4. Recycling Costs

It is difficult to address the cost of plastic collection and processing without including other recyclables as well. How effectively plastics can be added to a recycling program depends on the current collection system and the flexibility of it. It is necessary to evaluate these issues in order to identify the best method for meeting recycling goals and for providing an indication of capital and operating budget expenditures. Because there are large variations between levels of recycling, it is almost always necessary to examine recycling program costs on a case-by-case basis.

Presented in this chapter is a cost estimate of curbside recycling options for the City of Madison, Wisconsin and an estimate of the cost of adding differing levels of plastics collection to existing curbside collection programs in the Minneapolis/St. Paul, Minnesota area. Each is important because they examine a number of options, thereby providing a range of values based on the options, and because their estimates include the utilization of existing equipment, the need for capital purchases is minimized. Also presented are costs which may be expected for processing plastics (baling, sorting, grinding) at a material recovery facility, and computer methods for estimating and optimizing recycling costs.

4.1 Recycling Program Variables

Because curbside pickup achieves the highest recovery rates, cost effectiveness of recycling was evaluated using curbside collection. The following variables affect curbside or drop-off collection costs:

- Recyclables collected
- Method of sorting (curbside versus MRF)
- Households in the service area
- Household participation rate
- Collection period setout rate
- Collection frequency
- Portion of recyclables separated by the homeowner for recycling (termed capture rate)
- Generation per person or household
- Travel time between households
- Time required per stop
- Travel time to dump
- Time at the processing center
- Cost of personnel and equipment
- Personnel per truck
- Market prices of recyclables
- Cost to process/level of marketability
- Shipping cost
- Cost avoidance of landfill diversion

The generally accepted method for determining the cost of recycling is:

Recycling cost (or profit)	=	Revenue from sale of recyclable material
	+	Avoided cost of MSW collection
	+	Avoided cost of MSW disposal
	-	Cost of collection of recyclables
	-	Cost of sortation at MRF
	+	Future value of saved landfill space

4.2 Recycling Costs

Although there is a social desire to recycle, the current price of landfill space in some areas has not yet offset the cost of curbside collection of recyclables. Recycling in Illinois is generally paid for on a per household basis. The cost of recycling may be expected to add 10-25% to the cost of existing refuse disposal. This translates into an additional cost of $1-$2.50 per month per household, either paid by a municipality throu general/taxpayer funds or directly included on homeowner bills.

Madison, Wisconsin Recycling Cost Estimate

An example cost estimate of recycling options was performed by the city of Madison, Wisconsin in 1990. A pilot study was conducted because the local county landfill is facing closure, and the local legislature banned disposal of certain recyclables i the landfill after January 1, 1991. The following options were considered for the mandatory recycling cost estimates:

- Option 1 — Once/week collection on weekends only, using recycling bags (rather than bins) which would be purchased by residents. Existing refuse collection equipment would be used (rear load/side load packers).
- Option 2 — Once/week collection on weekdays only, using recycling bags which would be purchased by residents. Specialized collection equipment would be purchased.
- Option 3 — Once/week collection on weekdays only, using recycling bins which would be purchased by the city. Specialized collection equipment would be purchased.
- Option 4 — Same as option 1, except bi-weekly collection.
- Option 5 — Same as option 2, except bi-weekly collection.
- Option 6 — Same as option 3, except bi-weekly collection.

The assumptions used in the cost estimate are shown in Table 4.1. The cost comparison between each option is shown in Table 4.2. As may be expected, the cost fo

Table 4.1 Assumptions Used to Calculate Costs of Alternative Curbside Recycling Options for Madison, Wisconsin [City of Madison, 1990]

Option	1	2	3	4	5	6
Equipment	Existing	Special	Special	Existing	Special	Special
Collection device	Bag	Bag	Bin	Bag	Bag	Bin
Collection frequency	Weekly	Weekly	Weekly	Bi-Wkly	Bi-Wkly	Bi-Wkly
Collection days	Weekend	Weekday	Weekday	Weekend	Weekday	Weekday
Decision parameters						
Participation rate (%)	70	70	80	70	70	80
Set out rate (%)	31.2	31.2	40.0	44.6	44.6	58
Stops/week	15,600	15,600	20,000	11,166	11,166	14,500
Collection days	Sat&Sun	M-F	M-F	Sat&Sun	M-F	M-F
Pounds/stop	10.3	10.3	8.8	14.3	14.3	12.1
Collection time/stop (sec)	54.2	48	52	50.9	45.6	49.4
Equipment capacity (lbs)	5,000	4,200	4,200	5,000	4,200	4,200
No. stops/crew/day	332	375	347	350	300	347
Crew days/week	47	41.6	58	32	31.5	41.8
No. days operated/week	2	5	5	2	5	5
No. crews/day	23.5	8.3	11.6	16	6.3	8.4
Additional foremen needed	1	0	0	1	1	1
Additional equipt. operators	10	9.5	13	8.5	7	9.5
Additional trucks needed	0	10	13	0	8	10
Cost/truck ($)	110,000	67,500	67,500	110,000	67,500	67,500
Debt service/truck	8,164	9,450	9,450	8,164	9,450	9,450
Route (mi./truck/day)	40	42	40	40	44	45
Equipt. oper. cost ($/mi.)	0.38	0.20	0.20	0.38	0.20	0.20
Equipt. maint. cost ($/mi.)	1.00	0.29	0.29	1.00	0.29	0.29
Add'l bldg. space needed (ft^2)	0	14,500	18,600	0	14,450	14,450
Container cost	$.10/bag	$.10/bag	$7.50/bin	$.10/bag	$.10/bag	$7.50/bin
Container life	One use	One use	5 years	One use	One use	5 years
No. containers used/year	26	26	1.3	20	20	1.3

