Analysis of the Residential Curbside Collection of Trash and Recycling and the Generation of Associated Litter in Portland, Maine

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1. INTRODUCTION

Portland, ME, has had a municipal recycling program since the fall of 1990 when Regional Waste Systems (RWS), which later became ecomaine, installed 4 large roll-off recycling containers (known as “silver bullets”) on the peninsula. The recycling rate that year was just 3%.[1] By 1998, there were 14 roll-off containers at 8 different locations in the city yielding a recycling rate of 7%, which was far below the state’s 50% goal established in 1989. Because of the low recycling rate, the city instituted a number of major initiatives, including:

- In 1999, Portland adopted a pay-as-you-throw (PAYT) program for residential curbside collection of trash, which required residents to purchase and use only designated bags for the disposal of trash.[2]
- Also in 1999, in conjunction with the implementation of PAYT, Portland implemented a free curbside recycling collection program for residents. The city started its residential curbside recycling collection program by initially providing blue 16- or 18-gallon open-top bins for residents. This initiative was based on the findings of a 1991 pilot residential curbside recycling project conducted by RWS, which yielded a 70%-80% residential participation rate with a mean per household weekly collection rate of 11.26 lbs of recyclables.[3]
- In 2007, the city adopted single sort (a.k.a., “single stream” or “no sort”) recycling, eliminating the need for residents to sort recyclable materials into various categories at the curb.
- In April 2015, Portland implemented a ban on the use of expanded polystyrene foam (e.g., Styrofoam™) by restaurants, cafeterias, food trucks, convenience stores, shops, grocery stores, delicatessens, or other vendors located in the city that offer food for retail sale.[4] Similarly, since April 15, 2015, retail stores in Portland must

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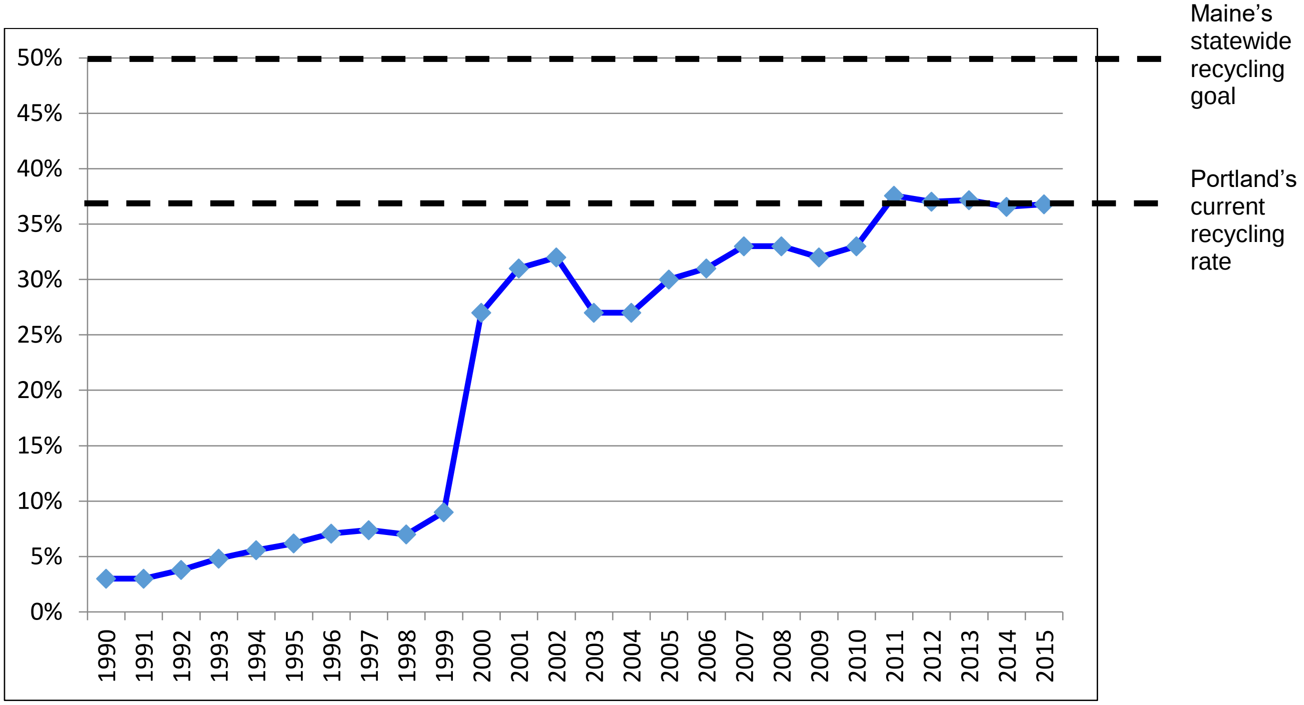
[1] *Recycling Advisory Committee Report to the Portland City Council*, October 26, 1998.
[2] The current residential fee for trash collection is $1.35 for a 15-gallon bag and $2.70 for a 30-gallon bag.
[3] During this period, only 4 categories of recyclables were collected: mixed paper, paperboard, #2 HDPE plastic, and metal and glass cans/bottles.
[4] Polystyrene, which is not recycled in Portland, is often mistakenly placed in curbside recycling containers, which must be removed from the recycling stream and sent for disposal at the waste-to-energy facility.

charge a minimum of $0.05 per each single use bag (plastic or paper) used to carry food or merchandise out of the store.[5]

These initiatives, in addition to regular education and marketing efforts, have collectively contributed to a 423% increase in the residential recycling rate (see Figure 1) for Portland from 3.0% in 1990 to a 2015 recycling rate of 36.79%; however, this is still significantly below the state's goal of 50%.[6]

Figure 1: Portland's recycling rate, 1990-2015



The fundamental question is how to close the 13.21% gap given that:

– Recycling is a voluntary action;
– Portland has limited resources for capital expenditures for solid waste;
– The direct economic benefits of any initiative must equal or exceed costs.

[5] Plastic bags are a problem material in the recycling stream with minimal economic value that can negatively impact recycling equipment operation.

[6] Since 1978, Maine has had a bottle bill program that is one of the most comprehensive beverage container refund programs in the US covering liquor, wine, beer, water, soda, and fruit juice containers made of metal, plastic, and glass. The estimated recovery rate of covered beverage containers is 90% statewide. Because of the bottle bill, Portland's reported recycling rate is comparatively lower than states without bottle bills as covered beverage containers are often removed prior to curbside collection.

One consideration is the type and volume of the recycling container: despite the increased amount of recycling collected, the volume of the recycling containers provided to residents, and those still most frequently used by Portland residents, remains at 18 gallons. This raises a fundamental question:

Is the design and volume of the bins a limiting factor in achieving a higher residential recycling rate in Portland?

