APPENDIX

F

Economics of Residential Recycling in Seattle

Contents

Figures and Tables

Appendix F Economics of Residential Recycling in Seattle

Jeffrey Morris, Ph.D. Economist, Sound Resource Management Group, Inc., prepared October 2019
Edited by Luis Hillon and Stephanie Schwenger, Seattle Public

Overview

During the fallout of China's implementation of economic and environmental policies on recyclables imports in 2018, Seattle Public Utilities (SPU) commissioned Sound Resource Management Group to conduct an economic analysis of the benefits and costs of residential recycling and composting in Seattle. This appendix presents the report of findings from that analysis, which demonstrates that the City's recycling and composting, "diversion," programs create net financial and environmental benefits.

The report begins with a summary of the findings from the three elements of economic analysis, which, in the sustainability industry, are often referred to as the "three Es of recycling:" economy, environment, and equity:

1. Economy, or financial costs of recycling compared with financial costs of garbage disposal avoided by recycling.
2. Environment, or costs of pollution and other externalized costs caused by solid waste management activities and facilities associated with recycling and recycled-content production, compared with those types of costs associated with garbage disposal and virgin-content production that are avoided by recycling.
3. Equity, or social costs of inequities associated with recycling that exacerbate racial, gender, ethnic, religious, class, economic or other societal disparities, compared with those types of social costs associated with garbage disposal that are avoided by recycling.

The report continues by showing how Seattle's zero waste-focused solid waste programs and policies have, over time, resulted in decreased waste generation and disposal. Against this backdrop, the report provides detailed results of the financial and environmental benefits and costs of residential recycling and composting in the City. The analysis does not quantify the social benefits and costs of residential recycling and composting but discusses potential options for considering these costs.

Note that analysis generally covers the 12-year period 2007–2018 and that all dollar figures in this report are in constant 2018 dollars unless otherwise stated.

Summary of Findings

Separate collection, processing, and remanufacturing or composting of single-family and multifamily household recyclables and compostable food and yard waste reduce financial costs for households by avoiding the costs to collect, transfer, haul, and dispose of these materials as garbage. During 2007 through 2018, savings averaged $1.85 per month per household, and $23.62 per ton of residential garbage, recycling, and food and yard waste. These cost savings account for the residential recycling and food and yard waste diversion program costs. Even in 2018, with its difficult disruptions in markets for recycled materials, net cost savings amounted to $0.46 per household per month and $6.77 per ton of collected residential discards. Net financial cost savings during 2007–2018 totaled $78.2 million. Of these cost savings, household recycling accounted for 78% and household food and yard waste composting for 22%.

Seattle's residential recycling and food and yard waste diversion programs also provide global environmental benefits. Recyclable and food and yard waste materials that end up in the garbage cannot be used in the production of other products, meaning virgin materials must be used. Garbage collection and disposal with its associated production of virgin-content products and packaging materials, as well as petrochemical-based fertilizers and pesticides, has a large environmental footprint. Much of this footprint is caused by pollution from extracting and refining global ecosystem raw material and energy resources to feed virgin-content manufacturing. In contrast, recovered materials for manufacturing recycled-content products and composted soil amendments from food and yard waste substantially lower the need for virgin raw material and energy resources.

After accounting for the environmental costs of recycling and food and yard waste diversion programs themselves, environmental net cost savings from avoided garbage disposal and virgin-content production averaged $349 per ton of residential collected discards and totaled $1.2 billion during 2007–2018. If the monetary value of net environmental benefits had been paid to SPU residential rate payers, the average household's monthly cost for solid waste collection services would have been $26.78 lower per month during the twelve-year period that just ended in 2018.

Table F.1 and Figure F.1 display financial and environmental benefits on average and over time. Increasing contaminants, especially in recycling; higher fees for food and yard waste; and an increasing proportion of glass and decreasing proportion of newspapers in recycled materials are the major causes of slight downtrends in both per household and per ton net avoided cost savings. Despite these challenges and the current challenge, at the time of the writing (2019), from low recycling market prices, Seattle's recycling and food and yard waste diversion programs continue to pay dividends to rate payers, global public health, and the environment.