Table 4.2 Annual Cost Comparison of Curbside Recycling Alternatives for Madison, Wisconsin [City of Madison, 1990]

Option	1	2	3	4	5	6
Equipment	Existing	Special	Special	Exisitng	Special	Special
Collection device	Bag	Bag	Bin	Bag	Bag	Bin
Collection frequency	Weekly	Weekly	Weekly	Bi-Wkly	Bi-Wkly	Bi-Wkly
Collection days	Weekend	Weekday	Weekday	Weekend	Weekday	Weekday
Cost Category						
Labor						
Overtime Salaries	0	0	0	7,543	7,740	10,085
Permanent Salaries	252,028	192,205	269,859	193,557	191,009	242,905
Benefits	75,238	61,331	83.296	61,587	60,952	77,560
Sub-total Labor	$327,266	$258,536	$353,785	$255,144	$251,961	$320,465
Materials, Supplies & Purchase Services						
Safety	1,000	1,000	1,300	700	800	1,000
Tools	0	550	650	0	400	500
Service Vehicle	15,000	0	0	15,000	0	0
Containers-buy & dist.	0	0	100,000	0	0	100,000
Sub-total mat. & purch	$16,000	$1,550	$101,950	$15,700	$1,200	$101,500
Motor Equipment						
Debt Service	195,936	94,500	122,850	130,624	75,600	94,500
Operation	37,149	17,264	24,128	25,293	16,380	17,472
Trasnsportation	85,540	26,910	35,648	66,560	24,079	21,840
Sub-total equipmenrt	$318,625	$138,674	$182,626	$222,477	$116,059	$133,812
Vehicle storage facility						
Debt service	0	111,265	143,220	0	111,265	111,265
Operation & maintenance	0	15,000	20,000	0	15,000	15,000
Sub-total buildings	$0	$126,265	$163,220	$0	$162,265	$126,265
Sub-total Operations	$661,891	$525,025	$801,581	$493,321	$495,485	$682,042
Public education	50,000	50,000	50,000	50,000	50,000	50,000
TOTAL Costs	$711,891	$575,025	$851,581	$543,321	$545,485	$732,042
Less:						
Tip fee diversion	($72,460)	($72,460)	($79,900)	($72,460)	($72,640)	($79,900)
Material revenue	0	0	0	0	0	0
Sub-total revenues	($72,460)	($72,460)	($79,900)	($72,460)	($72,640)	($79,900)
Net Total Costs	$639,431	$502,565	$771,681	$470,861	$472,845	$652,142
Tons Recycled	4,200	4,200	4,565	4,200	4,200	4,565
Net cost/ton	$152.25	$119.66	$169.04	$112.11	$112.58	$142.86
Cost/household/month	1.07	0.84	1.29	0.78	0.79	1.09
HH. cost/container/month	0.22	0.22	0.17	0.17	0.17	0.17
Total Cost/hh/month	$1.29	$1.06	$1.46	$0.95	$0.96	$1.26

once/week collection was higher than bi-weekly collection. Overall, cost estimates ranged from $0.96/month/household to $1.46/month/household. None of the options included the cost of processing or the revenues generated from the sale of recyclables.

In order to assess the cost of sorting and processing the recyclables collected, data from the nine week pilot study can be utilized. During the pilot, two contractors were paid $65.18/ton to process and separate the recyclables, and revenues of $42.20/ton were generated, resulting in a net cost to the city of $22.98/ton for recycle processing. Using this net processing fee and extrapolating the 126.25 tons of recyclables collected for the 11,325 household pilot to a yearly basis would result in an additional processing cost of $1.48/household/year. This example provides an objective cost estimate of implementing a municipal recycling program for a large community (50,000 households) and evaluates the use of new and existing equipment. A reasonable estimate of cost for municipalities greater than 50,000 households may be determined by scaling the values accordingly.

