2. Characterization, Generation and Collection of Plastics

When considering plastics for inclusion in a recycling program, the questions of "How much plastic is in MSW ?" and "How much plastic has been captured in existing recycling programs ?" come to mind. These questions are even more prevalent when mixed plastics collection is being contemplated. As may be expected, there are few recycling programs which currently collect more than HDPE bottles and PET bottles, and there are even fewer that collect film plastic in addition to rigid plastic containers. While generation rates have been developed for milk jugs and soda bottles based on collection data, there is little collection data for additional plastics. This chapter attempts to provide characterization and generation data from studies and programs involving multiple plastics. Many of the municipalities discussed in this chapter were either participants in pilot mixed plastics recycling studies or received public funding to conduct research on an aspect of curbside recycling collection. The data shown can be used in initial planning for estimating quantities involved in plastics recycling collection and for estimating non-specified plastic and non-plastic contaminants. They can also be compared to the experiences of other municipalities which have conducted forms of mixed plastics recycling. It should be noted that while plastic generation and composition data are presented from national and local studies, it does not replace the need for such an effort in a community's solid waste assessment.

2.1 Field Assessment of Plastic Types in Municipal Solid Waste

A study of the composition of plastics in the waste stream in Hamilton, Ohio identified that 6.2% by weight of MSW was plastic. The composition of plastic components is shown in Table 2.1. By comparison, the national average of plastic in MSW discards is 9.2% by weight [U.S. EPA, 1990b]. The "Other" category in the table included such items as HDPE bleach, laundry detergent, motor oil and margarine/butter containers, LDPE band-aids and shampoo bottles, PS caps, and PVC clear bottles [Peritz, 1990]. The Hamilton, Ohio analysis collected 1,000 to 1,200 pounds MSW per day over a 2 week period (11,900 pounds total). Bag/film plastic was the second highest percentage by weight after the "Other" category.

Table 2.1 Plastic in MSW of Hamilton, Ohio [Peritz, 1990]

Plastic Type	% by Weight in MSW	% by Weight of Plastics
PS Foam	0.5	8
PET Soda Bottles	1.0	16
HDPE Milk/Water Bottles	0.7	11
Bags (LDPE film)	1.8	29
Other [a]	2.2	36
Total	6.2	100

a. See text.

The city of Milwaukee conducted a waste characterization during 1989 and 1990 which included the composition of plastics disposed in MSW (Table 2.2). The MSW was from neighborhoods without curbside recycling services. The characterization was based on sorting one load/month of MSW during September, February, May and August to account for seasonal variations. The leaf contribution is zero due to separate collection, and therefore plastics composition should be adjusted. Estimating the contribution of leaves to be 50% by weight of grass clippings results in plastics comprising 7.8% by weight of the total waste stream (rather than 8.4% by weight without including leaves). Film and rigid plastic containers make up the majority of the plastics in the waste stream by weight.

The city of Chicago also conducted a four season waste composition analysis in 1989 and 1990, and identified that 9.4% by weight was plastic, of which 0.8% was PET beverage containers, 1.0% was HDPE containers and 7.6% was other types of plastics [City of Chicago, 1990]. "Other" types included such plastic items as film plastics, durable goods, toys, disposable diapers, packaging and fast-food containers. The data were taken from MSW collected in each of Chicago's 50 wards during April, August, October and February. The average monthly sample size was about 300 pounds per ward.

When assessing waste disposal rates from a large scale municipal facility such as an airport it may be desirable to assess recyclability of the waste stream. A study of plastic composition at Miami, Florida International Airport identified that of the 35 tons/day generated, 12.5 % was plastic by weight. The plastic composition is shown in Table 2.3. Overall, a large percentage of the airport waste was recyclable, with paper, corrugated

Table 2.2 Residential Waste Characterization for Milwaukee with Emphasis on Plastics [Engelbart, 1990]

MSW Component	Composition of Waste Stream (Weight %)
Dirt, diapers and fines [a]	6.6
Ferrous metals	5.1
Food	16.0
Hazardous materials	0.3
Glass	8.3
Leather	0.1
Multi-material packages	0.4
Non-ferrous metals	1.6
Paper	31.0
Plastics	
PET containers ≥ 1 liter	0.4
PET containers < 1 liter	0.1
HDPE colored, tubs	0.5
HDPE milk, water, juice, bottles	0.5
Rigid plastics	1.9
Flexible bags and films	4.5
Polystyrene	0.4
Other (durable goods, non-pkg.)	0.1
Subtotal	8.4
Rubber	0.7
Rubble	0.8
Textiles	4.6
Yard waste	
Leaves	0.0
Grass clippings	13.8
Brush / branches / weeds	1.5
Wood (lumber, stumps, pallets)	0.8
Total	100

a. Non-identifiable fine fragments or particles in the waste analysis (often crushed glass).

Table 2.3 Composition of Miami, Florida Airport Plastic Waste Stream [Peritz, 1990]

Product	Weight (%)
Film Plastic	40.6
Clear Cups	16.5
Foams	10.6
Translucent Cups	6.0
PET Beverage Bottles	4.6
Rigid (White) PS	4.4
Utensils	4.4
Rigid Coffee Cups	2.1
Mixed (Other) Plastic	3.3
High Impact Cups (Dairy)	0.8
Straws	0.6
Non-plastic residue	6.1
Total	100

products and glass composing 45.4% of the waste in addition to the plastic. Although this study does not replace the need for such a characterization at Illinois' large municipal facilities, it does provide an indication of what may be expected and demonstrates that the potential exists for large scale recycling at such installations.

