who wish to recycle anyway. Sheer bulk is a further deterrent: a ton of glass worth $30-$40 would take up two cubic yards and weigh, using U.S. equivalencies, 2000 pounds. Thus a closed-loop system would need to collect far more than either of these programs could.

Collection

The rate of mandatory recycling is increasing, and is expected to continue to accelerate as more areas of the country run out of landfill area capacity. As landfills are filled, the two remaining waste disposal solutions are incineration and recycling. In either case, glass gets recycled. Glass can be collected and separated in several fashions: households can separate it, and place it in a separate compartment of a hauling truck; mixed recyclables can be collected and the glass separated manually or mechanically at an intermediate processing facility; or mixed waste can be collected, and the glass mechanically separated.

Separation

In order to recover the maximum value from glass scrap, bottles must be separated from all other waste, and then separated by color. This can be done at the household level, or mechanically in an intermediate processing plant. In such plants the mixed waste or mixed recyclables are deposited on a long conveyor belt. At the top of the belt enormous magnets remove all ferrous materials. The remaining mix continues along a series of conveyors, shaking screens, and air classifiers that separate stones, plastics, and aluminum from the glass. The glass is then sorted by color (either manually or with photo-optical devices) and broken (generally with the help of gravity) and screened to remove closures, caps and extraneous material before being conveyed to storage areas. At this stage glass is known as cullet.

GLASS MELTING

Cullet is a substitute for traditional materials, and cullet processing is done in essentially the same way as with virgin materials. There are four basic steps to any glass manufacturing process: 1) raw materials preparation, 2) melting and fining, 3) forming, and 4) annealing. The readying of secondary glass as cullet is step one. Step two involves the melting of the glass so that it is a homogeneous mixture without air bubbles and particles of nonglass matter such as ceramic and stones.

Typically, the raw materials are poured into a pool of molten glass and heated until they melt at a temperature of about 2800 degrees Fahrenheit. As they melt, they react chemically, creating streams of bubbling gasses that in turn create currents within the melt. These currents help the gasses escape and ensure the production of a homogeneous melt (this is called fining). Cullet facilitates this melting process by melting first and acting as a solvent for the raw materials which would otherwise require much higher temperatures to melt. However, since cullet has already undergone the chemical reactions that refine the glass, the use of 100 percent cullet fails to produce the turbulent currents that encourage the escape of bubbles of air. This has positive aspects in that it reduces furnace wear and virtually eliminates the volatilization of chemicals to the atmosphere. However, without mechanical rather than chemical fining to remove the air, the bubbles are trapped in the glass and form "seeds" that weaken the final product.

Two solutions to this have been proposed: one works with the inputs, and the other with the process. In the first case, the poor fining is overcome by crushing the cullet into larger rather than smaller pieces: The risk of contamination in post-consumer cullet encourages processors to crush the cullet into very small pieces to expel large foreign particles such as bottle caps and rings. However, each of these pieces carries with it into the melt a bubble of air of more or less equivalent to itself in size. Large bubbles rise to the surface, entraining smaller ones. However, small bubbles of air introduced by the small pieces of cullet remain in suspension and produce the seeds mentioned above.

The second solution to the problem encourages either a chemical reaction through the addition of sulfates which result in more pollutants, offsetting the gains made through using cullet alone, or various mechanical means to encourage the air to escape: bubbling compressed air up through the floor of the furnace; forcing the melt through screens or "sieving"; stirring mechanically[3]; and loosening through ultrasound (suggested but as yet untested).[4]

FORMING

The forming operation varies depending upon the final product.

Container Glass

The molten glass flows out of the furnace, through the forehearth and into a feeder where it is cut into gobs. The gobs travel down a chute into molds and are then either pressed-and-blown or blown-and-blown to take on the shape of the container. In the press-and-blow technique, the gob is settled in the mold with a plunger, then preformed with a counter-blow, inverted, and blown into its final shape. In the blow-and-blow technique, the gob is settled in the mold with compressed air, then preformed, and so on as in the blow-and-blow technique.

While the technology for forming glass containers has remained more or less the same for 50 years, refinements have enabled the forming process to be speeded up to 300 bottles per minute.[5] This has been done not only by using more sections per machine, but by making the glass wall thinner, thus using less glass per bottle, and enabling the process to be speeded up as the bottle cools and heats more quickly.

Flat Glass

Float glass is is distinguished from other flat glasses by its method of production, though the end products are the same. Since all but one of the flat glass furnaces in the United States use the float glass process, this is the process we discuss.[6]

The glass is melted in a furnace similar to that described for container glass, but upon exiting the forehearth, the glass is poured onto a bed of molten tin (about 1950 F) in an oxygen-free environment. The glass is then stretched or squeezed to the desired thickness before cooling.[7] This technique can be used for producing both flat and patterned glass in one facility.

