System Design for Municipal Solid Waste Recycling

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Abstract

Municipal solid waste recycling is alleged to save precious landfill capacity and lower the use of raw materials. The Environmental Protection Agency and 42 states have set msw recycling goats of 25-70 percent We examine the volume and composition of household waste, the cost of landfilling and incinerating the waste, and the cost of collection and sorting recyclable materials. The additional cost of collection ami cost of sorting am far greater than the revenue from selling recydaUe materials or landfilling the waste. None of the examined changes in collection, including drop-off collection, make recycling costs attractive. For Pittsburgh and other cities, recycling significant fractions of municipal solid waste obtained from households harms the environment compared to placing it in a modem landfill.

L Introduction

Recycling substantial portions of municipal solid waste (MSW) is widely viewed as a desirable public action. In the United States, forty-two states (including the District of Columbia) have introduced recycling goals, ranging from 25 to 70 percent [Biocycle 93]. Twenty states require municipalities or counties to pass mandatory recycling ordinances or to develop recycling programs. The US Environmental Protection Agency has set a national goal of 25 % MSW recycling; the actual fraction of recycling was 13% in 1988. [Commerce 92].

In addition to addressing the environmental objective of reusing raw materials, recycling has a direct economic benefit in avoiding landfill and incineration costs [Curiee 86]. MSW recycling designed to save money by avoiding such charges. This paper is intended to consider system design issues and the economics of recycling MSW. System design issues include alternative collection methods (such as

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curbside vs. drop-off), types of recyclable materiel to collect, and various measures to improve management efficiency such as improved routing. In discussing these issues, we rely on the experience of Pittsburgh, PA, generalizing where data permit

We begin with a discussion of the entire waste stream from residences. Table 1 summarizes major categories of solid material outputs discharged from a typical United States household. In this table, large but infrequent outputs (such as buildings and vehicles) are included as an average "annualized" flow. These data are not collected systematically and so the table should be viewed as approximate. Nevertheless, Table 1 indicates that MSW is less than half the overall solid waste stream associated with a household. Residential building demolition is the largest category. Households can move some materials from one category to another. For example, small amounts of demolition waste may be included in MSW, while a sink disposal (i.e.. garbage grinder in a sink) will divert waste from MSW to wastewater. MSW system design, market forces and other regulation can significantly affect such substitutions, as we discuss further below.

Table 2 presents the estimated total quantity, the per capita amount, and the fraction of different components of MSW in the United States. Both the total amount and per capita amounts of MSW have been increasing over time. Also, the amount of plastic in US MSW has been increasing over time. Table 3 summarizes estimates of MSW amounts and MSW produced per capita for a set of OECD countries.[5] The US produces the largest amount of MSW per capita and roughly half of the entire OECD MSW production.

Disposal practices vary substantially among US municipalities. Table 4 provides some reported examples of disposal fractions and tipping fees for landfill and incineration for various states based on a 1992 survey. From the table, the average tipping fee for landfill is $ 35 per ton, while the average incinerator tipping fee is $ 44 per ton. Unfortunately, national data on collection and recycling costs are not available.

To provide a specific example of a municipal recycling operation, the next two sections describe the curbside MSW recycling system and the experienced costs in Pittsburgh, PA. The following section considers some different design parameters, emphasizing design changes that might reduce costs significantly for a conventional system such as the one in Pittsburgh. Section 6 considers the tradeoff

[5] The OECD, Organization for Economic Co-Opcration and Development, comprises a group of 24 developed countries.

Primary Outputs	Weight (lb/yr)	Recycle Fraction (%)
Building Demolition[1]	6,300	<5
Municipal Solid Waste[2]	3,900	13
Vehicles[3]	700	75
Waste Water Solids[4]	280	<1

Notes:

1. Baccini [Baccini 93] estimates a per capita mass of residential building as 110 metric t/per capita based on typical Western European construction methods. Assuming a typical residence life of 100 years, the annualized input is 110/100 = 1.1 t/yr. A metric ton is 2205 lb and there arc 2.6 persons *per* household in the United States, so 1.1*2205*2.6 = 6,300 lb. The small estimated fraction of recycling for residential construction reflects the rarity of organized recycling efforts in demolition; the fraction might be higher if demolition wastes used as fill were included. Also, note that considerable amounts of demolition debris is not measured in solid waste statistics.