Table F.1 Seattle Residential Net Avoided Disposal Cost Savings

Seattle Residential Net Avoided Disposal Cost Savings				
Avoided Disposal Cost Component	Per Ton of Collected Discards		Per Household Per Month	
	2018	12-yr Avg	2018	12-yr Avg
Financial	$7	$23	$0.46	$1.85
Environmental	$346	$349	$23.78	$26.87
Total	$353	$372	$24.24	$28.72

Figure F.1 Financial Plus Environmental Cost Savings of Residential Recycling and Food and Yard Waste (Organics) Collections

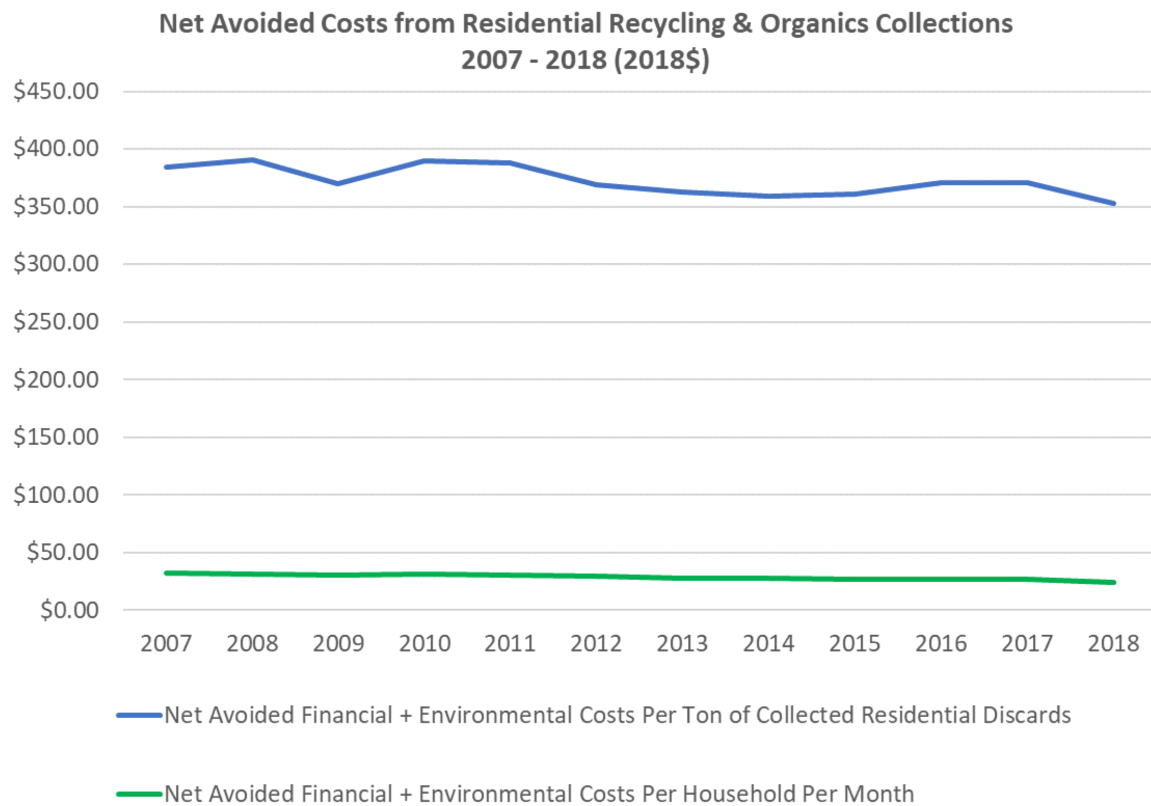


Figure F.2 portrays effects on residential garbage disposal from programs that in total have been cost-effective at diverting residential discards. Disposal quantities per residential household per weekday (the days when residential discards collections occur) declined 61% from a 1977 average of 6.2 pounds to 2.4 pounds by 2018. In the past 10 years, residential waste generation has also trended down. Results portrayed by Figure F.1 and Figure F.2 are discussed in greater detail in the following sections of this report.