ANNEALING

If glass fails to cool uniformly, stresses that weaken the glass and render it susceptible to breakages are created between the outer layer and the inner layer. To prevent this, the formed glass is reheated to the annealing temperature, between 1000° F and 1050° F, and then gradually cooled in an area called a lehr so that there are no temperature gradients between the inside and outside surfaces of the glass. The temperature gradient within the lehr ranges from 1000° F at the beginning to 900° F at the end. Nine hundred degrees Fahrenheit is lower than the point at which glass is stressed by cooling at different rates, so once the glass drops to 900° F it is allowed to cool to room temperature before being packed and stored.[8]

USE OF 100 PERCENT CULLET

While there are numerous markets for broken glass, ranging from glassphalt to telephone poles, the most elegant and valuable solution to glass in the waste stream is recycling bottles into their antecedent forms, thus bypassing the waste stream entirely. Firms have run exclusively on cullet for long periods of time[9] with none of the expected problems in quality. In Switzerland, several plants meet 95 percent of their material needs with post-consumer glass, and have done so for years. Post-consumer glass processors are attracting increasing interest in using 100 percent cullet from industry in the United States. This interest is motivated both by political considerations (bottle-bills, recycling movements, and the solid waste crisis), and economic considerations (periodically depressed end-product prices, and the relatively high savings to be had by using cullet).[10]

Because post-consumer cullet has been used for only a relatively short time compared to the 3000-4000 years during which virgin materials-based glass making has been perfected there is some reluctance to working at 100 percent post-consumer cullet: the uncontrolled experimentation inherent in the use of cullet is considered risky by some business managers. The reluctance to turn to cullet as a primary input is grounded in the

sensitive nature of the glass melting process, the lack of experience with very high percentages of foreign cullet, and the historical irregularity of supplies.
The following is an example of a situation which set back the use of 100 percent cullet: A plant in New York accepted post-consumer cullet containing a high percentage of Miller Beer bottles with aluminized labels. While it had been expected that labels, being primarily paper, would burn off, the aluminum agglomerated in the furnace, contaminated the glass, and ruined the refractory lining.[11] This required a complete reconstruction of the furnace at a cost of $2 million and several months downtime.[12]

The problems which come from using cullet are neither utterly mysterious nor insoluble. In this case, soaking the labels off would have prevented the problem, and running a chemical analysis would have foreseen it. The problems can be analyzed, explained, and then overcome through what become routine adjustments.[13] However, this incident does underline the difficulties inherent in the use of unknown inputs: Testing the composition of cullet is straightforward but not necessarily informative. There are wet chemical analysis tests which can accurately describe the composition of the sample. The problem lies in the sampling. It is almost impossible, given an entire truckload of post-consumer cullet, to grind it down finely enough to mix evenly, and then take a sample which will give a representative and accurate reading. Different sizes and compositions segregate readily thus destroying the results. However, over many truckloads, the variability tends towards the norm, and the composition is sufficiently homogeneous to operate a plant successfully. In this case, the high proportion of one container brand would have been recognizable over a number of tests, and steps could have been taken to remove the aluminum.

This is not a problem when recycling container glass exclusively, because the product is more or less uniform. It is a problem if other types of glasses, including glass from lightbulbs, TV vacuum tubes, etc., are commingled with the stock silica glass. It is also a problem if stray ingredients such as BBs, nuts, bolts, and pen nibs are present in the mix, but fail to manifest themselves in the sample. However, the materials recovery facilities which produce furnace ready cullet are producing cullet of a quality sufficient to produce high-grade bottles; as the supply of post-consumer glass increases and the techniques for cleaning it are increasingly refined, it can be expected that running on 100 percent cullet will be viewed more favorably.

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APPENDIX 4: PLASTICS PROCESSING

Plastics derive their name from the Greek word plastikos meaning to mold or form. There are thus numerous compounds, both organic and synthetic, which exhibit the characteristics commonly associated with plastics ranging along a spectrum from highly elastic rubber to extremely rigid thermoset materials. Plastics are chemically manufactured from components of natural gas by linking molecules into long, solid chains. These chains are called polymers and are sold as resins. The resins are in turn mixed with additives, heated to render them malleable, formed and cooled to create a plastic end product which will fall into one of two categories, thermoplastic or thermoset.

As mentioned in the text, while there are thousands of plastics in production, there are five major plastics in the packaging market and four more in the other markets. These are, in descending order, LDPE, PVC, HDPE, PP, Polyesters (PET and unsaturated polyesters), Phenolic, PS, Polyurethane, and Acrilonytrile-butadiene-styrene (ABS). These plastics make up almost 90 percent of plastics production. As a consequence, collection and separation of these plastics need not be as complicated as the existence of thousands might imply. However, while some of these plastics share processing characteristics, these plastics are for the most part diverse materials that cannot be processed together. Therefore plastics must be separated from one another as carefully as they are from aluminum, glass, or newspaper.

HISTORY

The development of modern plastics originated with Malaysians who used gutta percha, a gum elastic, to form knife handles and other articles by softening it in hot water, and then molding it to the desired shape. The western world, upon discovering the Malaysian discovery, immediately commercialized it through the Gutta Percha Company, founded in 1843 to produce inkstands and billiard balls. Shortly thereafter compounds were produced of straw, gutta percha and shellac, and were formed into buttons and checkers.