Minneapolis, Minnesota Plastic Recycling Cost Estimate

The Council for Solid Waste Solutions (CSWS) conducted a collection analysis for the Minneapolis, MN area in 1990. The impact of plastics collection on five existing curbside collection recycling programs was evaluated in terms of additional collection time, vehicle capacity and additional cost. The collection routes were as follows:

- Minneapolis A - Clear HDPE and PET soda bottles
- Minneapolis B - All plastic bottles
- Minneapolis C - All rigid plastic containers
- Minnetonka - Clear HDPE, colored HDPE, PET soda bottles
- Hennepin Recycling Group - Clear HDPE and PET soda bottles

Four different collection vehicles were used:

- An *Eager Beaver* brand recycling truck with a cage mounted on top for holding plastics, used on the Hennepin Recycling Group (HRG) route
- A *Lodal* brand recycling truck with nylon bags mounted for holding plastics, used on the Minnetonka route
- A *Labrie* brand semi-automated side loading recycling truck with an on-board perforator and flattener to densify plastics, used on Minneapolis routes B and C
- A customized *Isuzu* truck and trailer system with divided compartments for recyclables (including plastics), used on Minneapolis routes A, B and C

The following biweekly plastic set-out rates for Minneapolis measured by the recycling contractors were reported: Minneapolis A - 26.1%, Minneapolis B - 62.3%, Minneapolis C - 62.1%. Weekly plastic setout rates for Minnetonka and HRG were 21.5% and 29.5%, respectively. The Minneapolis B and Minneapolis C plastic setout rates were most likely so significantly higher than the setout rates of the other routes because they collected any type plastic bottle and any rigid plastic container, respectively.

A 50,000 household cost estimate of each of the three Minneapolis plastic recycling options was conducted using data from each of the routes. The estimate factored in amortized cost of capital expenses, administration, operation and maintenance expenses, labor expense based on collection times recorded, and waste diversion credit for the Minneapolis area. A summary of the economic analysis using data collected in the three Minneapolis (A, B and C) programs is shown in Table 4.3. For Minneapolis, adding plastics to a biweekly recycling program using semi-automated side loading trucks with truckside sort for a community of 50,000 households would add between $0.47 and $3.29/household/year, depending on plastics recycled, collection bin, inclusion of perforator and the other specific details of each program. The above costs include a diversion credit of $94.00/ton. The cost of adding plastics to the three programs without diversion credit would result in an additional cost of between $0.72 and $4.32/household/year, depending on the option chosen.

A similar analysis for the HRG and Minnetonka recycling programs was also conducted. The cost of adding plastics to a 50,000 household Minnetonka type route (i.e., collecting the plastics, using the collection vehicle arrangement and using the plastic generation rates of the Minnetonka program) was estimated at $3.80/household-year, and the cost of adding plastics to a 50,000 household HRG type route was estimated at $1.42/household-year. These costs do not include diversion credit.

The Minnetonka and HRG programs, which have weekly setout rates of 16 lbs./setout and 21 lbs./setout, respectively, had curbside collection costs less than the associated waste diversion credit of $94.00/ton regardless of whether plastics were collected. By comparison, the Minneapolis A, B and C routes had average weekly setouts of 10.75 lbs./setout, and for this reason did not have collection costs less than the associated diversion credit.

In order to determine the total cost of curbside collection (for plastics as well as other recyclables), it is necessary to add the above incremental plastics collection costs to the costs associated with curbside collection if plastics were not included. Also, there will be additional cost for performing sorting, baling and granulating even though the above stated costs include curbside sortation (in comparison to commingled collection).

Table 4.3 Plastic Collection Economic Analysis for Minneapolis, MN Area [CSWS, 1990]

Parameters	No Plastics	Type of Plastic Collection: Route A (Soft Drink & milk bottles)	Route B (All plastic bottles)	Route C (All rigid plastic containers)
Input Parameters				
Recycling Data				
Plastic recyclables (lb/setout/wk)	0.0	0.390	0.580	0.680
Other recyclables (lb/setout/wk)	10.75	10.75	10.75	10.75
Number of households served	50,000	50,000	50,000	50,000
Plastics setout rate (%)	0	26.1	62.3	62.1
Other recyclables setout rate (%)	74.5	74.5	74.5	74.5
Cost Data				
Additional container cost ($)	0	0	5	5
Interest rate (%)	8.5	8.5	8.5	8.5
Payback period (years)	7	7	7	7
Labor cost ($/hr)	$18.50/hr	$18.50/hr	$18.50/hr	$18.50/hr
Operation & Maintenance cost ($/hr)	$5.00/hr	$5.00/hr	$5.00/hr	$5.00/hr
Administrative cost (%)	10	10	10	10
Labrie Recycling Vehicle Cost Parameters				
Recycling vehicle cost ($)	85,600	85,600	85,600	85,600
Plastics perforator cost ($)	0	10,000	10,000	10,000
Isuzu Recycling Vehicle Cost Parameters				
Recycling vehicle cost ($)	50,000	50,000	50,000	50,000
Plastics bin cost ($)	0	0	0	0
Output Parameters				
Recycling Data				
Households served	50,000	50,000	50,000	50,000
Households served/day	5,000	5,000	5,000	5,000
Plastic setouts/day	0	1,305	3,115	3,105
Setouts/day	3,725	3,725	3,725	3,725
Plastic recyclables collected (tons/year)	0	132	470	549
Other recyclables collected (tons/year)	10,411	10,411	10,411	10,411
Using Labrie Recycling Vehicle				
Number of Vehicles Required	15	15	17	17
Additional cost of plastic collection [a] ($)	$0	$23,602	$172,088	$164,590
Plastic cost/household-year ($/hh-yr)[a]	$0/hh-yr	$0.47/hh-yr	$3.44/hh-yr	$3.29/hh-yr
Using Modified Isuzu Recycling Vehicle				
Number of Vehicles Required	14	15	16	16
Additional cost of plastic collection [a] ($)	$0	$45,356	$122,490	$115,000
Plastic cost/household-year ($/hh-yr)[a]	$0/hh-yr	$0.91/hh-yr	$2.45/hh-yr	$2.30/hh-yr