2. BACKGROUND

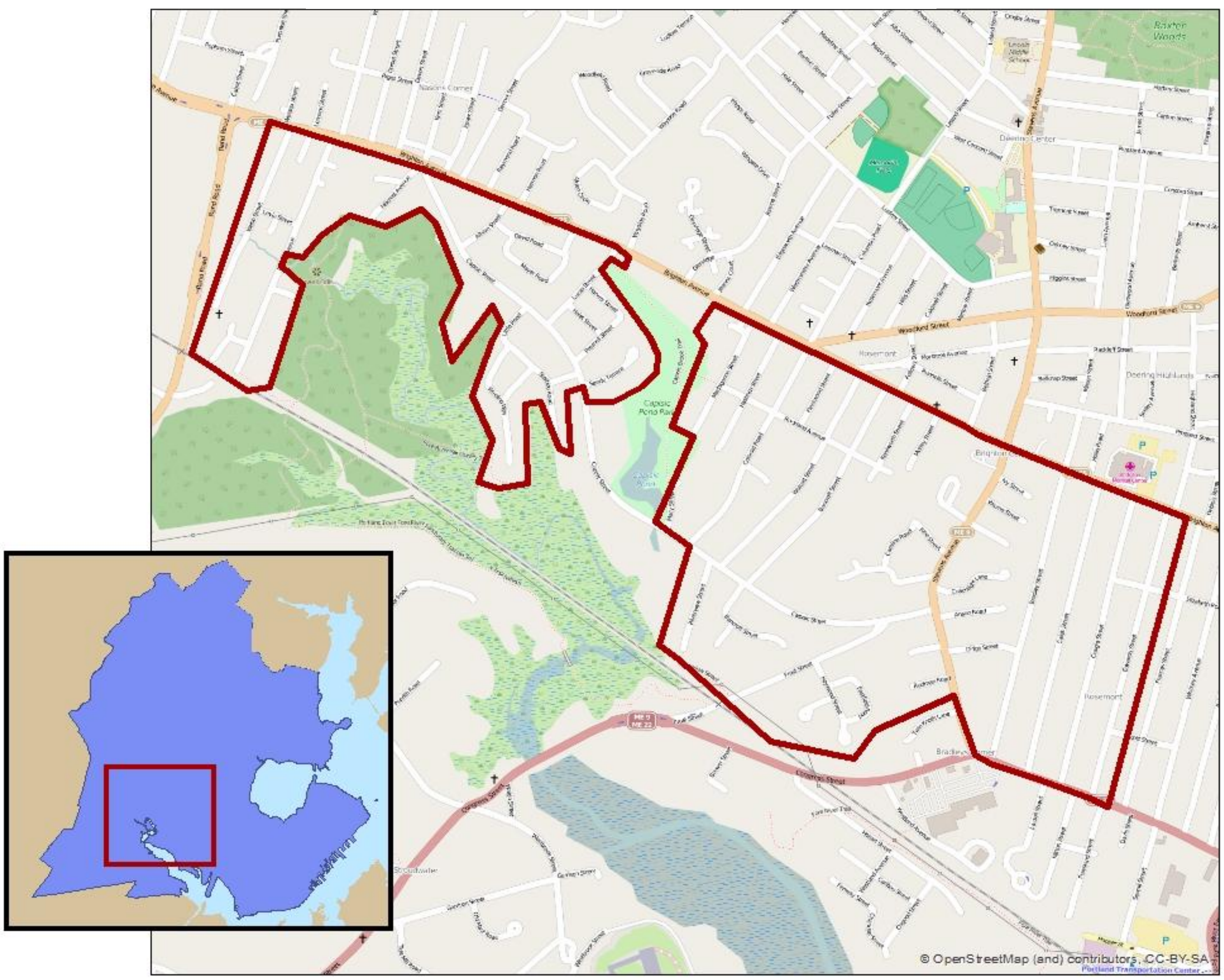
To address the above research question, a study was conducted between June 17, 2015, and August 20, 2015, by Travis Wagner, Professor of Environmental Science & Policy at the University of Southern Maine. The study was conducted in cooperation with the City of Portland and ecomaine and with funding support from the Maine Economic Improvement Fund. The focus of the study was to examine Portland's curbside residential trash and recycling program to answer specific questions regarding the potential impact of the currently used recycling bins on key programmatic metrics. The study was designed to collect empirical evidence to assess whether the design and small volume of the recycling containers have any demonstrable impact on the amount of recyclables being collected. Thus, specific research questions included:

1. What are the contents by weight and by volume of an average residential trash bag in Portland?
2. What are the contents by weight and by volume of an average residential curbside recycling collection?
3. How much recycling is being disposed of as trash?
4. What is the economic value of the recyclables being disposed of as trash?
5. What is the amount of trash contained in recycling bins (*recycling residue rate*)?
6. How much of each category of recyclables is being recovered (*recovery rate*)?
7. What is the frequency and volume of overflowing recyclables placed outside of recycling bins?
8. What is the marginal contribution of litter from the open top recycling bins?

Portland's current residential MSW collection program serves 15,860 customers--14,163 single family customers and 1,697 multi-family and municipal buildings. Upon consultation with the city, two study sites, an urban and a suburban area, were selected to represent the diversity of the city's residential curbside collection program sufficient to extrapolate to the entire city. These sites also were selected because they each are served by a single collection vehicle (packer truck), with one for recycling and one for trash:

Suburban Area – The Capisic study area straddles the Rosemont and Nason's Corner neighborhoods and has a relatively low density with 1,166 collection stops and 93,580 total feet of street in the study area (see Figure 2). The area is dominated (94%) by single-family homes and has a housing density of 2,046 households/ mi^2.

Figure 2: Capisic study area.



<u>Urban Area</u> – The West End study area is within the West End neighborhood and has a relatively high density with 814 collection stops and 46,790 total feet of street in this study area (see Figure 3). The area has a housing density of 5,016 households/mi^2 and contains a diverse mixture of multifamily and single units: 9.7% of buildings contain 4 or more units, 18% contain 3 units, 23.1% contain 2 units, and 48.9% are single-family dwellings.

Figure 3: West End study area.

2.1 Set out/Participation Rates

Portland's recycling containers do not use RFID technology.[7] Thus, to estimate participation and set-out rates, a windshield survey was required.[8] During a six-week period, on a weekly basis, researchers collected data to estimate the following:

- Participation rate (percentage of households setting out a container at least once during the study period)
- Set-out rate (the weekly participation rate)
- Number of city trash bags per collection stop
- Number of recycling containers per collection stop
- Frequency and volume of overflow of recycling external to the recycling bins

During the study period, two, 2-person research teams (one for recycling and one for trash) drove the identified collection route ahead of each collection vehicle to collect the above data, which was recorded on checklist sheets and then transferred to a spreadsheet.

2.2 Waste and Recycling Characterization

During the study period, 6 characterizations of residential curbside trash bags (3 for each study area) and 6 characterizations of residential curbside recycling (3 for each study area) were conducted. In accordance with ASTM D5231-92, the required sample size is a 250 lb random sample from a full packer truck. Because it was necessary to collect samples prior to the collection of trash by the packer truck, we needed to modify the approach. To collect the sufficient sample size for each event and to ensure that sampling was random, a random number generator was used to identify 45 unique addresses for each sampling event. (The number of addresses was based on the number of bags predicted to meet the minimum sample weight.) The list of addresses was provided to the Department of Public Services. They collected trash and recycling from 35 of the addresses (the additional addresses were necessary in case the household did not participate that week) and transferred the bags of trash and recycling

[7] Radio Frequency Identification (RFID) is a wireless technology used to transmit various data for individual collection bins.
[8] A windshield survey is method to make systematic observations from a moving vehicle.

(recycling was bagged at the curb) to a city-owned facility on outer Congress Street. In addition to this sampling approach, ecomaine simultaneously pulled 250 lb random samples from the tip floor based on ASTM D5231-92 to compare sampling methods for recycling, as discussed below.

On a bag-by-bag basis, trash and recycling was emptied onto the sorting table (see Figure 4) for respective characterizations. The sorting table had two divided sections, each with two layers that were clamped onto two adjoining tables. Each section consisted of a middle layer containing steel mesh wire with 1-inch openings. It was possible to process two bags simultaneously, one in each section. Bags were cut open and the contents emptied then spread using tongs. The tongs were used to pluck and segregate individual items into labeled containers corresponding to the 35 categories presented in Table 1. Following the completion of a waste or recycling characterization for each specific study site, the wooden frames were removed from the sorting table to examine the remaining <1 inch fraction, which was material that passed through the 1-inch screen. Larger items (e.g., batteries) in the 1-inch fraction were removed, segregated, and weighed; a visual assessment was made of the remaining material to estimate the organic portion. The material was then transferred into a container and weighed and the volume recorded. When questions arose as to the proper category for an item, the designated crew leader made the decision.