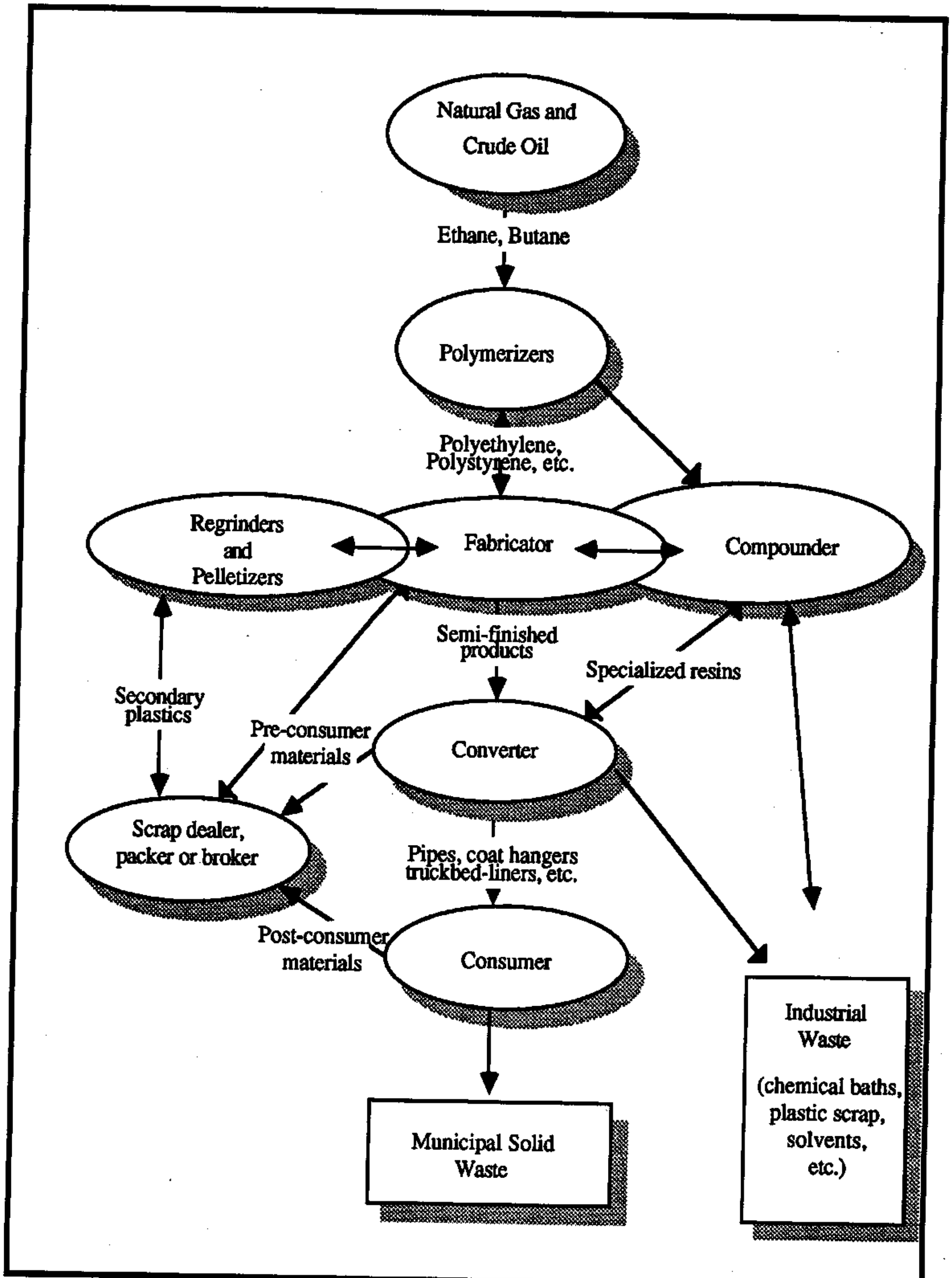
Scientists sought to replicate the plastic properties of the gum elastics in laboratories, but were unsuccessful until 1909 when Dr. Baeklund developed a controllable process for forming a synthetic resin. The result, called Bakelite, was used for telephones and distributor caps and is still widely used for electrical plugs and switches. Polyvinyl chloride (PVC) was developed in 1927 and polyethylene (PE) in 1935. Numerous other resins were developed during the war, but kept under wraps until the 1960s. While these resins were useful in the war effort, commercial markets were undeveloped. As a result, plastics' early growth was sluggish compared with the rate at which they are growing today.

Developments in plastics chemistry were paralleled by developments in the machinery to process them. By 1947 the basic equipment used to this day had been invented: injection molding, screw-extrusion and blow-molding.[1] More recent advances have enabled both layers of different plastics and mixtures of several incompatible plastics to be extruded from one machine. This has led to the squeezable ketchup bottle, recyclable only into lumber substitutes.

Plastics research is now concentrated on the development of new plastics for specialized applications, and the attendant technologies to process them. Plastics are now classified as commodity plastics, available in relatively standardized formulations for use in such products as soda bottles, plastic bags, etc.; intermediate plastics which exhibit somewhat more specialized characteristics--ABS for telephones, for example; engineering plastics which are significantly more specialized and, therefore, expensive and which are used in automobile panels; and advanced plastics which have application-specific strengths--thus liquid crystal polymers. The plastics in each successive grade generally have a greater ability to withstand impact and heat, resist chemical degradation, and carry loads.[2]

Recently attention has been turned to the development of technologies and additives to facilitate recycling. While recycling of manufacturing "runaround" scrap is almost as old as the plastics industry itself, recycling of post-consumer plastics waste only began under pressure from the forces of environmentalism, landfill shortages, and oil price increases in the 1970s. The result has been the development of compatibilizers that broaden the processing characteristics for plastics with widely varying properties: for example, a compatibilizer can be used to modify the melting and burning temperatures, enabling a plastic with a melt temperature above the burn point of another to be processed with the other plastic. Figure 17, Plastics Materials Flows, describes the structure of the plastics industry.