a. The additional cost of plastic collection includes a landfill savings diversion credit of $94.00/ton. The additional cost of plastic collection using the Labrie truck without landfill diversion credit would be $0.72/hh-yr, $4.32/hh-yr and $4.32/hh-yr for collection scenarios A, B and C, respectively. The additional cost of plastic collection using the Isuzu truck with trailer without landfill diversion credit would be $1.16/hh-yr, $3.33/hh-yr and $3.33/hh-yr for collection scenarios A, B and C, respectively.

It should be noted that while the above study shows cost advantages of specific vehicle types over another, there are other factors not shown which are directly related to cost. For example, a recycling vehicle which requires workers to empty a residential recycling bin at/above head level (between 5 and 7 feet off the ground) into open top collection bins on the truck 300 to 500 times/day (a typical collection rate for a recycling truck) can result in a significantly increased amount of worker back and muscle injuries. For this reason, a semi-automated side loading recycling vehicle, in which the worker empties the residential recycling bin at the waist high level into truck compartments which automatically empty themselves, may actually be preferable (even though the truck costs more) when examining total potential costs.

Other Recycling Cost Estimates

Additional economic evaluation regarding the incremental cost of curbside collection of plastic with other recyclables and MSW are reported by Rankin (1988) and Temple, Barker & Sloane (1989). Some of the economic parameters used in these reports (such as tip fee and market prices) are not representative of current conditions. However, the reports concluded that there was a net economic benefit associated with adding plastic bottles to the collection program studied.

4.3 Collection Times

The time it takes to collect recyclables has a direct impact on the economics of curbside collection. Discussed below are some field measurements of collection times using varying collection methods. Assuming collection methods are similar, the collection times shown can be used for assessing curbside collection of plastics and curbside recycling in general.

The Madison, Wisconsin pilot, which collected recyclables commingled in clear plastic bags, recorded the collection times shown in Table 4.4. The average collection time for all four collection trucks utilized is about 1 minute per stop. This does not include dumping time, break time, and other time spent not related to collection, but does include time driving to and from the collection routes. No separation of materials was performed at curbside.

Collection times with and without rigid plastics recycling were recorded in the Barrhaven, Ontario pilot discussed in Chapter 2. A bin was utilized for residents to place recyclables in. The collection utilized *Labrie* type semi-automated side loading trucks

Table 4.4 Collection Times of Commingled Recyclables in Madison, Wisconsin [City of Madison, 1990]

Collection Truck Type	Average Time/Setout (minutes/stop)
Low entry side-loading refuse packer (1 person)	1.06
Low entry rear-loading refuse packer (1 person)	1.13
Conventional cab rear-loading refuse packer (2 person)	0.75
Pick-up truck with attached trailer (2 persons)	0.84

where rigid plastics, glass, metals and old newspaper were each placed in separate compartments of the truck at curbside. The time required for each setout without plastics averaged 16 seconds, of which about 3 seconds was for travel to and from the truck and 13 seconds was for truckside sorting. Bins which contained rigid plastics required an average of another 7.5 seconds to sort at the truck. These figures do not include time between residences, dumping time or time required going to and from the collection route.

Collection times were also recorded in the Minneapolis area pilot to assess the additional time required based of the plastic types collected and the vehicle type. The times recorded for each of the route/truck combinations are shown in Table 4.5. The additional time to collect plastics varied from 3-11 seconds per setout of recyclables, with clear HDPE and PET soda bottle collection requiring the least time and rigid plastic containers requiring the most time. When adjusting the time to collect plastics to only households which set plastics out, the collection time per setout is as shown in Table 4.6. The differences are not large and range from 9-15 seconds. There is also no pattern between the level of plastic collection and the time per setout. For example, two clear HDPE and PET soda bottle programs required 9 and 13 seconds, and all plastic bottle collection required 10 and 12 seconds.