Figure 4: Trash and recycling sorting table.

Table 1: List of categories for segregated trash and recycling.

- Food
- Pet waste
- Green waste
- Cardboard
- Paperboard
- Newsprint
- Mixed paper
- Napkin/P-towel/tissue
- #1 -PET
- #2-HDPE, color
- #2-HDPE, natural
- #3-#7 plastic
- Grocery bags
- Polystyrene
- Plastic Film
- Flexible Pack/cellophane
- ME plast. Bev cont.
- Ferrous (cans)
- Non-ferrous Aluminum (foil/ cans)
- ME alum bev
- Fuel canisters
- C&D
- Textiles
- Glass jars/containers
- ME glass deposit
- Flat glass
- Electronics/Electrical
- CFLs
- Batteries, alkaline
- Meds/pharms
- Sharps/syringes
- Diapers
- NOS Fractions <1"
- K cups
- NOS Fractions >1"

All segregated materials were weighed and the weights recorded for each appropriate category in the data collection forms. In addition, a single designated person determined the volumes using containers with known volumes and then recorded the values. The completed data forms were given to the lead researcher for entry into a spreadsheet.

In ecomaine's method for sampling the recycling, as per the requirements of ASTM D5231-92, a loader operator on the tipping floor collected a random bucket full (3 yds^3) from the tipped contents. The loader was weighed to verify the sample was at least 250 lbs. The sample was then deposited on an isolated spot on the tip floor. A series of 22-gallon bins were used to collect segregated material, except for cardboard, which was segregated into 50-gallon contractor bags because of the large volume. Once filled, each bin was weighed and its volume recorded.

2.3 Litter Characterization

One of the research questions was the degree to which litter was created by the open-top design and small volume of the recycling bins. Litter was collected on 6 different times over the study period, with 3 discrete collection events for each study area. For each event, researchers conducted litter collection between 11:00 am and 3:00 pm after city employees had completed the curbside collection of recycling. All litter larger than 1 in^2 and judged to be attributable to a recycling container was collected. Litter not likely to have been in the recycling bin (e.g., bagged pet waste, cigarette butts, weatherworn litter, food waste, broken bottles, etc.) was ignored. Litter within 20 feet of the set-out location of each container was collected (10 feet into the street and 10 feet toward the dwelling). Following the collection, all litter was segregated and characterized by size, weight, and material type into the following categories and subcategories:

- Mixed Paper
    - Packaging (wrappers, etc.)
    - News/magazine/office
    - Paperboard
    - Other paper
    - Cardboard
- Mixed Plastic, #1-#7
    - Packaging
    - Beverage containers
    - Straws
    - Other plastic
- Metal
    - Packaging/Aluminum
    - Aluminum beverage containers
    - Other metal (e.g., ferrous pieces, cans)
- Glass
- Other

2.4 Household Survey

A survey of the households within each study area was conducted by ecomaine in August 2015. A door hanger was used as the survey recruitment tool, which invited participants to complete an online survey (see Figure 5). A door hanger, with the front facing out, was placed on 1,652 doors (693 in the West End and 959 in Capisic). In addition to the invitation on the front side of the door hanger, the backside contained basic educational information and a request to visit the ecomaine website. Recycling prizes were offered as incentives to participate. No follow-up recruitment requests were sent to the households.

Figure 5: Door hanger for the household survey.

Front side **Back side**

3. RESULTS

Although there are differences between the urban and suburban study areas, unless noted otherwise, results were pooled in order to estimate means in order to conduct extrapolations citywide.

3.1 Set out/Participation Rates

As noted previously, because RFID tags are not used in Portland, the set-out and participation rates had to be conducted in person by windshield surveys. Windshield surveys were selected because the study areas were large in area, the data sought for could be seen from a vehicle, and there was a tight time limit between residential set-out and city collection. Unfortunately, for reasons discussed below, the results obtained were of poor quality. While the calculated participation rate was approximately 70%, this significantly undercounts the likely true participation rate.[9] A central challenge in establishing accurate rates is because the research teams had to start collecting data as late as possible, but needed to stay ahead of the collection trucks, which started their route at approximately 6:45 am. The collection had to be as late as possible because although residents are requested to place all trash and recycling at curbside by 6:30 am, many residents set it out much later depending on when collection actually occurs at their address. That is, if the collection truck normally collects trash and/or recycling at 9:30 am at a specific address, the resident could set out the materials closer to this time rather than by 6:30 am. Researchers had already collected data for multiple addresses prior to set-out and in some instances recording that nothing was set out and thus, no participation. However, because of the zigzag patterns of the tuck route (e.g., crossing streets later where data had already been collected), researchers later witnessed the setting out of trash and recycling bins much later, just before the collection truck arrived. As a result, for some addresses, researchers saw containers set out later where they had previously recorded that no recycling container or trash was set out at the time data was collected. Because of the need to be ahead of the trucks, researchers generally were unable to backtrack as they had to adhere to the predetermined route in a timely fashion.

An additional challenging factor, especially in the urban area, was that because of convenience, multiple residents placed trash and recycling on streets and addresses that were different than their designated street address. Thus, because of the need to adhere to the predetermined route, there were clear data gaps in matching a bin to a specific address. Finally, there were many duplex and multi units with trash and recycling containers placed adjacent to each other. In these cases, ownership of the containers could not be differentiated.

3.2 Trash Characterization Results

The data obtained from the waste characterizations was valid. A total of 290 trash bags were characterized during the study period. The following results are based on the set-out/participation data collection phase and the 6 trash characterizations of randomly selected residential bagged trash set out at curbside:

[9] The 2015 Kessler Consulting study estimated Portland's recycling participation rate to be 90%.

- Mean weight of each trash bag collected = **11.76 lbs**
- Mean number of trash bags set out per housing unit = **1.54**
- Mean percent of recyclables contained in the trash by weight = **18%**
- Mean percent of non-recyclable compostables in the trash by weight = **45%**

The top 8 recyclable items in the trash by weight are presented in Table 2. The combined largest categories by weight in descending order were paper, plastic, and metal. The top 8 recyclable items in the trash by volume also are presented in Table 2. Household hazardous waste in the trash was minimal, with only a few sharps (syringes/needles), CFLs (compact fluorescent lamps), and pharmaceuticals found.

Table 2: Recyclables by percent weight and volume in average Portland trash bag.

	% by weight			% by volume
Plastic, #3-#7	5.9%		Plastic, #3-#7	14.6%
Mixed paper	5.3%		Paperboard	9.3%
Paperboard	3.1%		Newsprint	3.9%
Ferrous	1.3%		Mixed paper	3.6%
Newsprint	1.3%		Aluminum	2.2%
Aluminum	0.7%		Plastic, #1-PET	1.6%
Plastic, #1-PET	0.5%		Cardboard	0.2%
Plastic, #2-HDPE, color	0.3%		Plastic, #2-HDPE, color	0.6%

Table 3 and Figure 6 present a comparison of the contents by percent weight and volume of the average trash bag. At 33.19% by weight, food waste was the largest single category of the trash. Figure 7 presents examples of food waste disposed of as trash and Figure 8 provides examples of the organic fractions of less than 1 inch. The non-recyclable, compostable portion of the waste (e.g., food waste, green waste, and napkins/towels/tissue), was 45.02% by weight.

Table 3: Contents by percent weight and volume of average Portland trash bag.