2. Table 2 reports US MSW per capita of 1,500 lb/yr. With 2.6 people per residence [Commerce 92], MSW per household is 3,900 lb/yr.

3. The average retirement age of a vehicle is 7.8 years [Commerce 92] (Table 1000), the average number of nwtorvehides per household is 1.8 [Commerce 92] (Table 1021), and the average hulk weight is 3,200 lb. [Caimcross 92], so 700 = 3,200*1.8^7.8. Recycle fraction appears in [Caimcross 92].

4. 70 gal/person/day of wastewater is generated in a typical household [Metcalf 91], Table (2-9) and assuming an incremental increase in dissolved and suspended solids of 500 ppm (see [Metcalf 91]), annual solid weight is 70 (gal/person/day) * 365 (days/yr) * 500 ppm • 8.34 lb = 106. Multiplying by 2.6 people *per* household, our estimate is 280 lbAM>usehold/year.

Table 1: Major Categories of Residential Solid Material Wastes

between cost and the fraction of MSW recycled. A concluding section considers the role of recycling MSW in the broader context of environmental policy for solid waste management.

2. MSW Recycling in Pittsburgh, PA

Pittsburgh introduced KfiSW recycling in selected districts in 1990 and gradually increased coverage of the municipality and the number of products accepted for recycling. Recycling was introduced in response to Pennsylvania's 1988 Municipal Waste Planning, Recycling and Waste Reduction Act (Act 101) which required implementation of MSW recycling programs in all municipalities with population over 5,000.

After study of numerous alternatives [Daley 92], Pittsburgh implemented a system by which recycled trash was commingled in distinctive (blue) bags, separately collected at curbside and delivered to a

Category	1960	1980	1988
Annual US MSW (millions of tons)	88	150	180
US MSW per capita (lb/year/person)	970	1,300	1,500
Composition Percentages:			
Paper and paperboard	34	37	40
Glass	8	10	7
Metals	12	10	9
Plastics	1	5	8
YardWastes	23	18	18
Other	12	20	18

Source: Statistical Abstract of the United States, 1992, Table No. 359 [Commerce 92]

Table 2: Total Amount, Per Capita Production and Composition Fractions of US MSW

private "municipal recovery facility[1]" (MRF) for separation and eventual marketing to recyclers. Operation of the MRF is subject to competitive bid based on the tipping fee at the MRF. Collection of recycled trash is performed weekly by municipal employees using standard MSW trucks and equipment owned by the City of Pittsburgh. In addition, special leaf collections are made in the fall for composting. Figure 1 summarizes the 1991 curbside collection MSW flows in Pittsburgh, the last year for which complete data are available. Of the 167,000 tons of curbside MSW, a total of 5,100 tons were recovered at a MRF, or 3.1% of curbside MSW. Cuibside MSW represents roughly two-thirds of the total MSW reported by the City of Pittsburgh in 1991, with other major components including retail industrial, office and park wastes.

As in all areas, there is variation in the month to month flow of MSW. In Pittsburgh, the peak flow occurs during the summer, with a peak flow roughly 15 percent higher than the average flow whereas the lowest month occurs in the winter and is roughly two-thirds of the peak flow.

Three rounds of bidding for operation of the MRF have been held and are summarized in Table 5. In 1989, bids were solicited for the stream of recycled material with and without newsprint The best bid for recyclables (without newsprint) represented a *revenue* to the city of $ 2.18 per ton delivered to the MRF. During this same period, the tipping fee for landfill of MSW was $ 24 per ton, so the city would save $ 26

Country	Annual MSW (Millions lb)	Annual MSW Per Capita (Ib)
Australia	22,000.	940.
Belgium	6,800.	680.
Canada	35,000.	1,400.
Denmark	4,800.	950.
France	33,000.	600.
West Germany	43,000.	700.
Greece	5,500	550.
Italy	33,000	580.
Japan	91,000	740.
Netherlands	14,000.	960.
Spain	23,000.	600.
Sweden	5,800.	690.
Switzerland	3,300.	500.
United States	390,000.	1,500.
OECD	780,000	940.