The Minneapolis B and C routes, which used one container for plastics collection and one container for all other recyclables were reported to be effective. Such containers made the plastics collection easier for workers since it was not necessary to sort plastics from other container types.

The total number of stops per day by a recycling truck vary according to the amount of curbside sorting performed, the amount of sorting performed by a homeowner, the use of municipal or private collectors and the number of crew members per truck. In general, reviews of recycling routes have indicated that an average of 500 stops/day is achieved without considering any of the above factors [Glenn, 1990, 1988].

Table 4.5 Average Time Spent on Each Collection Task per Recycling Setout [Krivit, 1990]

Route	Collection Truck Type	Other Recyclables Collection [a]	Plastics Collection Time [b]	Loading Time [c]	Tagging Time [d]	Verification Time [e]	On Vehicle Time [f]	Idle Time [g]	Other Works Time [h]	Total Time
Average Time Per Recycling Setout (seconds/setout)										
Minneapolis A	Isuzu	40	5	0	1	2	13	1	1	1:02
Minneapolis B	Isuzu	43	7	0	9	5	24	2	4	1:33
Minneapolis B	Labrie	46	8	5	3	5	15	0	0	1:22
Minneapolis C	Isuzu	47	10	0	2	8	12	0	2	1:20
Minneapolis C	Labrie	38	11	4	2	5	16	10	2	1:26
Minnetonka	Lodal	30	3	0	0	0	19	0	1	0:53
Hennepin Recycling Group	Eager Beaver	27	3	0	1	1	21	1	3	0:56

a. Other Recyclables Collection Time: The time spent sorting and collecting recyclable materials other than plastics. Depending on the route, these materials may have included newspaper, corrugated cardboard, aluminum cans, steel cans or glass.

b. Plastics Collection Time: The time dedicated specifically to the collection of the corresponding routes' recyclable plastics.

c. Loading Time: The time taken to mechanically load the collection vehicle (applicable only to semi-automated side loading "Labrie" type vehicles on the Minneapolis B and C routes).

d. Tagging Time: The time used to tag either the other recyclables or the plastic materials that could not be picked up because of noncompliance with the recycling standards.

e. Verification Time: The time spent by the driver to collect household setout information.

f. On Vehicle Time: The time spent aboard and driving the collection vehicle.

g. Idle Time: Any time such as breaks taken by the driver.

h. Other Works Time: Time spent on productive activities such as cleaning spilled materials, talking to supervisor or other drivers about collection activities, transferring recyclables, and other activities related to collection work not defined above.

Table 4.6 Plastics Collection Time Per Plastic Setout [CSWS, 1990]

Route	Collection Truck Type	Plastic Collection Time (seconds/plastic setout)
Minneapolis A	Isuzu	13
Minneapolis B	Isuzu	10
Minneapolis B	Labrie	12
Minneapolis C	Isuzu	13
Minneapolis C	Labrie	15
Minnetonka	Lodal	9
Hennepin Recycling Group	Eager Beaver	9

4.4 Recycling Truck Costs and Truck Collection Methods for Plastics

Collection vehicles are often the largest capital expense associated with curbside recycling. There are three general styles available for recycling: open top trucks, closed body trucks and trailers. Trailers, which contain bins that may be single, segmented or removable, are commonly chosen for recycling. Depending on the application, there may be disadvantages with a trailer due to maneuverability or capacity. Open top trucks have an open top and are typically loaded through a series of doors along the side of the truck, which can slide up as a compartment fills. Closed body trucks have an enclosed, partitioned collection container and are loaded from the side or top through an opening. Closed body trucks are also manufactured with semi-automated loading devices, such as a trough along the side of the vehicle, which can be emptied hydraulically into the top of the vehicle container. Appendix A provides a listing of the manufacturers of recycling vehicles and recycling trailers.

Trailers are by far the lowest cost collection option. Their expected base cost ranges from \$12,000 for a 15 yd^3 trailer to \$18,000 for a 22 yd^3 trailer. The base price of an open top truck will range from \$25,000 to \$70,000, with an average price of around \$45,000/truck. Open top trucks have capacities of 15 to 25 yd^3. The price of a closed body truck ranges from \$50,000 to \$80,000, and semi-automated closed body trucks cost \$70,000 to \$90,000. Closed body trucks are the largest and have capacities of 20 to 35 yd^3. Prices of specific truck types are reviewed in Biocycle, 1989.

The following relative truck volumes have been estimated by the Center for Plastics Recycling Research for collection of recyclables: old newsprint, 23.2%; glass bottles, 13.0%; steel cans, 10.7%; aluminum cans, 16%; PET beverage bottles, 17.6%; and HDPE milk, water bottles, 19.0%. A recycle composition study with the per household generation and density conversion will help a locality determine the volumes to expect.