Figure F.2 Seattle Residential (Single-Family and Multifamily) Collected Waste Generation and Disposal per Household per Weekday 1977–2018

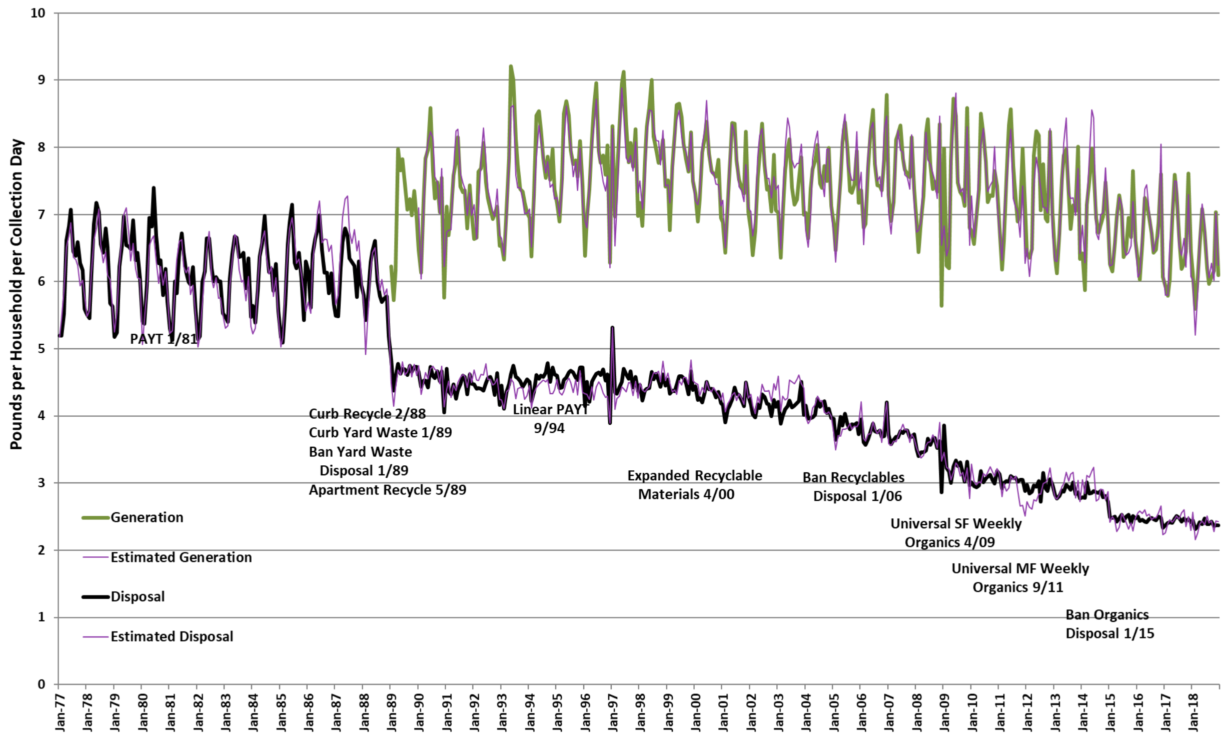


Chart acronyms: Pay-as-you-through (PAYT), single-family (SF), multifamily (MF)

Trends in and Factors Influencing Generation and Disposal Trends

Over the past 40 years, Seattle implemented innovative solid waste management programs and regulations to divert materials from disposal to recycling and composting. Through diversion, these otherwise disposed materials become resources for manufacturing recycled-content products or for improving the quality and sustainable productivity of soils. At the same time, Seattle aimed to make diversion financially cost-effective and environmentally beneficial.

Residential Sectors

Figure F.3 shows the success among Seattle's residential households, including both single-family and multifamily in diverting discarded solid waste materials from garbage collection to recycling and food and yard waste collection. Disposal per household per weekday (the days when residential solid waste collections occur) declined from an annual average of 6.2 pounds per household per collection day in 1977 to 2.4 pounds by 2018, a decrease of 61%.

Furthermore, the graph shows that the combined amount of solid waste discards that households set out for recycling, food and yard waste, and garbage collections has recently trended downward. Because most residential solid waste discards are managed through City of Seattle contracted collections, this downtrend may also indicate, at least in part, some success in reducing overall residential waste generation.