A national examination of plastic product types in MSW showed durable goods comprised 29%, nondurable goods 32% and containers and packaging 39% by weight with nearly all of it discarded (Table 1.5, U.S. EPA, 1990b). A materials flow methodology for the waste characterization was used in this study. This method incorporates production data (by weight) for the materials and products in the waste stream with adjustments for imports, exports and product lifetimes. Such a method does not directly allow for apportioning individual waste stream components (such as corrugated cardboard) to differing waste generators (commercial, residential, industrial). Materials flow methodology does not account for product residues present in containers (therefore an estimate of plastic detergent bottles in waste would not include the detergent residue as part of the bottle weight estimate). The method *does* account for the disposal condition of organic wastes such as food waste, yard waste and the moisture present in disposable diapers. The materials flow method is different from site-specific characterization of MSW where a locality may conduct sampling, sorting and weighing of waste stream components. A comparison of the plastic content in MSW using these two independent methods showed plastics were 9.1% (by weight) using the materials flow method and 4.9% - 12.6% (by weight) for 25 site-specific characterization studies [U.S. EPA, 1990b]. Both methods give reasonable estimates.

2.2 Mixed Plastics in Recycling Programs

While percentage of plastics in the waste stream has been studied in a number of locations, less information is available on the type of plastics collected in recycling programs requesting mixed plastics. Each recycling program is unique in its characterization. Most plastic curbside collection is commingled with other recyclables and sorted at a MRF. Curbside collection across the country has only recently started to include plastic containers, and even then most collections are PET and HDPE beverage bottles.

New Jersey

A study by the Center for Plastic Recycling Research (CPRR) at Rutgers University analyzed the curbside and drop-off collection of mixed plastics in which the only plastic types specified were <u>beverage</u> bottles. It showed the bottle composition to be roughly 50% PET soda bottles, 30% milk and water bottles and 10-20% non-specified plastic, by weight [Morrow and Merriam, 1989]. The plastic composition from two of the communities (curbside collection in Mt. Olive, NJ and drop-off collection in South Plainfield, NJ) is shown in Table 2.4. It provides details on plastics contributed that were not specified for collection in the program. There is a large increase in non-specified plastic collection for the drop-off site study in comparison to the curbside collection study. This illustrates the need for public education and clear, simple collection instructions.

In two other municipalities studied by CPRR, the directions for curbside plastic collection were potentially confusing. The handout sheets to residents requested beverage containers only, while instructions printed on the 20 gallon recycling bin requested "all plastic bottles." As a result, non-specified plastics for the two towns averaged 20-25% by weight, about twice the 10.9% of non-specified plastics collected in the Mt. Olive study [Morrow and Merriam, 1990].

Collection of rigid plastic containers (RPC) shows that there is a large constituent beside milk and soda bottles which will be deposited in a recycling bin. A study of the Sayerville, NJ curbside collection program, where plastics accepted included "any plastic bottle or container from which a product is poured," shows HDPE that would be collected in addition to only milk and water bottles (Table 2.5).

In addition to the above municipalities, CPRR has estimated an average generation rate of all recyclables in suburban New Jersey municipalities with single family homes. The average volume and weights of plastic as well as other recyclables expected per household is shown in Table 2.6. The average weekly setout of PET and HDPE bottles (colored and clear) was determined the to be 0.45 lb/setout and 0.30 lb/setout, respectively. The volume data shown can be used as a guide for apportioning truck volumes necessary for curbside sortation. Commingled collection of glass, steel, aluminum and plastics in one container and collection of old newspaper in another container (with processing at a MRF) is recommended by CPRR [Rankin, 1989].

Table 2.4 Composition of Collected Plastic Beverage Bottles [Morrow and Merriam, 1989]

Bottle Type	South Plainfield, NJ (Weight %)	Mount Olive, NJ (Weight %)
Population in collection study	20,000	22,000
Program type	drop-off	curbside
Number of samples	10	11
Time period of collection	4/88 - 1/89	5/88 - 2/89
PET beverage bottles	51.37	55.87
HDPE milk/water bottles	30.10	33.23
Other non-beverage bottles	18.53	10.90
Composition of "Other non-beverage bottles:" [a]		
HDPE detergent bottles	14.74	7.09
HDPE Motor oil bottles	0.63	1.01
PVC bottles	0.75	1.05
PET 2 liter	0.49	0
Other plastic	1.34	1.56
Unknown plastic	0.58	0.19

a. Plastics contributed that were not specified as part of the collection program.

Table 2.5 Composition of Rigid Plastics in Sayerville, NJ Curbside Collection Study [Morrow and Merriam, 1989]

Plastic Collected	Composition (Weight %) 3/10/89	4/27/89
PET bottles	41.5	40
HDPE milk and water bottles	15.5	16
Other	43.0	44
Composition of "Other:"		
HDPE Large detergent	22	18
HDPE Small detergent	8	7
HDPE Motor Oil	5	2
Shampoo	3	2
PVC vegetable oil, water	2	5
Miscellaneous	3	10
Total	100 %	100 %

Table 2.6 Composition of Recyclables Collected Weekly per Household in New Jersey [Rankin et al, 1988]

Recycle Stream	Weight (lbs/setout)	Weight (%)	Density (lbs/yd^3)	Volume (gallons/setout)	Volume (%)
Newspaper	7.75	48.4	500	3.1	23.7
Glass bottles	6.0	37.5	700	1.7	13.0
Metal cans	1.0	6.3	144	1.4	10.7
Aluminum cans	0.5	3.1	49	2.1	16.0
Plastic bottles, uncrushed					
PET (60%)	0.45	2.8	40	2.3	17.6
HDPE (40%)	0.30	1.9	24	2.5	19.1
Total per setout	16.0	100%		13.1	100%

Total MSW generated [a] (lb/household/week) = 63.5

MSW recycled (%) = 16.0 / 63.5 = 25.2

a. This is based on 1000 lbs of MSW generated/person/year and 3.3 people per household.