	% by weight			% by volume
Food & Green Waste	37.4		Plastic (#1-7)	17.5
Pet Waste	12.5		Mixed Paper/ONP	16.8
Mixed paper/ONP	9.7		Food & Green Waste	16.7
Miscellaneous	8.5		EPS/Flex Packing	13.1
Napkins/towels/tissue	7.6		Napkins/towels/tissue	9.7
*Plastic (#1-7)	6.9		Other/Misc.	6.7
EPS/Flex Packing	5.3		Textiles	3.1
Diapers	4.0		Metal	2.8
C&D	3.4		Pet waste	2.6
Metal	2.0		C&D	2.5
Textiles	2.7		Diapers	1.4
Glass	1.2		Electronics/Electrical	1.4
Electronics/Electrical	0.9		K cups	1.1
HHW	0.2		Glass	0.4

*****Plastic includes #1-#7, plastic film and plastic grocery bags.

ONP = old newsprint, EPS=expanded polystyrene, C&D=construction and demolition debris, and HHW=household hazardous waste.

Figure 6: Contents of average Portland trash bag by percent weight and volume.

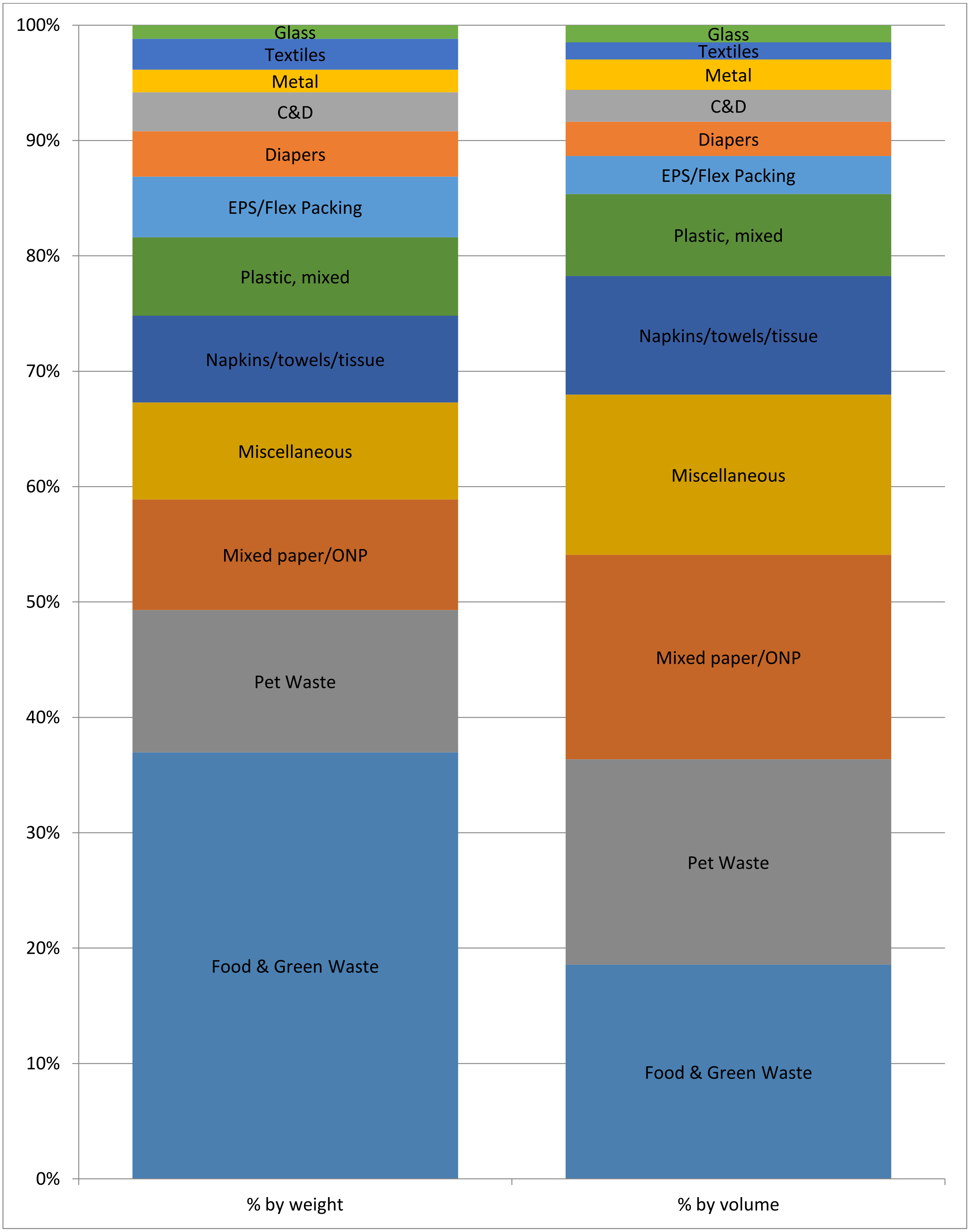


Figure 7: Examples of food waste disposed of as trash in Portland.

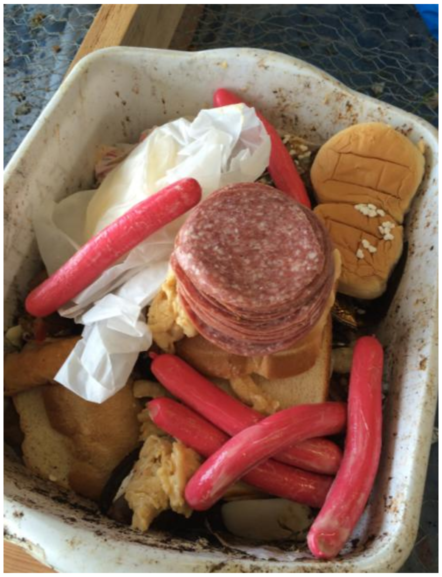


Figure 8: Examples of the organic component of fractions <1 in. in trash.

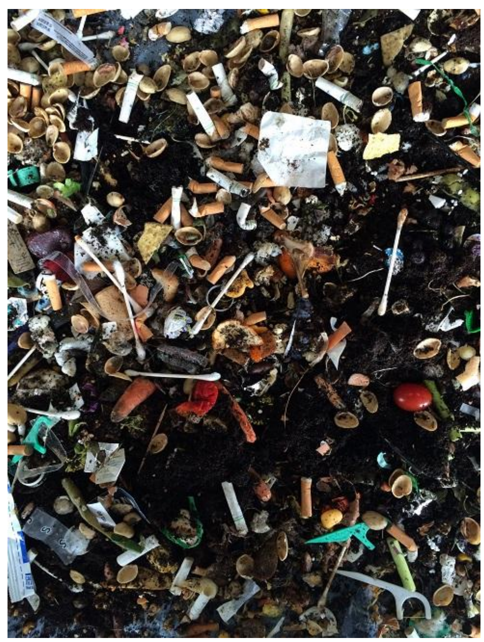
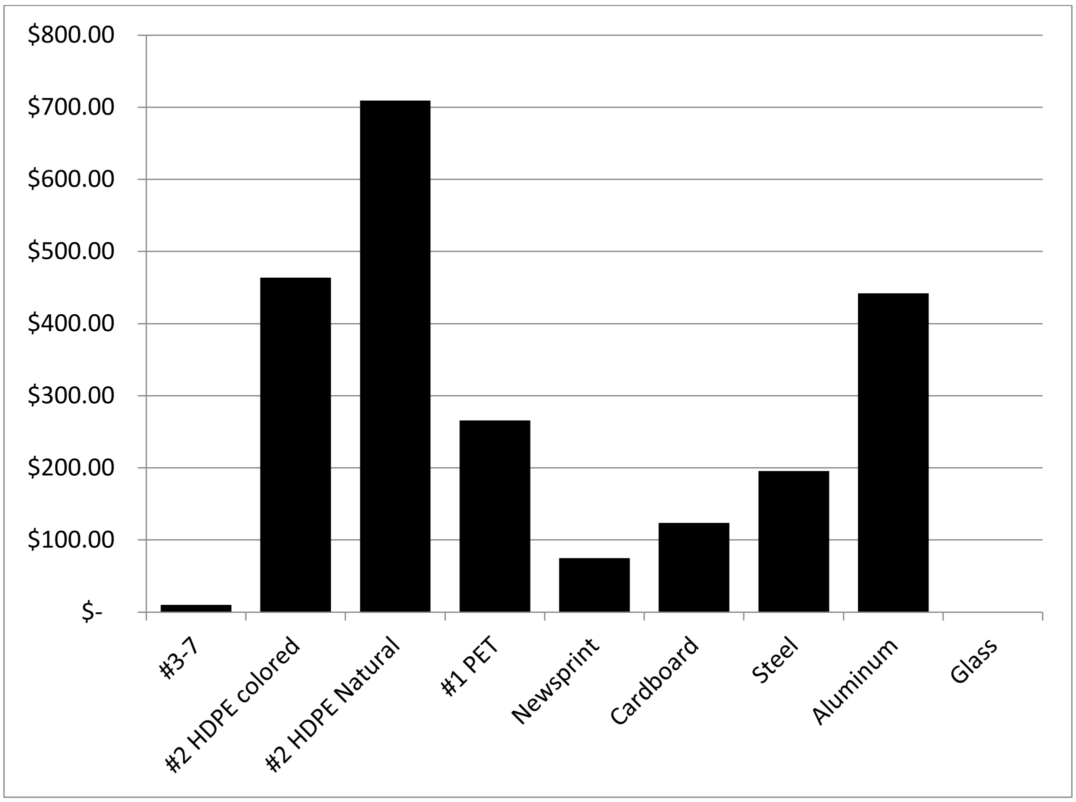