Figure 17:
Plastics Materials Flows



RECYCLING

As noted in the Plastics chapter, there are four generally recognized categories of plastics recycling: primary, secondary, tertiary, and quaternary. Primary recycling converts waste plastic into goods with physical and chemical properties identical to that of the original resin; Secondary recycling converts waste plastics into goods with properties that are inferior to those of the original resin either because of contamination, or, in the case of thermosets, because they can be used solely as fillers. Tertiary recycling converts the waste plastics into basic chemicals and fuels, and quaternary recycling converts plastics into heat through incineration.[3]

As noted above, plastics can be divided into two categories: thermoplastics and thermosets. Thermosets, which account for 20 percent of plastics production, cannot be remelted and are therefore recycled by regrinding and pulverizing for use as filler. However, thermosets are used for durable goods, and thus represent a much smaller fraction of the waste stream then their production figures would imply.

Thermoplastics, on the other hand, can be remelted, and are therefore fully recyclable. There are five major thermoplastic resins: polyethylene (PE), polypropylene (PP), polyethylene terephthalate (PET), polystyrene (PS), and polyvinyl chloride (PVC). Together, they comprised 85 percent of the total thermoplastic consumption in the United States in 1988.[4] Many of the plastics are recognizable at sight . However, this is not sure-fire, and the proliferation of alloyed plastics is complicating this procedure by reducing accuracy.

Separation

Because separation is so critical and so difficult, a number of plastics sorting mechanisms have been developed. The simplest has households separate soda bottle containers and milk jugs for recycling and discard the rest of the waste plastics. These two container types can then be sorted by hand or by using photo-optical devices that recognize container shape or transparency. This fails to target, and therefore wastes, 90 percent of the plastics which could be recycled, though.

A number of techniques have been developed to separate mixed plastics by their density. In these techniques the plastics are ground and then sent through a series of tanks with different fluids--in each tank the heavier plastics sink and the lighter ones float, and the two streams are diverted to different processing lines. In some cases some of the plastics can be segregated using forced air. Again, the lighter ones will fly to one processing line while the heavier ones fall to another.

Several plastics have almost identical densities--PET and PVC in particular. Since they tend not to separate with the techniques described above, various mechanical and chemical separation techniques have been experimented with. In the first case they are both ground finely, but PVC grinds more finely faster than PET and can be screened off. In the second case the two plastics are put in a solvent solution which dissolves one plastic. The other plastic is removed and the first plastic, now dissolved, is precipitated back into its solid form. Neither of these techniques has proven economic. Another technique exploits the difference in electrostatic properties between plastics: the plastics are both given a charge, but one loses it faster and falls off a rotating drum, while the other sticks to the drum until it is scraped off and processed in a different stream.

Cleaning

Once separated, the plastics must be freed of any contamination such as paper, stones, dirt, glue, food residue, and the like that would impede processing and flaw the final product. Several processes exist to accomplish this. The granulating process itself removes or loosens much of the contamination, especially aluminum caps, paper, and glue, which are removed through washing the granulate in a detergent bath. Alternatively, the plastics can be cleaned through repeated granulating and scraping on moving screens. However, in cases of severe contamination (especially agricultural mulch sheets) hydrocyclones are used: the contaminated plastic is whirled around and, being light, floats to the top where it is siphoned off. The contaminants sink to the bottom and are discarded. At this point the plastics are referred to as "clean flake" or "clean granulate."

Pelletizing

While some plastics can be dried after the cleaning described above and sold as-is, others find more ready markets in the form in which resins arrive: pellets. In order for the clean flake to become a pellet, it must be melted and squeezed through a die much as spaghetti dough is squeezed through a die to produce strands, run through a cooling water bath and, either then or later, chopped up into tiny pieces of the strands. At this stage, the plastic is considered pellet, and can substitute for resins in most applications.

Mixed Plastics

Mixed plastics processing eliminates the need to separate and clean the plastics. Instead the entire plastics mixture, including aluminum bottle caps, paper labels, dirt, etc. is coarsely ground and partially melted in an extruder. The unmelted parts tend towards the inside of the mixture, while the more viscous plastics move to the outside. The plastics are then squeezed through a die with a fairly large opening (4"x4", for example, rather than spaghetti dimensions), into a water bath, and then cut into varying lengths according to customer specifications. Since the melted plastics move to the outside, the mixture appears to be uniform. A cross-section cut, whoever, reveals air holes, pieces of aluminum, chunks of multicolored plastics, etc. These profiles, as they are called, are then used for road signs, fences, docks, park benches, and the like, because they weather well and are impervious to water and most chemical solutions.

Molding

There are four plastics molding techniques: injection molding, compression molding, blow molding, and thermoforming.

Injection Molding

Injection molders use the screw extrusion technology described above, but rather than force the plastic melt through a die, the screw shoots the plastic into a mold. In order to shoot sufficient plastic with sufficient force, the screw, having melted the material, is pulled back and then shot forward like a plunger, forcing the plastic melt into the mold. The plastic stays in the mold for several seconds, in which time it cools and hardens, the mold opens, and the plastic object is ejected, freeing the mold so that the process can be repeated. This technique is used for forming products as diverse as sinks, flowerpots, and traffic cones.