Figure F.3 Seattle Residential Collected Waste Generation and Disposal per Household per Weekday 1977–2018

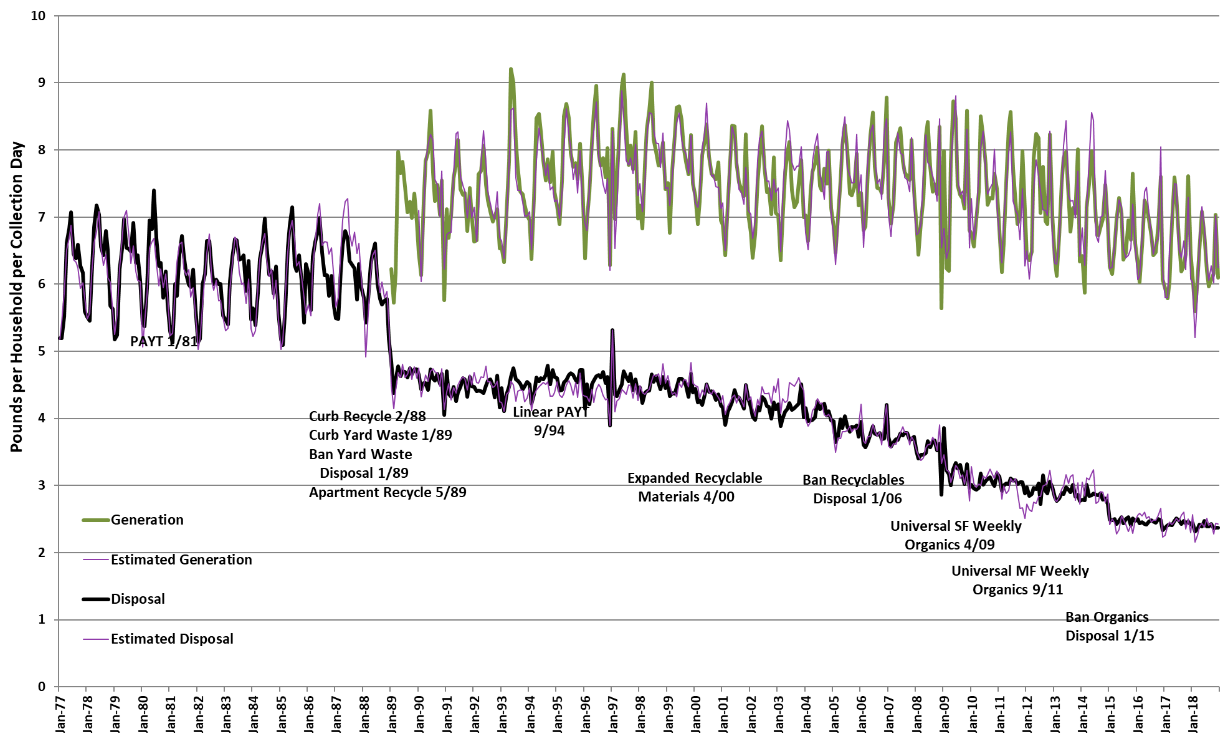


Chart acronyms: Pay-as-you-through (PAYR), single-family (SF), multifamily (MF)

The heavy black disposal line on Figure F.3 show average garbage collection pounds per residential household per weekday in each month from January 1977 through December 2018. The text boxes below that line name some of the programs and regulations implemented by Seattle during those years, some of which are associated with substantial drops in disposal per household.

The light purple disposal line represents fitted values from an econometrically estimated multiple regression equation that identifies statistically significant factors explaining cycles and trends in residential garbage disposal. Significant factors include programs, such as curbside collection, regulations such as disposal bans, weather and other seasonal influences, and economic variables, such as income and garbage collection fees. Some of these statistically significant factors are shown in the text boxes in Figure F.3.

Rules and Regulations

During 1988–1989, the introduction of curbside collections for recyclables and yard waste from single-family households, the ban on putting yard waste in the garbage, and the introduction of onsite collection of recyclables from apartment buildings resulted in large drops in per household disposal. The yard waste disposal ban and curbside collection of yard waste for composting also caused a related large decrease in seasonal variability of the amount of solid waste materials that remained in garbage. Expansion of material types collected for recycling, a ban on putting recyclables in the garbage, universal single-family and multifamily food and yard waste composting subscription mandates, and a ban on putting food and compostable paper in the garbage, all contributed to the continuing decline in disposal per household over the years since recycling and yard waste collections were introduced.