Hennepin County, Minnesota

Studies were conducted in the Minneapolis/St. Paul, Minnesota area in 1990 by the Council for Solid Waste Solutions and the local governments [CSWS, 1990]. The purpose of the work was to assess the feasibility of collecting plastics at curbside in Hennepin County, Minnesota. This study illustrates the addition of various plastics to existing recycling programs using differing collection vehicles and presented details related to composition and collection.

The programs consisted of adding curbside collection of plastics to five existing routes: 3 routes in the city of Minneapolis, 1 route in the city of Minnetonka and 1 route in three northwestern suburbs known as the Hennepin County Recycling Group (HRG). The three Minneapolis routes collected biweekly and the other two routes collected weekly. All methods utilized curbside sortation of material. The study duration was roughly three months. A summary of collection methods for each route is shown in Table 2.7. All field data were collected over a one month period by Cal Recovery Systems, Inc.

Municipal and private haulers were utilized to collect a variety of plastic types. The Minneapolis "A", "B", and "C" routes were operated by the local public works department with differing trucks and plastic collection methods. The Minneapolis "A" route collected plastic soft drink and milk bottles, the "B" route collected all plastic bottles and the "C" route collected all rigid plastic containers. The Minnetonka route collected plastic milk, water, soft drink, and detergent bottles (no bleach) and was operated by Waste Management, Inc. They originally used a cage for plastic mounted in the rear of their Lodal trucks and later changed to nylon bags on the back of the truck. When the bags were full, they were transferred to a standard packer truck dedicated to plastics collection for delivery to the handler. The HRG route collected plastic soft drink and milk bottles and was operated by Browning Ferris Industries. A cage on top of the recycling truck was used for plastics collection.

Compositions and estimates of collection amounts of the different plastics collected from the above described curbside programs are shown in Table 2.8. The specified plastics for the collection area are shown at the top of the table, and the estimated generation per household served per year and proportion of each plastic are shown within the table. The compositions shown do not include non-plastic contaminants. These data should be directly applicable to other moderate to large sized cities located in the midwest.

Table 2.7 Collection Methods Used in Minneapolis Area Pilot Collection of Plastics [CSWS, 1990]

City (Route)	Collector/ Frequency	Number Households Served	Collection Vehicles	Additional Containers Provided	Plastic Types Collected	Duration of Study (weeks)
Minneapolis (Route A)	City Crews / bi-weekly	5,195	Isuzu pick-up with trailer; packer for old newspaper	none	Soft drink & milk bottles	18
Minneapolis (Route B.1)	City Crews / bi-weekly	1,334 [a]	Labrie truck for everything	24 gallon	All plastic bottles	14
Minneapolis (Route B.2)	City Crews / bi-weekly	1,303 [a]	Isuzu pick-up with trailer for everything	24 gallon	All plastic bottles	14
Minneapolis (Route C.1)	City Crews / bi-weekly	1,280 [b]	Labrie truck for everything	24 gallon	All rigid plastic containers	14
Minneapolis (Route C.2)	City Crews / bi-weekly	1,306 [b]	Isuzu pick-up with trailer for everything	24 gallon	All rigid plastic containers	14
Minnetonka	Waste Management / weekly	13,685	Lodal trucks with nylon bag; unload plastics to packer for transport	none	Soft drink, milk, water & detergent (no bleach)	13
Hennepin Recycling Group [c]	Browning Ferris / weekly	3,715	Eager Beaver truck w/ cage	none	Soft drink & milk bottles	13

a. The Minneapolis "B" route originally had a total of 2,543 homes and was later split roughly in half in order to test a prototype perforation device on-board the recycling truck.
b. The Minneapolis "C" route had a total of 2,376 homes and was later split roughly in half in order to test a prototype perforator on-board the Labrie.
c. The Hennepin Recycling Group was a joint program between the towns of Brooklyn Center, Crystal and New Hope.

Table 2.8 Plastic Composition and Collection Amounts in Minneapolis Area Pilot Programs (pounds per household served per year) [CSWS, 1990]

Types of Plastic	Minneapolis Route A	Minneapolis Route B	Minneapolis Route C	Minnetonka Route	Hennepin Route
Collection Area Plastics Specified	Milk & Soft drink bottles	All plastic bottles	All rigid plastic containers	Milk, water, soft drink & detergent bottles	Milk & soft drink bottles
Plastics Collected:					
PET bottles	2.12 (40.8%)	4.90 (27.7%)	4.43 (19.8%)	2.38 (25.4%)	3.25 (36.8%)
PET non-bottles	0.0	0.24 (1.4%)	0.28 (1.2%)	0.01 (0.1%)	0.0
HDPE clear bottles	3.01 (57.9%)	5.74 (32.5%)	5.46 (24.4%)	5.22 (55.8%)	5.44 (61.5%)
HDPE color bottles	0.0	2.62 (14.8%)	3.59 (16.1%)	1.26 (13.5%)	0.0
HDPE non-bottles	0.0	0.15 (0.8%)	0.17 (0.8%)	0.0	0.0
PVC	0.0	0.49 (2.8%)	0.50 (2.2%)	0.03 (0.4%)	0.01 (0.1%)
Composites	0.0	0.23 (1.3%)	0.22 (1.0%)	0.01 (0.1%)	0.0
Unknown bottles	0.0	0.34 (1.9%)	0.83 (3.7%)	0.04 (0.4%)	0.02 (0.3%)
PP	0.0	0.38 (2.2%)	0.23 (1.0%)	0.02 (0.2%)	0.0
PS	0.0	0.19 (1.1%)	0.58 (2.6%)	0.01 (0.1%)	0.01 (0.1%)
Lids & Caps	0.03 (0.5%)	0.55 (3.1%)	1.04 (4.7%)	0.18 (1.9%)	0.05 (0.6%)
Unknown non-bottles	0.0	0.70 (4.0%)	2.48 (11.1%)	0.04 (0.4%)	0.01 (0.1%)
Plastic films	0.0	0.04 (0.3%)	0.01 (0.0%)	0.0	0.0
Non-Plastics	0.03 (0.5%)	1.09 (6.2%)	2.54 (11.4%)	0.15 (1.6%)	0.05 (0.5%)
Total	5.2 (100%)	17.7 (100%)	22.4 (100%)	9.4 (100%)	8.8 (100%)
Plastics portion of recyclables collected (% wt)	3.8%	5.1%	6.5%	3.7%	3.8%