• Source: [Economist 90], with underlying data based on United Nations and OECD statistics. MSW amounts and MSW per capita arc reported to two significant digits.

Table 3: Annual MSW Amount and Per Capita Amounts for OECD Countries

per ton of recycled material. Including newsprint in the stream of recyclables, the lowest bid was a cost of $ 8.39 per ton, so the savings in tipping fees declined to $ 16 per ton of recyclable material. In the second round of bidding in 1992, the tipping fee of recycled materials (including newsprint) increased to a cost of $ 31.60 per ton, removing any cost savings in recycling. Also, in 1993, the best bid for landfill tipping fees declined to $ 16.15 per ton, representing additional extra costs for recycling. Also included in Table 5 are bid values in 1992 dollars, with the effects of inflation removed.

The increased tipping fees for recycled materials reflects both recognition of the sorting costs associated with the Pittsburgh blue bags and the difficulties of marketing MSW recyclables. Table 6 shows the trend in the maiket price of a typical set of recyclable MSW materials from 1988 to 1992 as compiled by Waste Management, Inc. [WMI92]. The 1992 maiket price is only slightly more than half the 1988 level. As shown in Table 5, by 1993, the fee for recycling was double the fee for landfilling in Pittsburgh due to the high cost of sorting and the low value of recycled materials.

State	Solid Waste (OOOtons/yr)	Recycled (%)	Incinerated (%)	Landfflled (%)	Incinerator Fee($/t)	Landfill Fee($/t)
Connecticut	2,900	15	**65**	20	60	65
Florida	18,700	21	**17**	62	40	40
Indiana	5,700	8	**17**	75	18	21
Iowa	2,300	10	**2**	88	40	15
Maine	950	17	**45**	38	39	35
Maryland	5,100	10	**17**	73	49	40
Mass.	6,800	29	**47**	24	55	55
Michigan	11,700	25	19	56	49	40
Minnesota	4,400	31	**25**	39	83	43
Montana	600	*6*	**1**	93	12	15
New Hampshire	1,100	5	**23**	72	55	45
Utah	UOO	10	10	80	35	12
Virginia	9,000	10	10	80	35	25
Washington	5,100	34	**7**	59	50	35
Average		17	22	61	44	**35**

Note: Data derived a 1992 survey conducted by Bio^Cyde [Biocyde 92]. Only states reported both landfill and incineratibn tipping fees are included in the table.