Figure 9 presents the per-ton direct economic value of the major categories of recyclables. (Figure 10 depicts examples of the volatile nature of the market value of two common recyclables. The values represent the five-year mean of the price-per-ton received by ecomaine.) Table 4 presents the estimated economic value of recyclables disposed of in residential trash, which has been extrapolated to estimate city-wide values based on 7,900 tons of residential trash per year.[10]

Figure 9: Mean per ton value of recyclable commodities.



[10] The 7,900 represents residential curbside trash only and excludes public trash receptacles and dumpsters. See page 17, *Evaluation of Recycling and Solid Waste Collection Services*, prepared for the City of Portland by Kessler Consulting, Inc., April 2015.

Figure 10: The volatility of market values of recyclables in Maine.

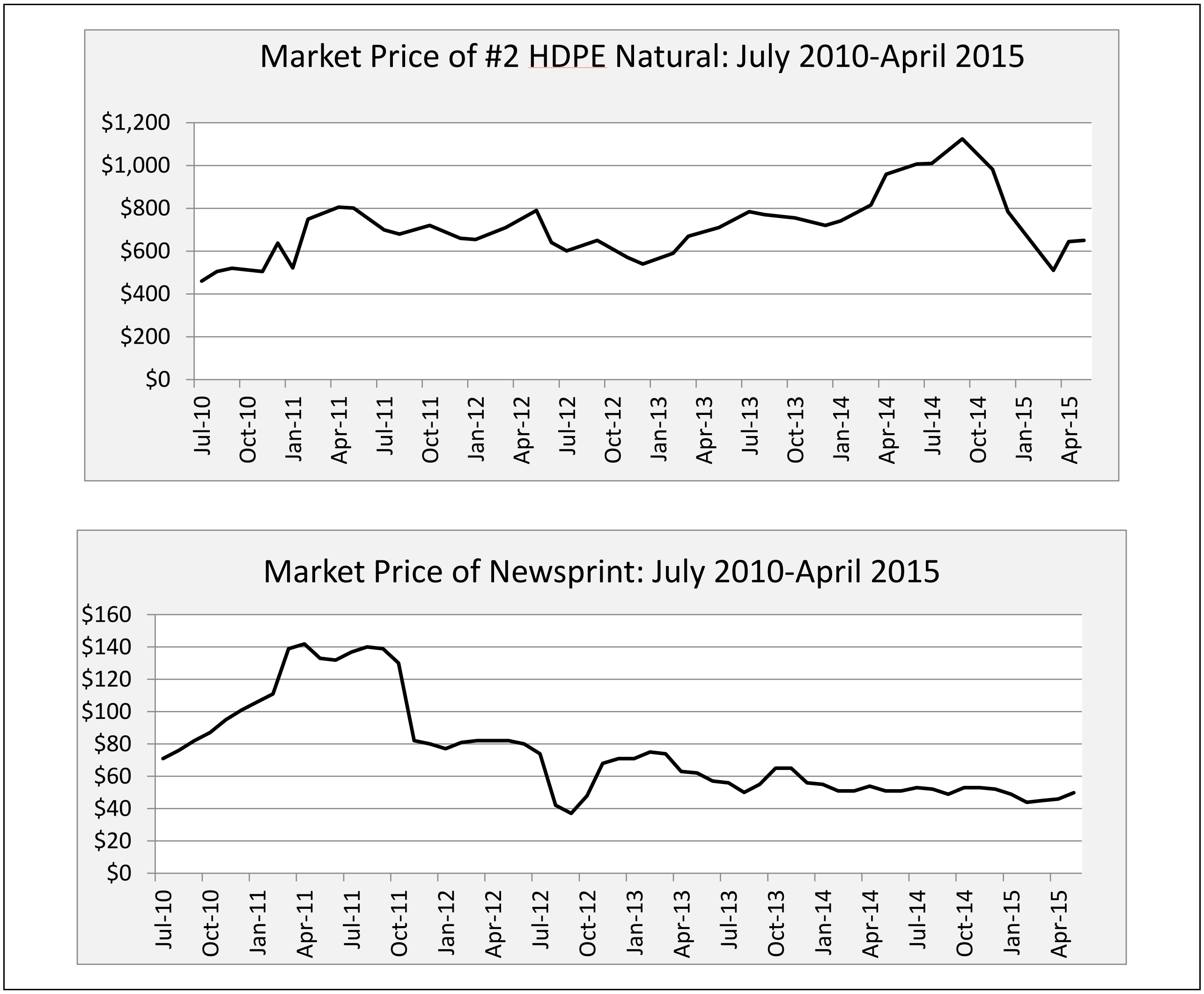


Table 4: Estimated annual value of recyclables disposed of as residential trash.

Recyclable material in trash	Content in trash	Estimated tons per year	Mean value per ton	Std. Dev.	Total lost revenue
Mixed paper/ONP	9.7%	766.3	$74.83	$29.50	**$57,342**
*****#3-#7 plastic	5.9%	466.1	$9.84	$4.70	**$4,586**
Steel/Ferrous	1.3%	102.7	$180.78	$86.34	**$18,566**
Aluminum	0.68%	53.72	$441.88	$34.92	**$23,738**
#1-PET	0.57%	45.03	$265.87	$202.86	**$11,972**
#2-HDPE, color	0.33%	26.07	$463.83	$147.51	**$12,092**
#2-HDPE, nat.	0.05%	3.95	$709.10	$154.20	**$2,801**
OCC	0.2%	15.8	$123.54	$26.01	**$1,952**
TOTAL		**1,479.77**			**$133,050**

*Includes plastic film and plastic bags.

Table 5 combines the lost revenue from disposing of recyclables in residential trash and the costs of the tipping fees for the disposal of these recyclables. Additionally, 45.02% of the trash was composed of non-recyclable, compostable materials: food waste (33.19%), green waste (4.23%), and napkins/towels/tissue (7.6%). Extrapolating citywide, for 7,900 tons of trash collected yearly, 3,556.6 tons of non-recyclable, compostable materials are disposed of in city trash bags. Disposal of this waste costs the city $250,740 in tipping fees annually. There are also directs costs for residents as well because of PAYT, but these costs were not determined. It should be noted that all the cost estimates are conservative, as they are based solely on tipping fees and lost revenues and do not include other direct costs such as labor, collection truck fuel, and vehicle maintenance costs, and indirect costs such as greenhouse gas generation.