Walnut Creek, California

The results of a 12 week pilot mixed plastic curbside collection program in Walnut Creek, California are shown in Table 2.9. Plastic types collected were any clean film or rigid plastic container. Also shown in the table is the fraction of non-plastic components or "trash." Four samples of 1,300 pounds each were characterized by hand sortation and physical and chemical tests. The average generation rate was reported to be 0.16 pounds/person/day.

Table 2.9 Curbside Collection of Mixed Plastics in Walnut Creek, California [Peritz, 1990]

Product	Composition of Plastics Collected (Weight %)	Range (Weight %)	Trash Compensated [a] (Weight %)
Film	21.0	14.6 - 27.1	24.2
Film Collection Bags	6.5	4.5 - 7.8	7.5
Foam	1.6	0.7 - 2.2	1.8
HDPE Milk/Water Bottles	16.4	11.2 - 19.1	18.9
PET Beverage	9.9	8.2 - 11.7	11.4
Mixed Other Plastics	31.2	27.1 - 34.7	36.0
Trash	13.4	8.0 - 21.2	-
Total	100	-	100

a. Composition of plastics when excluding the "Trash" portion.

Akron, Ohio

Akron, Ohio has curbside collection of rigid plastic containers (RPC) and PS from 14,000 households (1/4 of the city). The commingled RPC collection includes all clean bottles, wide-mouth tubs, trays, miscellaneous packaging and PS foam. Other materials collected are old newspaper, glass, aluminum and ferrous metal. Akron has established a materials recovery facility (MRF) to process residential recyclables and commercial sources of waste plastic, paper and corrugated fiberboard. Plastics are 5% by weight and 25% by volume of the incoming recyclables to the MRF. Plastics comprise 13% by weight of the residential recycle stream. For this municipality, collection of three plastics (HDPE, PET, PS) make up 91% by weight of rigid plastics collected from residences. The composition by weight of collected residential plastics plastics was [Bond, 1990]:

- 57% HDPE
- 28% PET
- 6% PS
- 2% PVC
- 7% mixed plastics

Ontario, Canada

The curbside collection study of RPCs in Barrhaven, Ontario by TransOntario Plastics identified the types of plastic collected using hand sortation and lab analysis. The types of plastic collected were reported by weight as:

- 75% HDPE/PP
- 13% PS/PVC
- 12% PET

Prior to the start of the 24 week Ontario RPC program, no curbside collection of any plastic had occurred. A separate curbside program collected PET beverage bottles (along with other recyclables) prior to the addition of RPCs for the study. Following RPC introduction, the plastics composition by weight was as follows: 65% HDPE/PP, 26% PET and 9% PS/PVC [TransOntario Plastics, 1989].

Seattle, Washington

A six month pilot collection of mixed plastics in Seattle, Washington, which included film, had the following plastic composition by weight:

- 29% HDPE bottles
- 24% PET bottles
- 47% film and "other" plastics.

No further breakdown of the "other" plastic composition was provided. Additional results of the program, which conducted a survey of participants, are described in Chapter 3.

PS Collection Data

The curbside collection of polystyrene is being examined to assess the economics of its recycling. Fitchburg, Wisconsin, a town with mandatory recycling, has conducted a curbside pickup of PS containers in a nine month pilot program funded by Amoco Chemical Company. The town additionally collects old newspaper, mixed paper, any #1 labeled plastic (PET), any #2 labeled plastic (HDPE), aluminum, glass and steel cans. In the first four months of the program, April through September, 1990, 5,281 pounds of PS were collected in a 3,000 household area. The weight of PS includes the weight of plastic bags used to contain the material. Analysis of a 489 pound PS shipment at the reclaimer's facility yielded the following composition of products collected [Adams, 1990b]:

• Container bag weight (lbs/wt. % of total)	67 / 13
• Packing material (wt. %)	25.8
• Meat/vegetable trays (wt. %)	24.2
• Fast food take-out containers (wt. %)	11.8
• Insulation (wt. %)	6.4
• Plates (wt. %)	6.4
• Egg cartons (wt. %)	5.7
• Rigid PS (wt. %)	2.6
• Dirty (moldy) PS (wt. %)	8.5
• Non-PS (wt. %)	8.5

The dirty PS required washing and drying prior to re-use. A sample of one week's normal trash indicated that most residents were using the service because only a small amount of PS was recovered from MSW. According to the town's recycling coordinator, including PS in the collection program does not affect collection truck times or efficiencies. PS is bagged by the homeowner before placement at the curb, and the collector has a separate hammock for placement of the bags. The bags can also be placed in with other plastics depending on the amount set out. Based on the rate of PS recycling thus far, the generation is estimated to be about 5.3 pounds per household per year in the curbside collection area.