Table 4: Reported Tipping Fees and Disposal Fractions for Various States

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                   Curbside
                 MSW Generation
                        I
                    167,000
                        I
        ______________________________
        I                            I
Blue Recycling                 Curbside MSW
Bag Pickup                      Collection
  5,700                          161,300
     I                               I
     I                               I
Municipal Recycling                  I
Facility  (MRF)     -> 600 ->   Landfill
     I                          161,9000
     I
 Recovered
 Materials
 to Market
  5,100
```

Figure 1: 1991 MSW Material Flows for Pittsburgh, PA

3. The Cost of MSW Recycling

MSW recycling processing can be divided into several distinct phases for the puiposes of system design and cost analysis. The initial phase is collection or drop off facilities. A transfer station followed by line haul transport is a common second phase for MSW. For recyclable MSW, sorting at a MRF is common. The sorted material is then re-sold to specific material iecyclers or is disposed of in landfills, incinerators or compost plants.

A summary of estimated costs in 1991 for recycling and regular MSW in the City of Pittsburgh is shown in Table 7. In Pittsburgh, curbside collection is performed by the same employees and type of equipment as is used for regular MSW, although only two person crews are used for recycling collection routes. In Table 7, the overall costs of collection are reported for several cost categories. These costs are divided between regular and recycling MSW. General office expenses were allocated in proportion to labor, collection labor cost was allocated on the basis of employee hours, and fleet costs were allocated in proportion to truck use.

The cost on a unit weight basis for recycling collection is substantially higher than collection for

Year	Facility	Materials	Best Bid Tipping Fee ($/ton)	Best Bid Tipping Fee (1992 Vton)
1989	Landfill	MSW	23.81	26
1989	MRF	Recyclables w/o newsprint	(2.18)	(2.)
1989	MRF	Recyclables w newsprint	8.39	9
1992	MRF	Recyclables w newsprint	31.60	32
1992	Composting	Yard Waste	29.65	30
1993	Landfill	MSW	16.15	$16.

Notes:

1. Data derived from City of Pittsburgh bid announcements. MRF is municipal recovery facility and MSW is municipal solid waste.
2. Recyclables include glass, plastics (HDFE, PET and film), aluminum cans and steel/ferrous containers.
3. Numbers in parentheses represent tipping *revenues* rather than tipping fee costs.

TabJe 5: Best Tiding Fee Bids for MSW Recyclables in Pittsburgh

regular MSW in large part because the density of recycled MSW is much lower and, consequently, one recycling truck collects a much lower weight of MSW. In addition, only a small amount of material is collected at each residence (about 3% of cuibside MSW) and so productivity (in pounds collected per worker per hour) is low. Recycling trucks in Pittsburgh have a crew of two rather than three, but the lower collection productivity per trade makes the collection cost of recycled MSW much higher than for regular MSW.

In the 1991 data shown in Table 7, tipping revenue was received at the MRF, whereas regular MSW was charged a tipping fee for landfill. The total disposal cost of regular MSW was $94 per ton. The total disposal cost of recycled MSW was $ 465 per ton, equal to the collection cost ($ 467) less the MRF tipping revenue ($ 2). With the 1993 tipping bid prices (summarized in Table 5), the cost of recycle tipping is higher than for landfilling regular MSW. The total cost per pound of recycled MSW for the

Year	Price ($/t)	Price (1992 $/t)
1988	97	107
1989	73	80
1990	62	66
1991	38	60
1992	44	44

Source: Resource Integration Systems, Ltd. [WMI92].

Table 6: Price Trend for A Set of Typical Recyclable MSW Materials 1988-1992

City of Pittsburgh is ova* four times higher than the cost per pound of regular MSW.

The large cost associated with MSW recycling in Pittsburgh is sobering. Collection costs have not been widely discussed because they are "hidden" in aggregate MSW costs. This cost also reflects significant environmental impacts such as additional truck fuel consumption and combustion emissions. Based on Table 7 and the current population of Pittsburgh, the per capita cost of MSW collection and disposal was $ 57 in 1991. The incremental or extra cost of the recycling program was $ 6 per person in 1991, or roughly $ 2 million (equal to 5,700 tons times the incremental cost per ton of 465-94 = 371.)

The cost of MSW and MSW recycling collection is significantly higher in Pittsburgh than in some municipal areas. Waste Management, Inc. reports an average collection and soiting cost of $ 175 per tem for recycled material obtained from 5.2 million households in more than 600 communities [WMI92], or 40% of the comparable figure in Pittsburgh, PA. Even if this cost were achieved in Pittsburgh, the cost of collecting recyclable goods would still be almost double the cost of regular MSW collection and disposal ($ 175 per tem versus $ 94 per ton). Other municipalities report similar cost comparisons. For example, San Jose reports costs of $ 28 per ton to landfill versus $ 147 per ton to recycle [Garbage 93], comparable to the ratio of costs noted above for Pittsburgh. The next section considers some system design factors which might result in significant savings in the Pittsburgh costs.