Pay-as-you-throw (PAYT) Garbage Rate Structure

Garbage collection fees, also called collection rates, also had a statistically significant impact on garbage collection pounds, although the quantitative impact is not easily visible on the graph. The size of that impact depends on the availability of convenient opportunities to divert recycling and food and yard waste. The diversion impact from collection fees also is affected by the extent to which garbage collection fees increase as a household's garbage disposal quantities increase.

Before January 1981, households with curbside garbage collection all paid the same garbage collection fee regardless of how much garbage they set out for collection, so they faced no financial impacts for disposing of more garbage. In January 1981, Seattle began charging differential fees related to the size of a household's subscribed garbage cart. At that time, weekly collection cost $6.40 per month for a 32-gallon cart, $7.90 for a 64-gallon cart, and $9.40 for a 96-gallon cart. The PAYT acronym on Figure F.3 stands for "pay as you throw" to indicate that a household that throws out more, pays more. In this case "more" is measured by the volumetric size of the garbage cart used by a household.

After 1981, as collection fees increased, the additional charges for larger garbage carts increased even more, reaching essentially linear levels in September 1994. Linear means that the cost to double the size of a household's garbage cart also doubles the collection fee.

Beginning September 1994, collection fees were $16.10 for weekly collection of garbage placed in a 32-gallon can or cart, $32.15 for a 64-gallon cart, and $48.25 for a 96-gallon cart.

Interestingly, econometric analysis shows that PAYT did not have a statistically significant effect on disposal weight until households began to have access to recycling and yard waste collections that were equally as convenient as curbside garbage collection. Before the introduction of curbside recycling and yard waste collections in 1988–1989, households had to self-haul recyclable materials they wanted to divert from disposal to one of the privately-operated recycling drop-off centers scattered rather sparsely around the city. Households wanting to keep yard waste and other food and yard waste out of the garbage had to compost those materials in their backyards.

Without convenient recycling and food and yard waste collection, PAYT was not particularly effective at reducing disposal weights. Yet, according to some analysts, PAYT did reduce the volume of garbage set out for curbside collection. The means for this volume reduction – stomping on the garbage in the garbage container size for which the household paid – became well-known in media stories as the "Seattle Stomp." While stomping reduced volume, it had a negligible effect on the weight of garbage disposal.

Other Factors

The heavy green line on Figure F.3 is the monthly average for combined pounds of garbage, recycling, and food and yard waste discarded each week on collection day by the average household (single-family plus multifamily) in Seattle. Possible causes for the recent decline in household waste generation include changes in the composition of household discards, decreases in the weight of materials used for packaging products, cessation of print publication of one of Seattle's two major newspapers in 2009, and recent increases in the proportion of multifamily versus single-family households in Seattle (where the average multifamily household is typically smaller than the average single-family household).

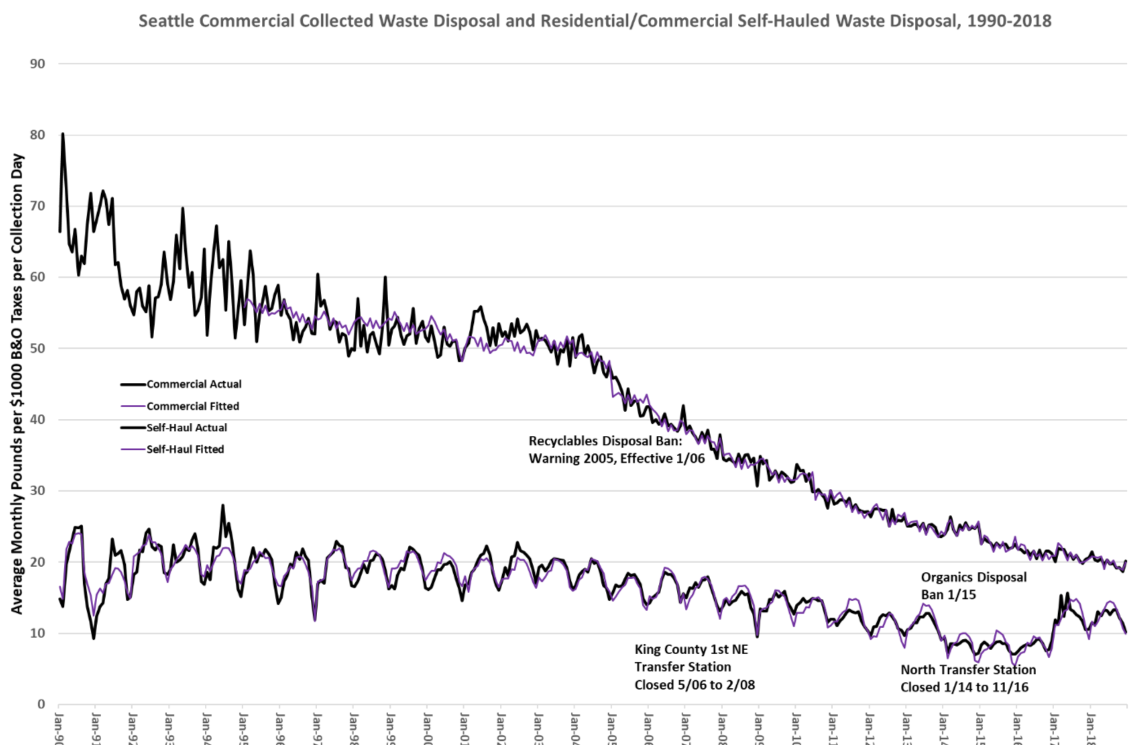
As with the disposal line, the light purple line represents fitted values from econometric multiple regression analysis. Unlike the disposal line, however, the light purple line represents combined fitted values for four regression equations related to:

1. Garbage collected curbside from mainly single-family households in cans or carts and collected on site from multifamily apartment building dumpsters
2. Recyclables collected curbside from mainly single-family households in bins or carts
3. Recyclables collected on site in dumpsters from multifamily households in larger apartment buildings
4. Food and yard waste collected curbside in carts from both single-family and multifamily households

Commercial and Self-Haul Sectors

Figure F.4 shows garbage disposal trends for commercial and self-haul garbage. For these two customer sectors, Figure F.4 shows average monthly garbage disposal pounds per day per $1,000 of business and occupation (B&O) tax obligations. Here, the days for commercial customers are commercial garbage collection days, which includes weekends for some commercial customers. Days for transfer station customers are days that transfer stations are open for self-haul customers. These two sectors have their pounds per day normalized by monthly B&O taxes, which is a regularly reported measure of business activity in Seattle.

Figure F.4 Seattle Monthly Commercial Collected Waste Disposal and Self-Haul Waste Disposal per $1000 of Business and Occupation Taxes per Day 1990–2018



B&O taxes are the normalization measure rather than number of businesses for two reasons:

1. Businesses vary greatly in size compared with the much smaller variation in number of occupants in residential households. Hence, garbage disposal per average business is not a particularly meaningful comparative measure for business enterprises.
2. Business waste generation and disposal trends and cycles over time are driven in large part by economic activity in Seattle. Holding overall business activity constant while searching for

additional drivers of disposal per collection day makes it easier to more accurately measure the influence of Seattle-instituted programs and regulations, weather, seasonality, and economic variables other than aggregate business activity.

Figure F.4 shows Seattle's success at reducing the rate of commercial garbage disposal over the recent 30-year period. Seattle has also had some success at reducing the disposal rate for self-haul garbage. However, success in self-haul garbage disposal has been moderated by the availability of nearby transfer facilities operated by King County. The effects of Seattle's effort are affected by differences between Seattle and King County transfer station tip fees, disposal bans, ban enforcement, as well as changes in those differences over time. Moreover, analysis of self-haul disposal quantities at Seattle transfer facilities is confounded by the closure for renovation of King County's Shoreline Transfer Station during May 2006 to February 2008 and of Seattle's North Transfer Station from January 2014 to November 2016.

Heavy black lines on Figure F.4 show actual garbage disposal, and lighter purple lines are for econometrically fitted disposal equations. The lower actual and fitted lines are for self-haul garbage. A few of the statistically significant drivers of each sector's garbage disposal quantities are shown in text boxes below each set of lines. Certain collection fees are also significant drivers of garbage disposal for commercial businesses and self-haulers of garbage. In addition, tip fees at Seattle compared with King County transfer stations are significant for self-haul garbage disposal at Seattle transfer stations. Note that implementation of Seattle's ban on putting recyclables in residential, commercial, or self-haul garbage coincided with King County's closure of its Shoreline Transfer Station for renovation. Based on econometric analysis, some customers of the Shoreline Transfer Station apparently used Seattle's North Transfer Station until it re-opened, moderating the influence of the recycling ban on self-haul garbage disposed at Seattle transfer stations.