2.3 Per Capita Generation

In order to estimate the benefits and costs associated with including plastics in a curbside recycling program, it is first necessary to estimate the amount of plastic recyclables which can be collected. This also helps determine collection truck compartment size and processing area necessary. In mixed plastics, it is helpful to measure the amount of total plastics collected as well as the individual types. With curbside pickup recycling, the setout rate (the percent of households in the collection program which set out recyclables each time collection occurs), the monthly participation rate (the percent of households which set out recyclables at least once in a 4 week period), and the frequency of participation over a time period help ascertain the level of success and degree of participation in a program. For most curbside pickup recycling programs, collection occurs weekly. Often times, only weekly setout rate is recorded by programs and a multiplier is used to estimate monthly participation rate. Even more rare is the recording of the frequency of participation over a period of time and/or recording of these parameters for individual recyclable components such as plastic, HDPE, PET, or PS. The cost of additional labor involved in recording and processing of such data is usually cited as reasons for not performing such a detailed review, and it is typically only done when funded by a grant. Without recording any of the above data, it is only possible to estimate pounds of recyclables collected per household in the collection area. Estimating the pounds per household in the collection area factors in non-participants and does not indicate the true amount set out by a household, but it does give an overall average, assuming participation stays similar. With the frequency of participation or weekly setout rate for each recyclable component recorded, it is possible to determine material per setout and per participating household. This provides the actual contribution on a per setout basis. The frequency of participation also provides the distribution of how often setouts occur.

An example of this can be seen from the recycling experience of Fitchburg, WI. In early 1990, the town received a grant to evaluate homeowner participation regarding each recyclable over an 8 week period, from March 1 to April 26, 1990. The town's weekly curbside recycling program served 2,823 households and collected 11,360 pounds of HDPE for an average of 1,420 lbs./week. The participation assessment study area included 1,185 households and therefore an estimated 596 lbs.of HDPE/week [(1,185 / 2,823)x1,420] were collected from it. Data recorded are as follows:

Total residences in participation assessment area:		1,185	(1)
HDPE collected during the 8 week period (lbs.):		4,768	(2)
Frequency of participation (# residences):			(3)
	1 in 8 weeks	206	
	2 in 8	193	
	3 in 8	178	
	4 in 8	137	
	5 in 8	84	
	6 in 8	73	
	7 in 8	28	
	8 in 8	12	
Total participating households (phh):		911	(4)
Households that never put HDPE out:		274	(5)
8 week HDPE participation rate	= 911/1,185 = 76.9%		(6)

Setouts in 8 week period $= 1 \times 206 + 2 \times 193 + 3 \times 178 + 4 \times 137 + 5 \times 84 + 6 \times 73 + 7 \times 28 + 8 \times 12$

$= 2,824$ (7)

Ave. setouts/week $= 2,824 / 8 = 353$ (8)

Ave. weekly setout rate $= 353 / 1,185 = 29.8\ \%$ (9)

Pounds HDPE per setout $= 4,768$ lbs / 2,824 setouts=1.69 (10)

Ave setouts/phh for 8 week period $=$ 2,824 setouts / 911phh = 3.1 (11)

Ave. setouts/phh/week $=$ 3.1 setouts/phh / 8 weeks = 0.39 (12)

Ave. time between setouts/phh $=$ 8 weeks / 3.1 setouts/phh = 2.6 weeks (13)

Est. HDPE/participant household = (1.69 lbs./setout)$\times$(52 wks/yr)$\times$ (0.39 setouts/phh/wk)

= 33.8 lbs/phh/year (14)

Therefore, it is estimated that 33.8 pounds of HDPE per year were setout by each house which participated in HDPE recycling. This estimate does not include non-participants. Another way to determine participating household generation is to record and average the weekly setout rates of each recyclable over a period of time. Although simpler and less costly, the disadvantage of this method is that it does not allow a recycling coordinator to view frequency of participation. Viewing the frequency of participation can allow the identification of non-users of a curbside recycling program and can assist in the modification of collection frequencies.

An indication of the plastic generation and recycling rates which can be achieved for the six primary types of plastic are shown in Table 2.10. It shows estimates of generation rates for different types of plastics collection developed from curbside pickup programs and from plastic recycling projection studies. The source of the data is listed along with the calculated per household rates.

For comparison purposes within Table 2.10 of per capita recycling contribution to actual per capita plastic production, the first three line items in Table 2.10 are per capita estimates of plastic consumption. The first item is the national per capita average of all plastics in MSW on a national basis, the second item is the total per capita production of the six primary thermoplastics on a national basis, and the third item is an estimate of the per capita consumption of durable and nondurable plastic products for Massachusetts.

Table 2.10 Estimates of Plastics Generation and Supporting Background Data

Plastic Type	Generation	Collection Size	Set-Out Rate [a] (%)	Participation Rate [b] (%)	Pounds Collected	Source	Comments
All plastics in MSW	117 lb/cap-yr	materials flow methods	-	-	-	EPA, 1990b	National average of all plastics in MSW
Six thermo-plastics	163 lb/cap-yr	material flow methods				CNT, 1990	National average of HDPE, LDPE, PET, PP, PS, PVC production
All plastics	190 lb/cap-yr	material flow methods	-	-	-	Brewer, 1988	Average durable and non-durable plastic product consumption for 1985
All plastic recyclables	24.7 lb/cap-yr	projected	-	-	-	Eyring, 1990	Estimated plastics available for residential curbside-pickup (CSPU) in Chicago area
All plastic recyclables	32-35 lb/hh-yr	projected	-	-	-	Moore, 1990	Estimated CSPU based on 5 sources. PET, PVC, PS, HDPE, LDPE and multi-layer included.
Any plastic (inc. film)	58.4 lb/cap-yr		-	50%		Peritz, 1990	Results of a 12 week CSPU mixed plastic study in Walnut Creek, CA
All rigid plastic cont-ainers (RPC)	7 lb/cahh-yr [c] 17.2 lb/phh-yr [e]	5,800	23% [d]	51% [d] 92% (all)	17,129	TransOntario Plastics, 1989	Results of a 22 week pilot CSPU of RPCs in Ontario.
All RPCs	20-30 lb/hh-yr	projected	-	-	-	Moore, 1990	Estimated CSPU based on 5 sources. PET, PVC, PP, PS, HDPE and multilayer.