Total Costs

CATEGORY	Cost (1991 10*$)
General Office Div.	2.5
Collection Div.	7.4
Recycling Div.	0.1
MRFFee	(0.01)
Disposal Fee	4.0
Fleet	3.8
Total	17.9

Collection Resources (1991 Data)

	Regular	Recycling
MSW (tons)	161,000	5,700
MSW Routes (tracks)	66	20
MSW Crew per Track	3	2

Collection Cost **per Ton**

CATEGORY	MSW (Vton)	RECYCLE ($/fon)
General Office	13.	74.
Collection Div.	38.	218.
Recycling Div.	--	25.
MRFFee	--	(2.)
Disposal Fee	25.	--
Fleet	18.	155.
Total	94.	**470.**

1. Total costs and collection resources arc derived from internal City of Pittsburgh accounts. Collection costs per ton are based on the author's calculations. Note that the recycling operation collected 5,700 tons, even though only 5400 tons were actually recycled (See Figure 1).
2. General office and collection division costs are allocated to regular and recycling service on the basis of labor.
3. Fleet costs arc allocated on the basis of truck usage.

Table 7: Costsof Collection and Tipping for Recycled and Regular MSW in Pittsburgh, 1991

4. Design of Collection Systems

In this section, we describe some alternative system designs that might be introduced to slash the costs of MSW recyclable collection in a city such as Pittsburgh. The various alternatives considered include improved routing, privatization, combined collection, drop-off centers and product reverse logistics. Table 8 summarizes the general results.

Improved routing and districting of collection routes can lower costs. In Pittsburgh, districts for recycling collection routes were simply combinations of existing (and traditional) MSW collection routes. Individual drivers are given lists of blocks on the route and plan their own routes among the assigned routes. Raja [Raja 92] applied several systematic routing algorithms to observed routes to ascertain the possibilities for improvement He identified potential reductions in collection lengths on the order of 5 to 10%. While these potential savings are significant, they impose costs associated with improved planning and may not be responsive to local traffic conditions. Moreover, a 5 to 10% improvement in route length will not substantially alter the incremental costs shown in Table 7, especially since the same magnitude of savings should be available from improved routing of traditional MSW collection.

A second possible alternative for cost savings is to use a private firm for collection which could achieve lower costs through greater efficiency and a lower wage structure. As noted earlier, Waste Management, Inc. reports an average cost of $ 175 per ton for collection and sorting of recyclable MSW.

A third possibility for cost savings is to alter die equipment used for collection. Currently, Pittsburgh uses 25 cubic yard tracks with a hydraulic compacter for both recydkig and regular MSW collection routes. Purchase of these vehicles is paid for by capital grants from the Commonwealth of Pennsylvania (and so capital costs for trucks are excluded in Table 7), and the capital grants are limited to a small number of acceptable vehicle types. Also, the City of Pittsburgh simplifies maintenance by limiting the numbers of different types of collection vehicles in use. It might be the case that some savings might be gained by mechanized loading devices, but again these savings would accrue to both recycling and traditional collection. Indeed, mechanized loading equipment is likely to be more beneficial to the heavier MSW pickups.

Another possibility would be to combine the collection of both recyclable and other MSW in the same route. For example, collection trucks might be modified to have a compartment for recycled MSW. West Palm Beach, Florida, has adopted collection vehicles of this type. With the lower density of recycled MSW, this solution would still result in some increased costs due to lower truck capacity. However,

Alternative	Estimated Cost ($/ton)	% Cost Savings (Relative to Pgh)	Extra Cost (Relative to Pgh Regular MSW)
Current System	470	-	370
Improved Routing[2]	420	10	320
Privatization[3]	180	290	80
Combined Collection[4]	260	210	160
Drop-off Center[5]	800	(340)	700.

Notes:

1. Cost estimates reported to two significant digits.
2. improved routing is assumed to reduce collection division and fleet costs by 10%.
3. Privatization uses the average cost experience by the largest private recycles, Waste Management, Inc. as noted in the text Narrow streets, congestion and steep topography in Pittsburgh may make this figure unattainable. Alternatively, ft might be possible to find even a lower cost provider.
4. Combined collection assumes mat collection and fleet costs for the entire system will increase 10%.
5. Drop-off Center costs includes estimates of center operating cost and costs of private vehicles used for drop offs.

Table 8: Summary of Estimated Cost Savings in Pittsburgh, PA Due to Different System Design Choices