Compression Molding

Compression molding, rather than melt the plastic materials before they enter the mold, melts them after they are in the mold. Granular plastics are loaded into a heated mold, the mold is closed under high pressure, and the plastic is squeezed into all parts of the mold, the excess being squeezed out to be trimmed after the product has cooled. This technique is used primarily for thermoset materials, the plastics that cure in the mold and cannot be remelted. However, this technique is also being used to form mixed plastics products: mixed plastics are loaded into the mold and the polyethylenes, which melt at the lowest temperature, melt to form the "glue" for the other, unmelted plastics. Under pressure the glue is forced between the unmelted particles to forms pallets or floor tiles.

Blow Molding

Blow molding techniques for plastics are very similar to the techniques used for forming glass bottles. A gob of molten plastic known as a parison is extruded into a mold. The bottom of the parison is pinched off to seal the bottom of the container and air is blown in to force the plastics to the sides of the mold. The mold is then opened, the container drops out, and the procedure is repeated.

Thermoforming

Thermoforming techniques involve reheating plastic sheets to just below melting temperature and then applying a vacuum to suction the plastic to the sides of the mold. The mold is chilled, the plastic cools, and the product is ejected. This technique is used to form refrigerator door liners, bathtubs, trays, etc.

CONSTRAINTS

There are three distinct sets of constraints to recycling plastics. The first is a chemical/technical series of constraints having to do with the problems of recovering, cleaning, and otherwise processing the plastics. The second is the problem of including in the mix of reprocessible plastics plastics that degrade in an accelerated fashion, either biologically or chemically. The third concerns the markets for secondary plastics and the barriers to secondary plastics' use.

The technological constraints have to do with variability in plastics and in their additives, contamination, and degradation. As mentioned above, there are thousands of different plastics, each with its own processing characteristics, melting temperature, and end-markets. Thus any one plastic can serve as a contaminant to the other plastics. This is not a problem if one has plastics with similar characteristics, such as HDPE, LDPE and PP. However, polyethylene particles in a polystyrene mix, for example, would burn before the polystyrene was melted sufficiently to process, leaving burnt spots, holes, and other imperfections in the final product.

Other plastics can also serve as contaminants in the extrusion process, as can paper, glue, etc. Once melted, but before passing through the die, the plastics are squeezed through a fine mesh screen, similar in mesh size to window screens. Tiny particles of paper, unmelted plastic and aluminum can hopelessly clog up the screen, often bringing the process to a standstill and requiring constant supervision.

Individual plastics, even such familiar plastics as PET and PE , are not made up exclusively of one resin; they are generally modified with additives to increase various desirable properties. The most common of these additives are plasticizers, stabilizers, antioxidants, slip agents, pigments, and fillers. While most of these additives do not significantly alter the plastics' technical recyclability, fillers, especially nonpolymer fillers, can render recycling impossible, and pigments can lower the value of the final product.[5]

Melting secondary plastics can lead to embrittlement, degradation, discoloration, and inconsistent processing. The extent of these effects varies depending on the resin and on the severity and duration of the heat treatment. These problems can be overcome through the use of additives which broaden the range of temperature within which a plastic will easily melt, various antidegradation additives that protect the plastic from heat and light, plasticizers that overcome the tendency towards brittleness, etc. While they have not existed long, additives are now available, and are being further developed, to deal exclusively with the problems in reprocessing secondary plastics.

Additives that speed up the degradation of the plastics, either through sensitivity to light or microbes, pose a significant risk to recyclers as they undermine guarantees of the strength and life of the final product. Since most additives are not visible, there is fear that increased use of degradable plastics by citizens and corporations responding to perceived environmental threats will result in growing proportions of degradable plastics in secondary markets. Because they have the potential to diminish the quality of products based on secondary plastics, they could destroy markets for secondary materials and put plastics recycling in jeopardy.

There are several artificial barriers that discriminate against secondary materials. For example, for reasons of expediency, many standards and specifications are materials-based rather than performance-based. Thus virgin materials are specified, even though secondary materials can meet the performance specifications. Furthermore, ignorance of plastics' recyclability prejudices potential buyers and can put entrepreneurs who substitute secondary materials for virgin materials at a competitive disadvantage despite the success of secondary plastics in meeting specifications.

Current standards developed and published by the Association for Standards and Testing of Materials (ASTM), a nonprofit company that develops test methods and specifications for virtually every material and engineering process, are being examined for discrimination against secondary materials, and new specifications are being developed for secondary plastics. A committee has been formed to develop performance-oriented rather than materials-oriented specifications, a development which would favor secondary plastics in many applications given their tremendous price advantage. If this were combined with recycled products procurement guidelines which covered plastics as well as other materials, the markets for both secondary plastics and end products manufactured from secondary plastics would increase dramatically.

As mentioned in the main text, a further constraint lies in the Food and Drug Administration's (FDA) regulations that, while not explicitly prohibit the use of secondary plastics in food contact packaging, nevertheless suggest that such approval would be unlikely. Again, because plastics cannot be "distilled" and thus purified (nor can they be heated at temperatures equivalent to glass or aluminum whose processes volatilize practically all contaminants and thoroughly disinfect the rest), purity cannot be guaranteed.