Table 5: Estimated annual cost of disposing of recyclables and compostables as trash.

Item	Value
Lost revenues from recycling	$133,050
Tipping fees for disposing of recyclables	$87,050
SUBTOTAL	**$220,100**
Tipping fees for disposing of non-recyclable compostable waste	$250,740
TOTAL	**$470,840**

3.3 Recycling Characterization Results

The estimated mean quantity of recycling per household was 6.47 lbs (mean per trash bag weight was 11.76 lbs), which equates to an approximate per-household recycling rate of 35.5% by weight.[11]

Table 6 and Figure 11 compare the contents by percent weight and volume of residential recycling collected at curbside.

[11] This estimate is slightly lower than the actual recycling rate because during the collection of recycling for subsequent characterization, which was bagged by the city and transported to the characterization site, cardboard that would not fit into the bags was left at the curbside. This is based on visual assessments by researchers of cardboard set out at the curbside and the quantity of cardboard obtained at ecomaine as discussed below.

Table 6: Recyclables by percent weight and volume of average curbside collection.

	% by weight			% by volume
Mixed paper	19.91%		Cardboard	20.3%
Newsprint	17.09%		Paperboard	19.5%
Paperboard	15.75%		**Trash**	**13.2%**
Cardboard	15.20%		#3-#7 plastic	9.2%
Glass	8.39%		Mixed paper	9.1%
Trash	**6.63%**		Newsprint	8.8%
#3-#7 plastic[12]	5.19%		#1 -PET	4.9%
Metal	3.35%		#2-HDPE, natural	4.0%
#1-PET	3.07%		#2-HDPE, color	3.5%
#2-HDPE, color	1.88%		Metal	3.3%
#2-HDPE, nat.	1.29%		Glass	1.9%

[12] The #3-#7 category includes plastic film and plastic bags.

Figure 11: Contents of average Portland recycling bin by percent weight & volume.

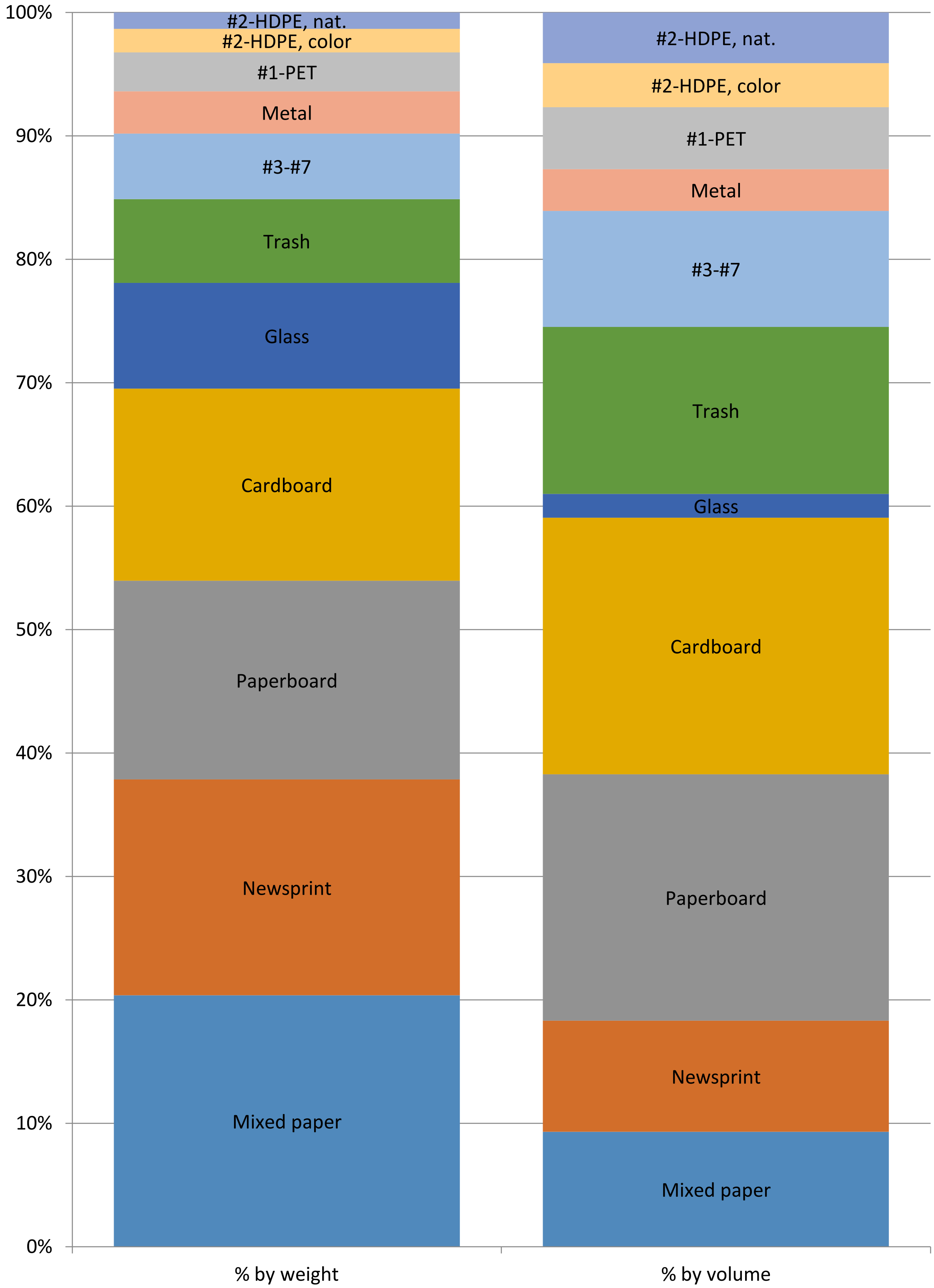
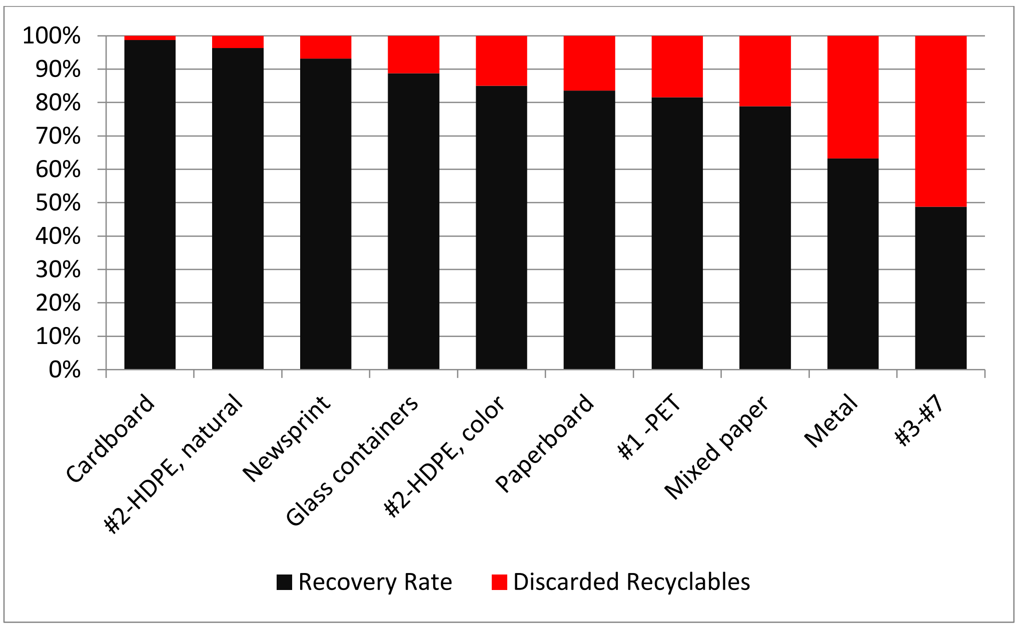


Figure 12 depicts the *recovery rate*, which is the percentage of the total amount of a recyclable material generated that is captured as recycling (an amount of 100% means all the material generated is being captured in the recycling stream).[13] As shown in Figure 13, with the exception of metal (which was dominated by aluminum), the recovery rate for each of the categories was largely attributable to the economic value of each material. Metal recovery is of concern because while post-burn ferrous metal can be removed at ecomaine, there is no collection of post-burn, non-ferrous metal (e.g., aluminum, copper, brass, and stainless steel). As a consequence, all non-ferrous metal sent to ecomaine as trash is subsequently disposed of in the ashfill.