collection cost savings could be substantial. With multiple drop-offs and dual storage vehicles, we estimate that collection costs for combined regular and recyclable KCW would be 10 % more for fleet and collection costs than for current MS W collection in Pittsburgh.

In addition, collection routes for recycled MSW might be abandoned altogether in favor of distributed dropoff stations. While used in many locations, this alternative has the disadvantage of lower participation rates. Since households would be driving to drop off small quantities of waste, total person hours and transport costs are likely to rise, although these costs are transferred directly to households. Direct household cost would be (private) vehicle trips to the drop-off center. An average motor vehicle shopping trip is 10.6 miles round trip in uibanized areas [NPTS 85, Tablel3], but some recycling drop-off trips would be combined with other trip purposes. Assuming three miles of extra travel per trip (or 30% of an average shopping trip), bi-weekly trips to the drop-off center and a typical motor vehicle operating cost of $ 0.30 per mile, the cost for the roughly 60 lb. (0.03 ton calculated as 3,700 tons divided by the number of Pittsburgh households) of recyclable waste in each household is 26*3*0.3/0.03 = $ 780 per ton. Costs of drop-off crater implementation and maintenance should also be added. In Wellesley MA, the operating cost of a drop-off center is reported as $ 16 per ton of recycled material in 1988/1989 [Platt 91] or roughly $ 18 in 1992 dollars. Thus, an estimate of the total direct cost of recycling in drop-off stations is $ 800 per ton. This does not include volunteer labor, including the time to sort recyclable material by type and driving time to the drop-off center. This total might be reduced by having numerous drop-off centers near maikets to which travel already occurs, but the collection and maintenance costs of these numerous drop-off centers would increase.

Finally, recycling MSW as a responsibility of local governments might be abandoned in favor of a reverse logistics system for individual products. This alternative reflects the German "take-back" legislation [OTA 92] in which manufacturers must take-back packaging materials. There are also legislative proposals in Germany to require manufacturers to take-bade and recycle their own products. In the United States, take-bade regulation exists for specific products such as the lead acid batteries used in automobiles. In this system, producers of individual products in MSW would be required to arrange "reverse logistics" systems for collecting and eventually recycling their discarded products. For example, newspaper delivery services would have to collect used newspapers. Initially, the cost of this type of system might be comparable to the drop-off center cost, but it might serve to encourage demand for recycling as producers could count on a stream of their own returned products and make material selection and design decisions accordingly. We will return to this collection alternative in the final section.

5. Mandatory MSW Recycling Fractions

An important design variable in a MSW recycling program is the different types of materials accepted and their maiket values. Tipping fees at a MRF reflect the costs associated with separation, subsequent transportation, marketing and re-sale of the different recycled commodities. Table 9 summarizes the various material components of the Pittsburgh recycle stream, a typical spot value of these components and the resulting revenue of the material. While spot values of recycled materials vary a great deal, it is evident from Table 9 that the bulk of value from the recycled stream comes from aluminum, in the form of aluminum cans.

Processing costs for the recycled materials are not included in Table 9; a typical processing cost might be $ 150 per ton [Garbage 93]. A city sees the cost of MSW as the sum of collection and tipping costs; the cost of recycling is the higher collection costs and processing cost minus the revenue from selling the recycled materials. If collecting recyclables costs $75Aon more than collecting MSW, if tipping fees are about $35/ton, and if processing costs are $150/ton, a recyclable would have to sell for at least $190/ton to be worth separating from MSW: only aluminum qualifies on this criteria.

For Pittsburgh with its high additional collection cost and low tipping fee, recycling is not an attractive policy. For New York City and Philadelphia with very high tipping fees, there is a greater incentive to recycle.

Some people might reply that recycle programs were not set up to make a profit and so the high costs of collection are irrelevant As discussed in [Lave 94], what is important is the total energy and resource costs of a program. Recycling is meant to lower environmental discharges and reduce the use of virgin materials. The current programs in Pittsburgh and some other cities do not serve these goals since the large amount of raw materials going into fuel and equiinnent and the environmental discharges from operating the equipment is greater than the environmental benefits of the recycling. Recycling programs should be judged by the total environmental discharges (toxicity weighted), the total use of virgin materials, the total use of labor, and other social costs. While the costs shown above are imperfect measures of ttiese recycling costs, there is such an imbalance between the savings from recycling and the costs such that the current program is questionable.