A number of trends, while seemingly complicating recycling, may in fact end up facilitating it. For example, engineering plastics, manufactured in quantities too small to be collected and recycled efficiently, are considerably more valuable than commodity plastics and often sell for four or five times the commodity plastics price, and therefore attract much more interest in recycling. Firms might therefore be encouraged to "lease" the plastic rather than sell it. Additionally, the multi-layer containers, a bane for recyclers because of their laminated layers of different plastics, can absorb secondary resins in some of the layers since they will not come into contact with food, thus expanding the market for recycled plastic. Advances in compounding may render it easier to alloy and compatibilize plastics that must, currently, be separated from one another to process.

Thanks to the increasing rate of mandated recycling, plastics collection is rapidly expanding. As reliable quantity and quality increase it is likely that we will see innovations in their cleaning, reprocessing, and reuse. These innovation may well be pushed by legislation banning certain plastics and legislating the recyclability of others. It is likely that the effects of such legislation would be to reduce both the numbers of plastics currently used and the incidence of layered plastics in favor of several, easily separable engineering resins with broadly applicable properties and sufficient value to warrant their reclamation on a large scale. If innovation continues at the present rate (plastics recycling patents have averaged 350 a year for the past 4 years), we may well see very large quantities of plastics recycled soon.[6]

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APPENDIX 5: ALUMINUM PROCESSING

Aluminum is one of 92 naturally occurring elements. Along with oxygen and silicon, it is one of the most commonly found elements, representing 8 percent of the earth's crust.[1] In its naturally occurring state it has a high affinity for oxygen, which is what makes it, when refined, highly resistant to corrosion.[2] Aluminum is found primarily in bauxite ore, but it is also found in a number of clays.[3]

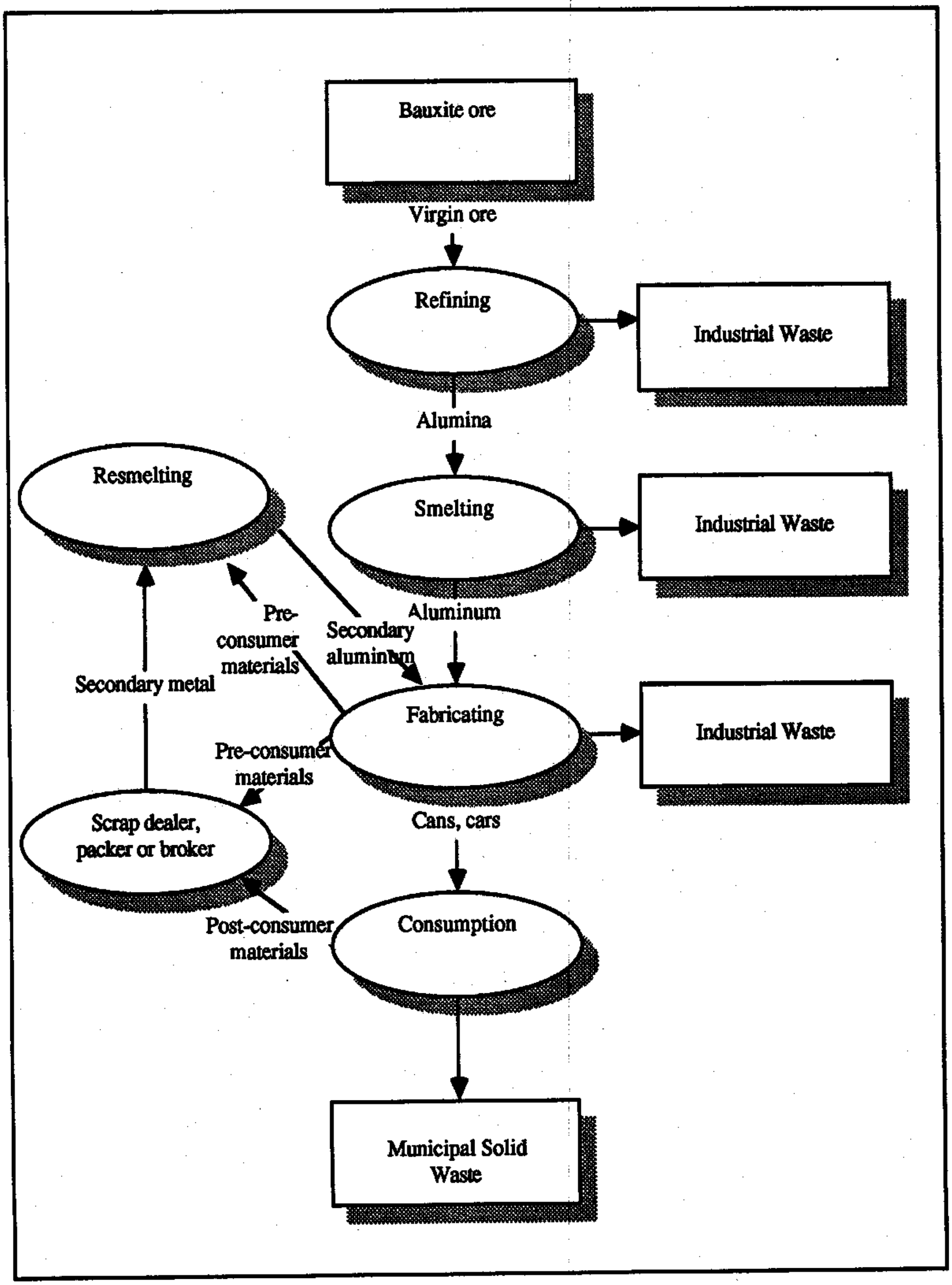
Aluminum is mined in its raw form as bauxite, found primarily in tropical areas. Bauxite is refined into alumina, an oxidized form of aluminum. Through a reduction process aluminum and oxygen are separated producing molten aluminum. This metal is alloyed and sent to be fabricated into products that supply uses including transportation and packaging. Finished aluminum alloys fall into two broad categories, wrought and cast. Cast aluminum is poured into a mold. Car parts and tools are cast. Wrought aluminum is stretched and beaten, then made into foil, cans, etc. Both cast and wrought aluminum have nine major groups of alloys, defined by the minerals that add specific properties to the final metal.