Table 2.10 Estimates of Plastics Generation and Supporting Background Data (Continued)

Plastic Type	Generation	Collection Size	Set-Out Rate [a] (%)	Participation Rate [b] (%)	Pounds Collected	Source	Comments
All RPCs	22.4 lb/cahh-yr	2,376	61.9%	-	6,520	CSWS, 1990	Results of 14 week bi-wkly CSPU study in Minneapolis. Data collection duration 6wks.
All plastic bottles	16-25 lb/hh-yr	projected	-	-	-	Moore, 1990	Estimated CSPU based on 5 sources. PET, PVC, PP, HDPE (colored and natural) and some multilayer incl.
All plastic bottles	17.7 lb/cahh-yr	2,543	62.3%	-	5,580	CSWS, 1990	Results of 14 week bi-wkly CSPU study in Minneapolis. Data collection duration 8wks.
HDPE all types	9.0 lb/cap-yr	projected	-	-	-	Eyring, 1990	Easily separable HDPE for residential CSPU in Chicago area
HDPE milk & detergent	4.3 lb/cap-yr	projected	-	-	-	Eyring, 1990	Potential for all HDPE residential CSPU in Chicago area
HDPE #2 bottles	16.5 lb/cahh-yr 21.4 lb/phh-yr [f]	2,823	-	-	46,500	Adams, 1990a	1989 results of mandatory Fitchburg, WI CSPU program
HDPE #2 bottles	25.5 lb/cahh-yr 32.9 lb/phh-yr [f]	2,823	29.8% [f] 51.8% (all)	64.2% [f] 82.7% (all)	54,000	Adams, 1990c	Jan.-Sept. 1990 results of Fitchburg, WI CSPU program
HDPE any #2	8 lb/cahh-yr	36,000	42% (all)	83% (all) [g]	144,560	Englebart, 1990	Results of first 6 mo. 1990 CSPU in Milwaukee, WI.

Table 2.10 Estimates of Plastics Generation and Supporting Background Data (Continued)

Plastic Type	Generation	Collection Size	Set-Out Rate [a] (%)	Participation Rate [b] (%)	Pounds Collected	Source	Comments
HDPE bottles PET bottles	24.3 lb/cahh-yr	25,603	-	76% (all)	624,600	TBS, 1989	Results of 6-12 mo. CSPU study of 4 NJ towns. Participation weighted & annualized collection shown.
HDPE milk & detergent (no bleach) PET solft drink	9.2 lb/cahh-yr	13,685	21.5%	-	13,685	CSWS, 1990	Result of 13 wk weekly CSPU study in Minneapolis. Data collection duration 9wks.
HDPE/PET beverage bottles	10-18 lb/hh-yr	projected	-	-	-	Moore, 1990	Estimated CSPU based on 5 sources. Nat. HDPE only.
HDPE milk, PET soft drink	5.2 lb/cahh-yr	5,195	26.1%	-	3,200	CSWS, 1990	Result of 18 wk bi-wkly CSPU study in Minneapolis. Data collection duration 6wks.
HDPE milk, PET soft drink	8.8 lb/cahh-yr	3,715	21.5%	-	8,280	CSWS, 1990	Result of 13 wk weekly CSPU study in Minneapolis. Data collection duration 13wks.
HDPE milk PET soda	10.7 lb/cahh-yr	11,325	24.5% (all)	60% (all) [h]	21,017	Madison, 1990	Results of a 9 week pilot CSPU in Madison, WI
HDPE milk, juice, water	15.6 lb/hh-yr	not reported	not reported	not reported	not reported	Rankin et al., 1988	Average generation of 3 NJ suburbs; 6 mo. duration
HDPE milk bottles	6.5 lb/hh-yr	projected	-	-	-	Fearncombe, 1990	Historical average for Illinois households
HDPE milk bottles	6.6 lb/cahh-yr	36,000	37% (all)	82% (all)	122,902	Milwaukee, 1990	Results of 24 week pilot CSPU in Milwaukee, WI.
HDPE milk bottles	3-6 lb/hh-yr	projected	-	-	-	Moore, 1990	Estimated CSPU based on 5 sources. Nat. HDPE only.