Figure 12: Recovery rates of the major recyclables categories (percent by weight).



The mean percentage of trash contained in the recycling, known as the *residue rate*, was 6.63% by weight (13.2% by volume) with the largest contributor being C&D waste. Table 7 lists the top 8 categories of trash found in the recycling. The percent listed is the percent of that material in relation to the total weight of recycling. For comparison, Figure 13 depicts the residue rate for all recycling (i.e., this includes multiple towns and residential and commercial materials combined) processed at

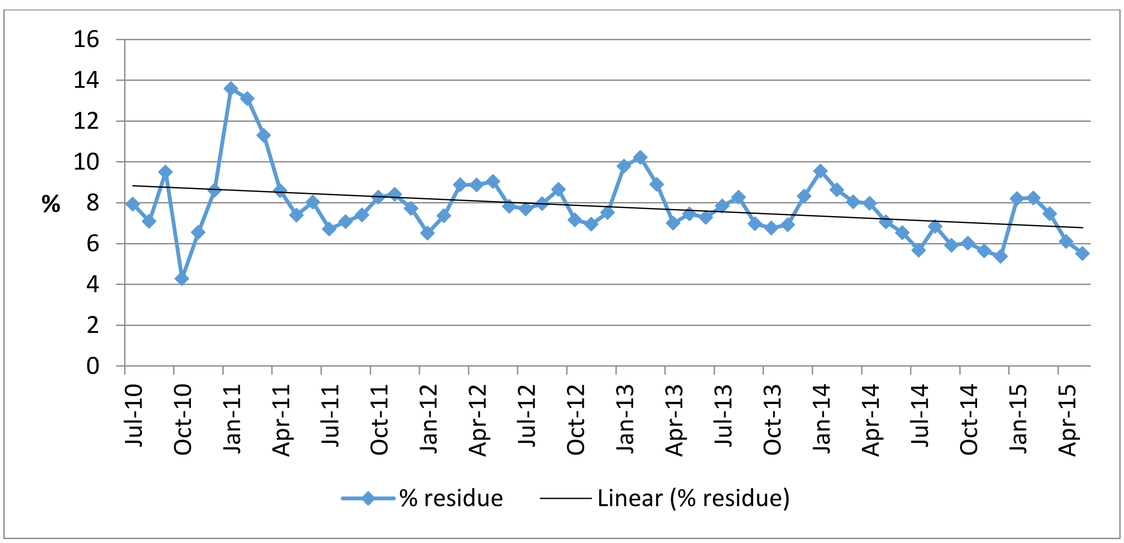
[13] The Recovery Rate **=** amount recycled/(amount in trash + amount recycled).

ecomaine over the past 5 years, which is 7.8% (s.d.=1.64%).[14] Although the quantity of EPS/Styrofoam™ is not significant from a weight perspective, it is proportionally high volume material. Based on the characterizations, the predominant items in this category were coffee cups, takeout food containers, and packing material. As noted earlier, because of Portland's recent ban on EPS for certain uses, the amount of EPS in the recycling bins likely will proportionally decrease.

Table 7: Top categories of trash found in the recycling by weight.

Category	% by weight
C&D	1.92%
Flexible Pack/cello	1.03%
Napkins/towels/tissue	0.83%
Textiles	0.73%
NOS/Other	0.57%
Food waste	0.46%
Electronics/Electrical	0.30%
EPS/Styrofoam™	0.25%

Figure 13: Residue rate, ecomaine recycling facility, July 2010-May 2015.



[14] ecomaine serves multiple communities in Southern Maine servicing some 25% of the state's population.

3.4 Recycling Bin Assessment Results

Table 8 presents the results of the inventory and the assessment of the recycling bins. Note that a significant percentage (26%) of residents setout multiple bins. Nonetheless, each week, the mean percent of bins that had material overflow located outside of the bin (i.e., on the ground next to the bin) was 15.2%. Regarding the weekly mean volume of overflow per bin, 66.9% of the volume of the bin was on the ground next to the bin.[15] That is, of the bins with material overflow outside of the bin, the overflow amount was an average of 69% greater that then volume of the bin(s) used. (Figure 14 depicts examples of overflows of recyclables beyond the capacity of the bin.) Note, however, that the data on multiple bins, frequency of overflow, and volume of overflow are recognized as an underestimate as discussed previously in Section 3.1 on determining the set out and participation rates. The prevalence of multiple bins and frequency and amount of overflow are indicators of the constraint of the small volume on the recycling rate. In addition, as discussed below, the overflow is a root cause of the generation of litter.

Table 8: Prevalence of recycling bins and external overflow.

	Mean
Percent of recyclers with >1 bin	26.0%
Mean number of bins per recycler	1.69
Weekly mean percent of recycling bins with external overflow	15.2%
Mean weekly percent of the volume of overflow for bins with overflow	66.9%

[15] Note that external overflow refers to the placement of recyclable material on the ground adjacent to the container and does not include material protruding from the container.

Figure 14: Examples of typical overflowing recycling containers.

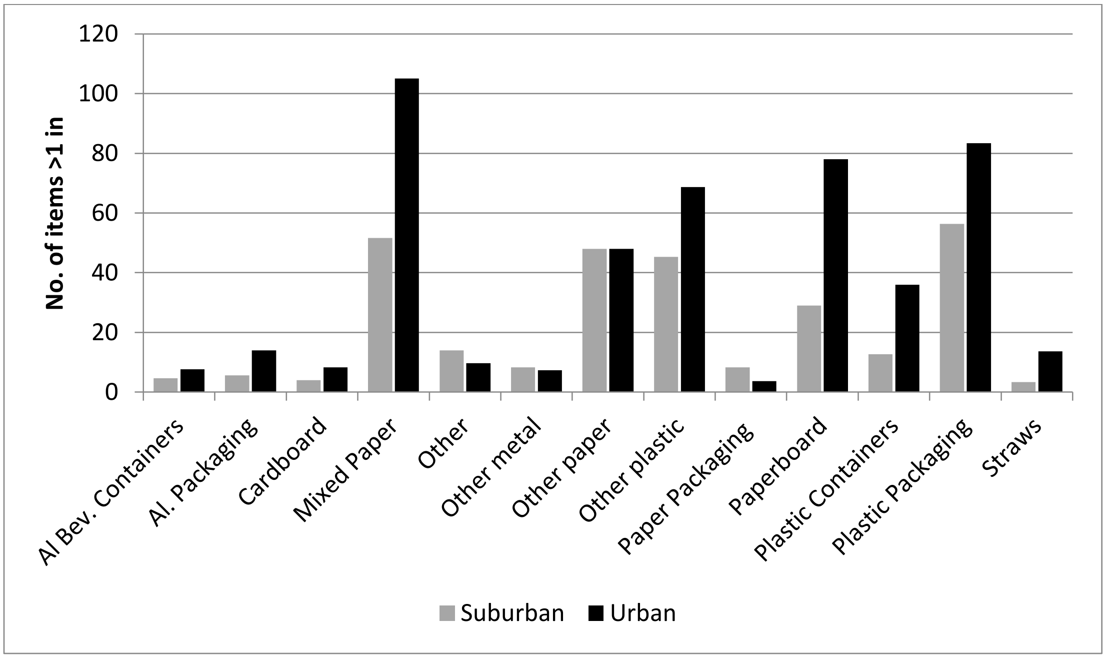
3.5 Litter Assessment and Characterization Results

Table 9 presents the results of the litter characterizations conducted during the study period that identified and assessed the litter attributable to the use of the open top recycling containers and the recycling collection process. Figure 15 compares the mean prevalence of litter of each material type (the number of pieces collected of each type of recyclable material) in the urban and suburban study areas. As discussed in the previous section, the prevalence and volume of overflow contributes to the generation of litter because protruding material is vulnerable to weather related wind and wind generated from passing vehicles.