If the recycle MSW stream was limited to fewer materials, then the separation costs at the MRF would be lower. However, if the recycled MSW were limited to only high value materials (i.e.. aluminum and others metals), then the unit collection cost would increase and the amount of recycling would fall far

short of the legislative goal for recycling. In effect, mandating 25% recycling by weight (or even 15%) imposes a significant additional expense.

Material	Gross Recycle Value ($/ton)	(cents/lb.)	Tons Recycled	%ofMSW	Gross Value (000$)
Aluminum	750	38	1,000	0.6	750
Clear Glass	50	3	6,700	4.0	335
Steel/Bi. Cans	80	4	3,000	1.8	240
Newsprint	30	2	5,000	3.0	150
Plastic (PET)	100	5	500	.3	50
Plastic (HDPE)	130	7	500	.3	65

• Source: Recycle material values from [Garbage 93], pg. 41; recycled material amounts from the City of Pittsburgh.

Table 9: Quantity and Value of City of Pittsburgh Recycle MSW Components

One possible policy prescription for reducing the imposed costs of recycling is to stimulate the demand for recycled materials. For example, the federal government has changed its procurement policy to insure that 20% of paper purchases are of recycled pulp. In some cases there is needless discrimination against recycled materials. When recycled materials are inherently more expensive, even when accounting for externalities, this requirement can be costly.

6. Integrated Planning of MSW Policy

In the previous sections, we have shown that the social cost of MSW recycling are far greater than placing the waste in landfills for Pittsburgh and similar cities. While many people object to landfill disposal, modem landfills are designed and operated to have minimal environmental discharges [EPA 89, Davis 91]. No modification in collection programs are likely to change this conclusion. Indeed, drop-off stations are the most expensive collection system, even though they involve no cost to the city.

The current MSW recycling systems being initiated in most US metropolitan areas represent a striking analogy to the "end-of-the-pipe" emission controls enacted three decades ago. In the same way that air and water emission were targeted, MSW has been singled out for remediation attention, with ambitious goals and a focus on a single waste stream. The result is a significant additional cost The City of Philadelphia has already abandoned its newly instituted recycling program as a result of the (unforeseen) additional costs [AP 93].

A more recent approach to environmental management emphasizes pollution prevention and waste reduction among producers. In the case of MSW, this approach would suggest designing consumer products to reduce waste and to facilitate recycling. As one pertinent example, requirements for reduced packaging or mandated packaging material return program for manufacturers (as occurs in Germany [OTA 89]) could reduce the total amount of MSW. As Table 2 indicates, paper and paperboard represents 40% of US MSW. Return of old newspapers to publishers (using the existing delivery network) could be mandated possibly with a requirement for recycling as in Germany. At least for some years, returning wastes to the manufacturer would increase costs and prices, simply shifting who bears the initial costs. Property done, a return program for some products could be efficient in inducing both product and process design improvements.

Recycling MSW must also be assessed against the possibility of MSW incineration. It may be advantageous to introduce recycling solely for metals, using the plastic and wood product portions of MSW as feedstock for energy producing incineration. Incineration for energy production can reduce demands on non-renewable petroleum supplies. More generally, all streams (as in 'Fable 1) should be assessed for cost effective disposal and re-use [Schall 93].

Finally, it should be evident that effective MSW recycling will require the adoption of inexpensive collection mechanisms and the encouragement of secondary recycling markets. For example, until maikets are created for substantial amounts of recycled plastics, plastic recycling will be a large burden for municipalities. The national packaging recycling program in Germany has swamped the EEC with inexpensive (and subsidized) recycled plastic (Rose 93]. Research and environmental regulation should be focused on developing economic recycling opportunities, likely to be targeted at individual product types and incentives for both producers and consumers [Menell 90].

Those seeking to improve environmental quality must examine the details of the resources, environmental implications, and raw materials usage of alternative plans. For Pittsburgh and similar cities, we find that costs of collecting and sorting recyclable materials are not offset by selling the materials. In these cities, placing the MSW in modem landfills is a cheaper alternative with less use of fossil fuels and other materials; it also leads to better environmental quality.

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