Table 2.10 Estimates of Plastics Generation and Supporting Background Data (Continued)

Plastic Type	Generation	Collection Size	Set-Out Rate [a] (%)	Participation Rate [b] (%)	Pounds Collected	Source	Comments
HDPE laundry bottles	1-2 lb/hh-yr	projected	-	-	-	Moore, 1990	Estimated CSPU based on 5 sources. Colored HDPE
LDPE	6.0 lb/cap-yr	projected	-	-	-	Eyring, 1990	LDPE potential for residential CSPU in Chicago area
PET any #1	4.8 lb/cahh-yr	36,000	42% (all)	83% (all) [g]	87,304	Milwaukee, 1990	Results of 24 week pilot CSPU in Milwaukee, WI.
PET	3.0 lb/cap-yr	projected	-	-	-	Eyring, 1990	PET potential for residential CSPU in Chicago area
PET soda bottles	2.8 lb/cap-yr	projected	-	-	-	Eyring, 1990	Easily separable PET for residential CSPU in Chicago area
PET soda bottles	12.0 lb/hh-yr	projected	-	-	-	Fearncombe, 1990	Average based on household consumption of soda, adjusted for PET soda share
PET soda bottles	6-11 lb/hh-yr	projected	-	-	-	Moore, 1990	Estimated CSPU based on 5 sources
PET #1 bottles	1.9 lb/cahh-yr 4.3 lb/phh-yr [f]	2,823	-	-	5,240	Adams, 1990a	1989 results of mandatory Fitchburg, WI CSPU program
PET #1 bottles	5.0 lb/cahh-yr 11.6 lb/phh-yr [f]	2,823	9.9% [f] 51.8% (all)	28.5% [f] 82.7% (all)	10,600	Adams, 1990c	Jan. - Sept.1990 results of Fitchburg, WI CSPU program

Table 2.10 Estimates of Plastics Generation and Supporting Background Data (Continued)

Plastic Type	Generation	Collection Size	Set-Out Rate [a] (%)	Participation Rate [b] (%)	Pounds Collected	Source	Comments
PET soda bottles	23.4 lb/hh-yr	not reported	not reported	not reported	not reported	Rankin et al., 1988	Average generation of 3 NJ suburbs; 6 mo. duration
PET soda bottles	4 lb/cap-yr	-	-	-	-	Morrow and Merriam, 1990	Total PET soft drink bottles available for recycle
PP	3.5 lb/cap-yr	projected	-	-	-	Eyring, 1990	PP potential for residential CSPU in Chicago area
PS	1.7 lb/cap-yr	projected	-	-	-	Eyring, 1990	Potential for all PS residential CSPU in in Chicago area
PS foam	0.7 lb/cap-yr	projected	-	-	-	Eyring, 1990	Easily separable PS for residential CSPU in Chicago area
PS foam & cont. labeled 6	5.28 lb/cahh-yr	3,000	10.5%	60%	5,281	Adams, 1990b	Results of PS CSPU during 4 month study of participation rates.
PVC	1.5 lb/cap-yr	projected	-	-	-	Eyring, 1990	PVC potential for residential CSPU in Chicago area

a. Set-out rate is specifically for plastic given, unless followed by (all). Weekly collection was used unless stated otherwise, with average taken over time period given in comments.
b. Participation rate is specifically for plastic given, unless followed by (all). Participation rate was monthly, unless stated otherwise.
c. Pounds collected per total number of households in collection area, including non-participants (lb/cahh-yr).
d. Based on a recording of one-truck's route for the last 4 weeks of the program.
e. Pounds collected per participating households (lb/phh-yr), either specifically for plastic participation rate if recorded, or using overall recorded participation rate.
f. Fitchburg, WI mandatory program began 1/1/88. Actual lb/hh-yr set out and participation and set-out rates based on 8 week monitoring between 3/1/90 and 5/1/90 of set-outs contributing particular plastic type.
g. Based on a phone survey of 800 randomly picked households.
h. Using the entire 9 week period for participation.

Table 2.10 is organized by plastic type collected and shows the recycling parameters when an actual collection study was performed. The setout rates and participation rates shown are for the plastic component specified, unless they are followed by "(all)", in which case the setout rate or participation rate for all recyclables is shown. As can be seen from the table, only a few programs have recorded component specific setout rate or participation rate. The "generation" column indicates projected recycling rates on a per capita or per household basis and is based on material flow methods in pounds per household per year (lb/hh-yr), while actual recorded quantities from programs show rates on a pounds per collection area household basis (lb/cahh-yr) or a pounds per participating household basis (lb/phh-yr). Generation rate based on participating households provides the best indication of recycling potential. As can be seen in Table 2.10, there is a large range in amount collected, even for similar materials. Urban density, average income level and degree of recycling acceptance in the area are all factors that impact plastic generation rates. However, Table 2.10 does provide an expected range for almost all combinations of plastic types collected.

2.4 Commercial and Food Sector Sources of Waste Plastic

In addition to residential post-consumer plastic available for recycling, per capita estimates of post-consumer plastic generated in the food service industry and the commercial sector (aside from food service) have been estimated (Table 2.11). The estimates shown were made using a combination of manufacturing data, measurements from actual recycling programs, and measurements from excavations of landfills or from intercepted MSW [CNT, 1990]. The table shows that HDPE, PS and LDPE comprise a majority of the plastic available for recycling in the U.S. from the commercial and food service sectors.

Examples of additional commercial sources of scrap plastic are shown in Table 2.12. Such materials are usually separated by the source by plastic type. One of the fastest growing areas is the collection of film HDPE and LDPE grocery sacks by grocers. A collection container for the used sacks is typically placed at the entrance to a store for consumers to deposit upon entry. As previously indicated, films form one of the largest components (by weight) of post-consumer plastic waste. This type of collection represents the beginning of broad acceptance of film plastics into recycling programs.