Table 9: Results of the litter collection and characterization.

	Urban Area (N=733)	**Suburban Area** (N=1,050)	**Combined Mean**
Mean total weekly count (pieces >1 inch)	486 pieces	292 pieces	389 pieces
Mean total weekly weight	218.6 oz	74.5 oz	146.5 oz.
Count per 1,000 curb feet	5.2 pieces	2.7 pieces	3.87 pieces
Weight per 1,000 curb feet	2.33 oz	0.69 oz	1.46 oz
Mean weekly piece count per collection stop	0.66 pieces	0.28 pieces	0.44 pieces

Figure 15: Comparison of the mean litter count for each material type.



3.6 Household Survey Results

The major findings from the 59 responses (3.6% response rate) are presented in Table 10. These results should be viewed with caution given the low response rate and response biases common with this type of survey, but they nonetheless provide important indicators.

Table 10: Summary of results from household survey.

Question	Reponses
What size Portland Trash Bags do you normally purchase?	Large/30 gal = 12% Small/15 gal = 86.2% Not sure = 1.8%
In a typical week, how many full Portland Trash Bags do you set out on your curb for pick-up?	Mean = 0.94 bags
Where do you store your recycling bin(s)?	Inside apt/home = 47.5% In garage/shed = 22% Outside = 11.9%

Question	Reponses
	Basement = 8.5% Other = 13.6%
If Portland were to provide a larger recycling container (3x more volume than the current container) that was a cart with wheels, would you (scale of 0 to 10), 0 “not want it” and 10 “really want it.”	Weighted average of 4.93 0, not want it = 28.8% 10, really want it = 18.6%
If you do not want a cart, what is the primary reason?	Do not generate enough recyclables = 7.9% Not enough space to store large recycling container = 34.2% Like my current container = 23.7% Other = 34.2% Other responses included: winter storage a problem, we have multiple blue bins, would have to take recyclables outside
Which items are you most unsure about as to whether it is recycled in Portland?	Plastics (films, bags, ABS) = 58.3% Styrofoam = 13.9% Metal bottle caps = 8.3% Misc. = 19.5%
How do you dispose of garden and yard trimmings (leaves, grass, small branches, but not including food.)	Portland trash bags = 14% Bring it to Riverside Recycling Facility = 24% Compost it in our yard = 19% Fall curbside collection = 31%

Recognizing that the response rate is limited and suffers from response biases, it is nonetheless clear that switching from the small bins would be problematic for some respondents because of a lack of storage space. This comports with the body of research literature; one of the major barriers cited to recycling is a lack of storage space for containers. The primary, standard curbside collection options are listed in Table 11. The container’s footprint to storage capacity ratio is important; the 32-gallon container’s footprint is 58% larger than the currently used 18-gallon and the 64-gallon’s footprint is 82% larger.

Table 11: Comparison of standard curbside collection containers.

Collection Container Type	Standard Dimensions	Footprint (in^2)
18-gallon bin, no cover	16H x 17W x 16D	272
32-gallon cart with wheels	36.75H x 19W x 26D	494
64-gallon cart with wheels	41.5H x 24W x 27D	648

4. CONCLUSIONS/OBSERVATIONS

Some of the key research questions on set-out and participation rates could not be answered because of the lack of data collection technology, which limited the research methods to counting and inventorying by hand. As noted, there are many factors that limited the accuracy of this time-consuming and costly technique. Regardless, a key finding is that the city should consider retrofitting existing containers with RFID technology or ensure that any new recycling containers purchased contain RFID technology. RFID technology is an essential component of solid waste management. Containers with encapsulated RFID tags would allow the city to assign the container to a specific address and generate real time data on set-out rates and participation, identify problems as they occur, and measure route efficiency.

The data regarding trash, recycling, and litter are valid and indicate that while there are some recyclables being thrown away as trash, the amount is not substantial. However, the prevalence of households setting out multiple bins and the frequency and volume of overflow are indicators of the constraint of the small volume of the bins on the recycling rate. The amount of recycling collected would increase if larger recycling containers, such as carts, were used. Carts could also reduce city collection costs because of fewer containers to handle as one cart could replace the multiple containers now used. In addition, because of the substantially greater capacity, carts could be set out less frequently. Carts also could improve worker health and safety because there is less bending over and carrying involved. And, as the data indicate, changing recycling containers to those with a larger volume and with lids will reduce the litter associated with the open-top bins. One of the negative unintended consequences from switching from bins to carts is increased contamination—the residue rate, defined as the inclusion of non-recyclable materials in recycling collection containers. In a 2011 study in Oregon, an increase in contamination was attributable to the switch from 15-gallon bins to roll carts.[16] The study found contamination rates of 2-3% with the bins, but observed a significant increase to 9-10% with the introduction of carts. The study remarked that larger carts allow for the inclusion of larger items that users may or may not know are recyclable or that may permit the hiding of trash underneath recycling to avoid fees for trash collection. This could be addressed through targeted education, compliance monitoring, and enforcement.

The most significant finding of this study is simply a confirmation of numerous other findings from similar studies nationwide. In order to make significant progress with diversion rates, food waste, green waste, and organics currently disposed of as trash need to be segregated and managed separately. Given that food and green waste constituted 37.4% of the trash, and non-recyclable organics (paper napkins, towels, and tissues) constituted 8.02% of the trash, collectively (46%) these represent a significant cost to the city for collection, hauling, and disposal. While private curbside organics collection companies exist, our data suggests that participation remains low due mainly to the additional monthly fee for participation. While policies to reduce the generation of these wastes should be explored, serious consideration should be given to exploring a city-sponsored curbside collection program for organics.

Additionally, as the litter characterization demonstrates, the curbside recycling program contributes significantly to litter. The lack of lids, length of time set outside prior to collection, bottle bill scavenging, and winds all are significant contributors especially when there are frequent occurrences of recyclable materials protruding beyond the top of the bin and overflowing materials are placed directly on the ground outside of a bin. Because of the litter potential from recycling, it is likely some residents halt the filling of the recycling container at some point and shift excess recyclables to a trash bag.

In addition, based on direct observation and comments collected in the household survey, the method of curbside collection is also a factor in litter generation. It is common practice to flip the emptied recycling bins over (see Figure 16) to track

[16] See page 5, *Composition of Commingled Recyclables Before and After Processing*, Oregon Department of Environmental Quality, Report # 11-LQ-014, March 2011.

progress of collection. This practice can release any material that was not emptied or was temporarily stuck in the container due to moisture.

Figure 16: Post-collection management of recycling bins.

Finally, as noted by the 2015 Kessler Consulting Study, the city's use of a task-based incentive approach where workers are incentivized to collect recycling as fast as possible, likely leads to an increase in litter.[17] Consideration should be given to altering the incentive approach to reward the reduction of litter over the speed of collection.

[17] See page 7, *Evaluation of Recycling and Solid Waste Collection Services*, prepared for the City of Portland by Kessler Consulting, Inc., April 2015