The possibility of extracting aluminum from bauxite ore and various clays was predicted long before it was realized. Prior to its effective isolation as a metal, aluminum was recognized as a strengthening agent in clay pots. In 1782, a French chemist theorized that a metal could be extracted from clay. Throughout the early 19th century various attempts were made to refine aluminum from bauxite. The use of chemical processes relying on sodium led to the first separation of the bond between aluminum and oxygen. Toward the end of the 19th century, the metal had the approximate value of silver.[4] It wasn't until 1886 that two chemists simultaneously discovered a process by which aluminum could be purified. In France Paul Héroult and in the United States Charles Hall both discovered an electrolytic process for processing alumina into aluminum. The process relied primarily on carbon and forms the basis for our current methods of reducing alumina to aluminum. Two years later, a German chemist, Karl Bayer, developed the process for isolating alumina from the sodium aluminate found in bauxite ore.[5] The first commercial production of aluminum in the United States began later that year. In the early 1900s aluminum manufacturers began remelting scrap metal, thus bypassing the extraction and refining processes.

After alumina has been refined from bauxite, aluminum is smelted from alumina using the Hall-Héroult process. After smelting, aluminum from various pots is blended and alloyed to attain a uniform purity level. The resulting metal is cast into temporary forms, commonly called sows or ingots. Alternately, the molten material is delivered directly to fabricating plants.[6]

Figure 18, Aluminum Materials Flow, represents the flow of materials in the aluminum industry. The use of scrap material makes use of the embedded refining and smelting that preceded final production. The complex, energy-intensive processes are thus circumvented. Recycling aluminum produces less pollution and costs significantly less. In addition, capital investment and reliance on foreign sources of materials are reduced.

Figure 18:
Aluminum Materials Flow



After smelting the aluminum must be alloyed to bring out the appropriate properties for end use, either wrought or cast. There are eight series of cast alloys, with the designations in the cast alloy series approximating the designations in the wrought alloy series. There are seven main series of wrought alloys characterized by varying degrees of corrosion, electrical resistance, melting temperature, strength, and malleability. These alloys are employed in uses ranging from aircraft applications, cans, welding, transportation, building, and marine applications. The alloys are shown in Table 36, Aluminum Alloy Series and Applications.

Table 36:
Aluminum Alloy Series and Applications

Aluminum Association designations	Major alloying element	Applications
Wrought alloy series:		
1xxx	≥ 99 percent Aluminum	Electrical, chemical, cooking
2xxx	Copper	Aircraft, rocket fuel tanks
3xxx	Manganese	Ductwork, can bodies, hydraulic tubing
4xxx	Silicon	Welding and brazing, wire, pistons
5xxx	Magnesium	Bus and truck bodies, screens, can lids
6xxx	Magnesium and Silicon	Heavy duty structures, pipe, bus bars
7xxx	Zinc	Aircraft structurals and skins

Source: Aluminum Association, Aluminum standards and data; and U.S. Bureau of Mines, Mineral Facts and Problems.

Table 37, Materials Consumed in the Production of Aluminum, presents the use of materials in the production of alumina from bauxite using the Bayer process and aluminum production from alumina using the Hall-Héroult process. More than seven tons of materials are consumed in order to produce one ton of finished aluminum. These figures are based on current industry averages using the conventional technology applied in the United States. When aluminum is recycled, this consumption of materials is significantly reduced.

Table 37:

Materials Consumed in the Production of Aluminum

Alumina production	Ton/ton of finished aluminum
Bauxite	4.632
Limestone	.257
Soda Ash	.145
Starch	.012
	5.046
Aluminum production	**Ton/ton of finished aluminum**
Alumina	1.930
Calcinated Petroleum Coke	.520
Pitch	.150
Cryolite	.035
Aluminum Fluoride	.030
Calcium Fluoride	.003
	2.668
Total Tons of Materials Consumed Per Ton of Finished Primary Aluminum	7.714

Source: Arthur D. Little, Aluminum Industry: Scoping Study.

Scrap consumed by the aluminum industry falls into three general categories: 1) internal, home, or run-around; 2) new, or prompt industrial; and 3) old or obsolete. Run-around scrap is waste material remelted within the establishment that created it; for example, foil that has been punctured during processing. Sometimes these items are sold to another aluminum manufacturer, making them new scrap. The final category, obsolete scrap, consists of aluminum products that have fulfilled their intended use and have been collected from the consumer. This type of scrap is most commonly associated with recycling.