Table 2.11 Projected Plastic in the MSW Stream Available for Recycling in the U.S. [CNT, 1990]

Resin	Total Plastics Produced (pounds/capita-year)	Available for Recycling (pounds/capita-year) Total	Residential	Food Service	Commercial
PS	19.9	5.2	1.7	1.8	1.7
HDPE	33.3	14.0	9.0	4.0	1.0
PET	8.3	3.3	3.0	0.2	0.1
PP	27.7	4.7	3.5	0.6	0.6
PVC	33.2	2.5	1.5	0.2	0.8
LDPE	40.0	14.0	6.0	1.0	7.0
Total	162.5	43.7	24.7	7.8	11.2

Table 2.12 Commercial Sources of Recyclable Plastic Material

Source	Scrap Materials
Airlines, airline food service	PET liquor miniatures, PS cups, PET food service items.
Bakeries	PP bread trays, tote bins
Dairies	Scrap HDPE bottles, packing crates
Drinking water distributors	PC 5 gallon water bottles, PP crates
Dry cleaners	LDPE garment bags
Equipment/parts manufacturers	Tote boxes, shipping crates, scrap
Farming enterprises	PE agricultural film, feed, fertilizer bags
Food service/cafeterias	Foam PS trays, PS utensils
Grocers	LDPE grocery sacks, HDPE grocery sacks
Large construction sites	PE shrink wrap, construction film
Newspaper distributors	LDPE home delivery newspaper covers
Nurseries	HDPE and PP buckets and pots, PS plant trays
Soft drink bottlers	Deposit bottles, PP crates

2.5 Post-Consumer Plastic Weights

Tables 2.13 and 2.14 show typical properties of collected HDPE and PET, and other recyclables. The pellet and flake values shown for milk bottles may be used for other blow molded HDPE bottles (such as detergent) as well. The "flake" values represent material conditions following grinding. Such detailed information does not readily exist for other plastics collected in recycling programs.

2.6 Summary

This section has presented data on plastics generation. Plastics comprise 6 to 9% by weight of MSW. Depending on the material collected, plastics will comprise 4 to 14% by weight of the recyclables in a recycling program. When collected, film plastics make up a large portion (25 to 40% by weight) of plastics collected. Collection of any type plastic bottle will result in a 75 to 200% by weight increase in the amount of plastics collected over collection of just PET and clear HDPE beverage bottles.

There is a large range of amounts of plastics collected in plastics recycling. programs. In order to accurately assess the effect of plastics on a recycling program, a municipality specific composition estimate should be conducted. Generally, rigid plastic recycling will capture 30 lb/hh-yr, plastic bottle recycling will capture 20 lb/hh-yr, and beverage bottle recycling will collect 15 lb/hh-yr, as a minimum, on a per household served basis.

The contribution of non-specified plastics and non-plastic contaminants to plastics recycling programs is dependent on the plastic types collected. Non-specified plastics range from as little as 1% for relatively simple plastics collection (PET and clear HDPE beverage bottles) to as much as 10 to 20% for plastic bottle or colored HDPE recycling. Non-plastic contamination can be 1% to 10% by weight. Even a narrowly defined plastic stream of PS resulted in 8% non-PS plastics and non-plastic contaminants.

Table 2.13 Typical Properties of HDPE and PET Beverage Bottles [PRC, 1990a]

Description	2 liter PET beverage bottles	1 gallon HDPE beverage bottles
Weight / bottle (lbs)	0.14	0.15
Bottles / lb. (number)	7.1	6.1
Bulk density, uncrushed (lbs/ft^3)	1.5	0.9
Bulk density, stepped-on (lbs/ft^3)	3.0	1.8
Typical quantities for a gaylord size of 34"x43"x38"		
Uncrushed, weight / gaylord (lbs)	48	29
Stepped-on, weight / gaylord (lbs)	96	58
Uncrushed, bottles / gaylord (number)	341	194
Stepped-on, bottles / gaylord (number)	682	389
Typical quantities for a bale size of 31"x45"x63"		
Weight / bale (lbs)	750	600
Quantity / bale (number)	5,325	4,020
Target minimum for shipping (lbs/ft^3)	15[a]	12[b]
Processed resin properties		
Pellet density (lbs/ft^3)	50	35
Flake density, 5/16" max size (lbs/ft^3)	29	27
Flake density, 3/8" max size (lbs/ft^3)	28	26
Typical flake and pellet weights for a gaylord size of 34"x43"x38"		
Pellet	1,600	1,060
Flake, 5/16" max size (lbs)	930	870
Flake, 3/8" max size (lbs)	900	840

a. 15 lb/ft^3 specified by Plastic Recycling Corporation of California to achieve 40,000 lb semi loads.

b. 12 lb/ft^3 realistic target, with typical range of 8-15 lb/ft^3

Table 2.14 Specific Volumes and Densities for Recyclable Waste [Rankin et al, 1988, Moore, 1990]

Material	Specific Volume (yd^3/ton)	Bulk Density (pounds/yd^3)
Newspaper	3.3	500-600
Baled shredded paper bundles	2.7	740
Whole glass bottles	3.3	600-700
Clear and colored glass, -5/8" cullet	0.9	2200
Clear and colored glass, -2" cullet	2.0	1000
Whole ferrous cans	10-13	145-200
Flattened ferrous cans	2.2-2.5	800-910
Whole aluminum cans	27	49-74
Flattened aluminum cans	8	250
Uncrushed 1 gallon HDPE milk and water containers	93	22-24
Uncrushed HDPE detergent/bleach bottles	67	30
Hand crushed 1 gallon HDPE milk bottles (74 g/bottle)	76	26
Crushed HDPE detergent/bleach bottles	33-40	50-60
Uncrushed 2 liter PET bottles	58	34
Hand crushed PET 2 liter bottles	41	49
Baled PET	4.3	460
Chipped PET	2.5	800
Uncrushed mixed bottles	57	35
Crushed mixed bottles	25	80
Uncrushed rigid plastic containers	44-50	40-45
Crushed rigid plastic containers	22-25	80-90
Uncrushed any type plastic	15	135
Crushed any type plastic	13	160