It is estimated that collection of uncrushed plastic HDPE and PET beverage bottles can occupy 37% of a collection truck's volume while only contributing to 5% by weight of the load. If collection of plastic fills recycling truck bins and results in modifying a collection route to clear the load prior to the filling of other truck bins (such as old newspaper), the cost of plastic collection can rise significantly. Simple solutions have been suggested:

- Add a cage on the top or back of the truck to hold plastics.
- Use netting or a bag on the side of the collection vehicle to hold plastics.
- Collect plastics in transportable bags which can be removed and replaced with empty bags when full.
- Put plastics in an unused portion of the collection vehicle.
- Add or modify the collection vehicle to include compaction.

All but the last option requires curbside sorting of materials or at least the plastic from other recyclables. However, many curbside recycling programs use a commingled collection. Adding on-board compaction is offered commercially but its effectiveness is not well known. Problems with on-board compaction are the additional cost of modifying an existing collection vehicle and the resulting minimal net volume savings after addition of the compactor. The Council for Solid Waste Solutions is conducting research on increasing compactor effectiveness. The results should be available in 1991.

One method of reducing plastic volume is to educate consumers to crush their plastic bottles prior to disposal. The National Association for Plastic Container Recovery, (NAPCOR) an industry trade group which promotes plastic recycling, provides extensive media and mailing services to assist communities in educating homeowners.

4.5 Process Cost

Manual separation of plastic bottles, the current most commonly accepted method, is estimated to sort anywhere from 1 to 6 bottles per second per sorter with a conveyor belt/manual pick station arrangement. A 1 bottle/second pick speed at an average bottle weight of 0.14 - 0.15 pounds/bottle results in a process rate of 500-550 pounds per hour. At $10/hour labor, the sort cost is $0.02/lb., not including overhead, benefits, baling, grinding, or shipment.

The general cost for plastic handling and processing has been estimated as follows [PRC, 1990b]:

- Sorting 2 - 3 ¢/lb
- Baling 3 - 4 ¢/lb
- Grinding 3 - 4 ¢/lb.
- Cleaning (flake input/output) 10 - 15 ¢/lb
- Pelletizing 5 - 7 ¢/lb

As an illustration of the overall sorting costs, Somerset County, NJ, which has mandatory recycling of any plastic bottles and manual sortation at its MRF, processed about 8,000 lb/day of plastic bottles in 1990. When the material is brought into the MRF, a negative sort is performed on the material to remove all non-bottle items and bottles that are not marketable. The end result is a mixture of PET, HDPE clear and colored, and PVC bottles which are marketed in a baled commingled state. The county receives $0.03/lb. for the commingled bales. The operation utilizes county employees at an average rate of $7.50/hour along with a work detail from the county jail. Daily manpower costs are $660, with overhead being another $200, for a total daily cost to run the plastic operation estimated at $860/day. After revenue, the cost is reduced to $620/day [Lazo, 1990]. This puts the approximate overall sort and baling cost at 11 ¢/lb, not including revenue. The Rutgers Center for Plastics Recycling Research has similarly estimated plastic bottle sorting and baling costs at about 12 ¢/lb [Dittman, 1990].

Baling equipment is typically necessary for plastic as well as paper product processing. There are two types of balers, vertical and horizontal. The baler type describes the ram movement in the baler. Horizontal balers are geared for large recycling operations and vertical balers for small recycling operations. A summary of the capability of each type is shown in Table 4.7.

4.6 Cost Estimate Computer Programs

Because there are so many variables, it is difficult to assess what the exact cost of recycling will be for a locality. Computer programs can be used to estimate the various costs involved in recycling.

Eastman Chemical

A computer modeling program by Eastman Chemical, a major PET producer, shows that including plastics can reduce the overall costs of a recycling program. In general, the program projects that recycling is the most cost effective when at least

Table 4.7 Recycling Center Baler Types [Firpo, 1990]

Description	Horizontal Baler	Vertical Baler
Typical Bale Size	30" x 40" x 72" 40" x 48" x 72"	30" x 48" x 60"
Bale Weight (lbs)	700 - 1,800 lbs (depending on plastic density and baler pressure)	600 - 1,000 lbs (for cardboard) 350 - 650 lbs. (for plastic)
Power requirements (Hp)	30 - 150 Hp	10 - 20 Hp
Cost ($)	$30,000 - $150,000	$8,000 - $13,000
Advantages	• Higher production than vertical (3 - 10 bales per hour) • Higher bale density than vertical baler	• Requires less than 100 square feet of total operating and material storage space • Does not require special-assembly or maintenance
Disadvantages	• Requires large floor space • May require specialized assembly or maintenance • More technical to operate • Greater safety precautions required	• Slower production than horizontal baler • Lower bale density than horizontal baler