To be recycled, aluminum alloys must be separated and processed to meet the specifications of end-use manufacturers. A scrap processor must be able to identify each of the alloys according to the presence of the different alloying elements. In sorting, processors follow general guidelines--for example, certain types of pipes are made usually with a specific alloy series. Initial scrap separation is accomplished by visual inspection. More sophisticated testing involves spectroscopes and acid baths. Depending on the needs of the end processor the scrap can be more or less carefully separated.

Recycling of post-consumer aluminum relies on the presence of alloys that can be extracted in sufficient volume from solid waste. Today, this kind of recycling centers around aluminum packaging, particularly used beverage cans (UBCs), due to this application's easy identification and fast turnaround.

Scrap aluminum can be treated through either dilution or demagging, the removal of magnesium. Most metal contaminants can be minimized by diluting with high purity aluminum or with high grade scrap such as electrical wire. Demagging involves the addition of chlorine or aluminum fluoride, a byproduct of the Bayer system of refining alumina.[7]

Table 38, Energy Consumption in Aluminum Production, presents a comparison of energy consumed in the various stages of processing aluminum in both scrap and virgin production. The figure excludes transportation costs as well as mining energy consumption. (Energy consumed in mining and transportation of bauxite to its first point of processing ranges from 1.8 to 7.3 million Btus per finished short ton of aluminum.) Primary production of aluminum requires significantly more energy, primarily electrical. In sum, secondary processing consumes approximately 7 percent of the energy used in primary processing.

Table 38:
Energy Consumption in Aluminum Production
(Per short ton finished Aluminum)

	Primary		Secondary	
	Electricity (kWh)	Fuel (MBtu)	Electricity (kWh)	Fuel (MBtu)
Refining/Scrap prep:	531.0	11.6	0.0	1.2
Smelting/Resmelting:	15,600.0	16.6	14.8	10.0
Casting:	0.0	1.5	0.0	2.9
	16,131.0	29.7	14.8	14.1
Total MBtu Equivalent:	199		14.19	

Source: Based on Aluminum Industry Scoping Study

The simplest method of recycling aluminum is secondary smelting. At such smelters, scrap is delacquered and shredded in preparation for melting. In the delacquering process organics including the hydrocarbons present in inks are volatilized through heating. The aluminum base is then melted in a gas- or oil-fired reverberatory furnace with capacity anywhere from 30,000 to 100,000 pounds. When the metal has been melted a sample is taken and the chemical composition tested.[8] Depending on this composition and the desired end use, the chemistry can be adjusted. Most scrap treated in this way is simply remelted and then treated to attain a specification alloy.[9]

Another more sophisticated process for recycling aluminum presents the possibility for recyclers to produce products with higher value added. Specifications are not as rigorous if a mill has a captive consumer, for example it produces siding which it paints. Unlike secondary smelters, which merely produce metal for someone else's production, minimills have the capacity to produce end products.

Products made by the minimills are generally divided into the categories of sheet and foil products, divided by their thickness. Most minimills produce guttering, siding, and other general building materials. With a higher grade of scrap and a larger investment, the mills may make foil and cans. This, however, demands greater stock purity and may require the addition of primary aluminum.

Minimills have two basic components, the casting mill and the cold mill. The delacquering process used in simple secondary smelters is also used to prepare aluminum for minimill processing. In the casting mill, metal is introduced into a melting furnace. The molten aluminum is then passed into a holding furnace, where the chemistry and flow of aluminum are regulated. From the holding furnace, the metal is metered into the continuous caster, a series of water cooled, rotating caster rolls. Some mills sell the resultant "hot coil," which has not yet been rolled to a specific thickness.[10] Usually, though, mills then transfer the metal to the cold mill where it passes through a series of rollers as many as six times. This process can take more than a week from the initial melting. After being rolled to a specified thickness the aluminum is then either sold to a fabricator or used for fabrication on the premises.[11]

Casting equipment for minimills falls into two general categories, twin roll and twin belt. Each of these casters can produce aluminum to be sold to fabricators. Twin roll minimills most commonly contain cold rolling mills that roll the aluminum to a desired thickness for fabricating. Table 39, Capital Costs for Selected Minimills, shows comparative costs for the different types of minimills.

Table 39:
Capital Costs for Selected Minimills

	Capacity (tons per day)	Total Capital cost	Capital cost/ton
Twin roll	44	$5,930,000	$135,000
Twin belt	30	$10,000,000	$340,000
Minimill (twin roll)	44	$18,530,000	$420,000

Source: Based on quotes from Reed von Gal, Hazelett Engineering, and Chris Romanowski, Hunter Engineering.

The reason that the minimill containing the cold mill is so much more expensive is that the cold mill has a capacity of 45,000 tons per year, and thus one end of the mill has a lot of capacity that it is not using. The primary advantage of a minimill with a cold rolling mill is that it can provide a nearly finished product for the consumer. With only casters the scrap mill is dependent on a fabricator to consume its products. With a cold mill, the mills have the potential to make foil and, with the addition of new technology, stock for cans. These products can bypass the fabricator. In some cases, minimills deal directly with building contractors.

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