newspaper, glass, aluminum, HDPE and PET beverage bottles and steel cans are collected from at least 100,000 households and landfill fees are over \$50/ton. The cost of adding PET to commingled collection for 100,000 homes is about \$148/ton and will range from \$125 to 200/ton, depending on what else is collected. Adding glass is \$56/ton, steel is \$49/ton, newspaper is \$36/ton and aluminum is \$83/ton (Figure 4.1). The above values do not include revenue from the sale of recyclables. When deducting the revenue gained from the cost of adding a material, the cost of PET and/or milk bottle collection is about the same as that for other recyclables (Figure 4.2). It is also estimated that crushing plastic bottles can have a significant effect on the cost of adding plastic to a program, and even make PET a net revenue earner depending on the amount of volume reduction. For a typical community of 100,000 with recycling, the cost of MSW disposal (including recycling cost) decreases when recycling exceeds the 3% level. The computer program is available through the National Association for Plastic Container Recovery (NAPCOR). The NAPCOR address is 5024 Parkway Plaza, Charlotte, NC 28217, (704) 357-3250.

Wasteplan

The Illinois Department of Energy and Natural Resources (IDENR) also makes available a computerized integrated solid waste management planning model called WASTEPLAN (developed by Tellus Institute of Boston, MA). The program addresses composting, recycling, incineration and landfilling options. Plastics can be included in the recycling portion of the model. It has a menu driven structure and allows for variation of a variety of input data including waste stream definition, solid waste generation, recyclable material, collection systems, and processing and disposal facilities. It also is equipped with a default data file to allow for learning and customization. IDENR correspondence should be addressed to the Office of Solid Waste and Renewable Resources, 325 W. Adams Street, Springfield, IL 62704, (800) 252-8955.

Least-Cost Scheduling

A least cost scheduling of recycling has been proposed by Lund [1990a, 1990b]. Linear programming can be used to minimize the present and future costs of recycling, landfilling and waste disposal. It allows the user to address the limited capacity of an existing landfill. The method can also be used to assess the recycling decisions of waste collectors which do not greatly affect the lifetime of a landfill operated by another entity. The model accounts for the following variables: recycling option costs, closure costs, construction costs of future waste disposal facilities, revenues from recyclables, future landfill life, household generation rates and market prices. Estimates for

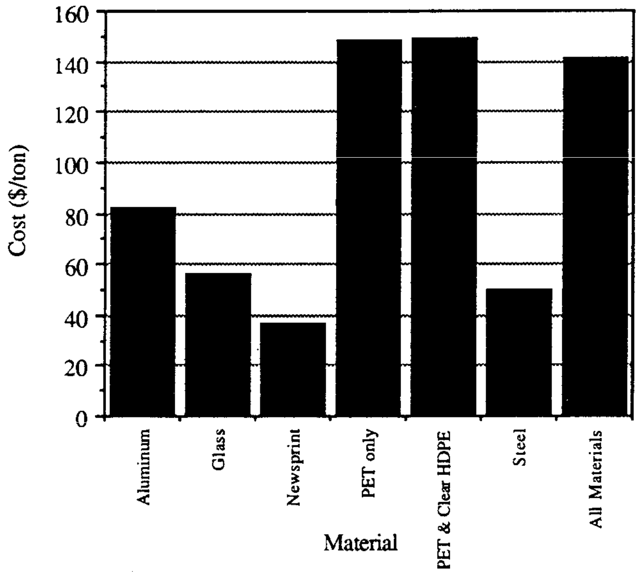

Figure 4.1 Example Costs of Including Recyclables in a Curbside Collection Program [Cornell, 1990]

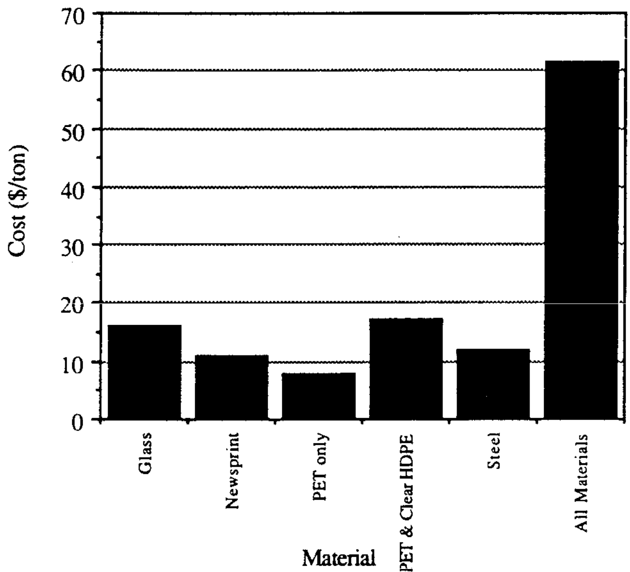

Figure 4.2 Example Costs of Including Recyclables in a Curbside Collection Program when the Revenue of Recyclables is Included [Cornell, 1990]

these variables must be made prior to entering the program. The method does not include indirect costs such as environmental impacts (e.g., aquifer contamination). However, direct costs related to environmental impacts, such as insurance coverage, may be included.

An example which includes the costs associated with landfill closure and replacement landfill construction may be used to illustrate this method. A small city (10,000 households) wishes to implement recycling to defer landfill closure and future replacement costs of waste disposal facilities. Three options are considered:

Option 1 Recycling of household waste paper (old newspaper and junk mail) and old corrugated cardboard (OCC) with weekly collection of the separated material by a recycling vehicle. Estimated recovery rate is 70% of the waste paper and 50% of the OCC.

Option 2 Recycling of glass, steel cans, ferrous and aluminum in addition to the household waste paper from option 1. The recovery rates are 75%, 70%, 70% and 70%, respectively. Option 2 requires a larger truck moving more slowly than the option 1 truck.

Option 3 Collection and composting of yard waste. The estimated recovery rate is 90% of all yard waste and 30% of dirt disposed (much of the dirt comes from yard waste).

The MSW composition for the three options is shown in Table 4.8. The existing landfill has a capacity of 1,000,000 yd^3, and the cost of closure will be $8,000,000 in the year it is closed. The cost of replacing the landfill with a series of future landfills and/or incinerators covering a 50 year planning period is $82,000,000 in the year the landfill is closed. The current population is 10,000 households and expected to grow at 500 households per year.

The cost and landfill effectiveness of each recycling option is shown in Table 4.9. Since option 2 requires only a larger truck on routes used for option 1, the cost of option 2 is only the incremental cost of running trucks slower to pick up, process and market the additional material.

Without recycling, the landfill would be filled and closed in 11 years. If all recycling options were implemented for all households, there would be a 65% volume reduction in the rate of waste disposal in the landfill, and landfill life would be extended another 13 years to year 24. Figure 4.3 shows the present value of cost and savings calculated at each year of projected landfill closure beyond the initial minimum of 11 years. The least cost option would yield a landfill lifetime of 21 years. This is 10 years greater than if no recycling option were implemented, but three years shorter than if all recycling options were implemented on all households at all times. The model output also indicates the optimum implementation year of each option. Based on the cost output data, recycling options 1 and 2 would be implemented immediately and yard waste collection would not be scheduled until year 15. Extending the landfill lifetime until year 21 by recycling would result in a net present value savings of $9,1000,000.

Table 4.8 MSW Composition for Least Cost Scheduling Recycling Example [Lund, 1990a]

Material	Option [a]	Generation (lbs/hh/yr)	Landfill Volume (ft^3/yr)	Capture Rate of Recyclables [b] (%)
Paper	1,2	2,202	86.4	70
Cardboard	1,2	332	26.8	50
Glass	2	383	19.0	75
Tin cans	2	266	8.7	70
Non-ferrous metals	2	77	1.4	70
Ferrous metals	2	220	3.9	70
Garden Waste	3	731	28.1	90
Wood	3	179	3.6	90
Dirt, etc.	3	56	1.6	30

a. See text for description of options.
b. From all MSW generated.

Table 4.9 Input Parameters for Least Cost Scheduling Linear Program Example [Lund, 1990a]

	Option 1	Option 2	Option 3
Recycling Reduction (ft^3/hh/year)	73.9	24.0	28.9
Annual cost ($/hh/year)	40	15	40
Cost Effectiveness ($/$ft^3$/year)	0.54	0.63	1.38
People per household	4		
Number of options considered	3		
Rate of household growth	10,000+500 households per year growth		
Waste generation rate	195.5 ft^3/hh/year		
Remaining capacity	1,000,000 yd^3		
Interest rate	5%		
Cost of closure	$8,000,000		
Cost of replacement	$82,000,000		

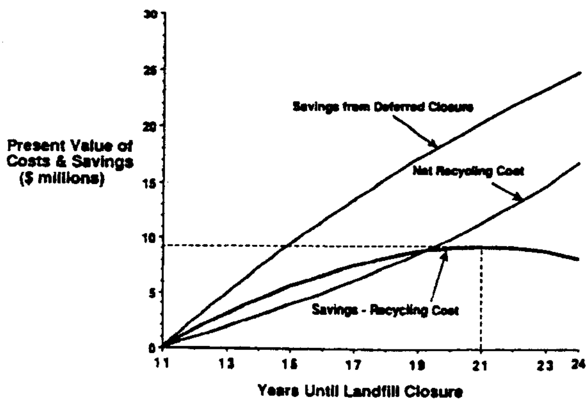

Figure 4.3 Net Present Value of Disposal and Recycling Costs for Differing Landfill Lifetimes [Lund, 1990a]