Given Seattle's success at reducing garbage disposal, what are the financial and environmental benefits and costs associated with reductions in garbage disposal and increases in recycling and composting? Has Seattle succeeded in making diversion financially cost-effective and environmentally beneficial? The following two sections focus on a quantitative evaluation of the financial and environmental cost and benefit facets of the economics of recycling.

The residential sector provides the detailed data for these quantitative results. Virtually all residentially generated garbage, food and yard waste and recycling discards are handled via City-managed private contractors and the two City-owned transfer stations. Recycled or composted commercial wastes are largely handled directly by the private sector. Wastes self-haul to City transfer stations can come from outside of Seattle. In addition, self-haul discards are not accurately identifiable as residential versus commercial in origin. As a result, the residential sector provides more accessible, complete, and accurately identified data on Seattle-generated waste quantities and their financial costs and benefits than other sectors.

Financial Benefits and Costs of Residential Recycling and Composting

Seattle offers curbside garbage, food and yard waste, and recycling collection services to single-family households and to some multifamily households. The proportion of total households receiving curbside versus onsite collection services varies greatly among the three discards streams. For 2018, the split ranged from 100% of households (single-family + multifamily) having curbside food and yard waste collection access to 54% of households receiving curbside versus onsite garbage collection. In 2018, 68% of households received curbside recycling collection. The remaining portion of multifamily households, mostly larger apartment building dwellers, received onsite garbage and recyclables collection in 2018. These splits also are reasonably representative of other years in the analysis, 2007 through 2018.

Seattle contracts for collection of garbage, food and yard waste, and recycling; processing of collected recyclables; composting of collected food and yard waste; and rail-haul and landfill disposal of garbage. It also contracts for some portions of the haul of garbage from transfer stations to the rail head and of food and yard waste from transfer stations to composting facilities. In all these contracts, a substantial portion, in some cases 100%, of contracted charges for services are calculated per ton of material handled. This means that when recycling or food and yard waste tonnages increase and garbage tonnages decrease, the City pays more for diversion and less for garbage handling. These garbage savings are included in calculations of diversion program cost effectiveness.

Table F.2 shows average and variable costs in 2018 for managing discards collected in each discards stream. Costs are separated into solid waste management activities that are carried out on materials discarded by households into each stream. For collection, the figures represent the weighted average for curbside and onsite collections. Variable costs, sometimes also called marginal costs, represent how costs would vary at the margin when something else varies by a small amount. For example, while the average cost of managing recycling is $235 per ton overall, the cost of managing one extra ton of recycling is $118.

One of the financial benefits of diversion programs is that one ton of discards diverted from garbage to recycling or composting reduces garbage collection, transfer, hauling and disposal costs by their variable costs per ton. These costs for garbage are avoided when material discards are diverted to recycling or composting. Hence, the terminology "avoided costs" or "avoided garbage disposal costs."

As indicated in Table F.2, both variable and average costs per ton for recycling and composting were lower than for garbage in 2018. This finding for recycling is especially significant because 2018 was a year when prices paid for processed recyclables by recycled-content paper mills, glass manufacturers, recycled plastics re-manufacturers, and other recycled materials end-users were particularly low. Seattle receives a market credit from its contracted recyclables processor that offsets a portion of the costs of processing. That credit was $51 per ton in 2018, down from over $85 per ton in 2017.

Table F.2 2018 Average and Variable Costs for Management of Residential Discards

Residential Discards Stream	2018 Variable Cost Per Ton	2018 Average Cost Per Ton	Variable % of Average
Garbage			
Collection	$81	$225	36%
Transfer	$3	$11	27%
Short Haul	$6	$6	95%
Long-Haul & Disposal	$42	$42	100%
Garbage Total	$131	$284	46%
Organics			
Collection	$66	$186	35%
Transfer	$3	$11	30%
Hauling	$17	$18	94%
Composting	$42	$42	100%
Organics Total	$128	$257	50%
Recycling			
Collection	$73	$190	39%
Processing	$96	$96	100%
Market Credit	($51)	($51)	100%
Recycling Total	$118	$235	50%

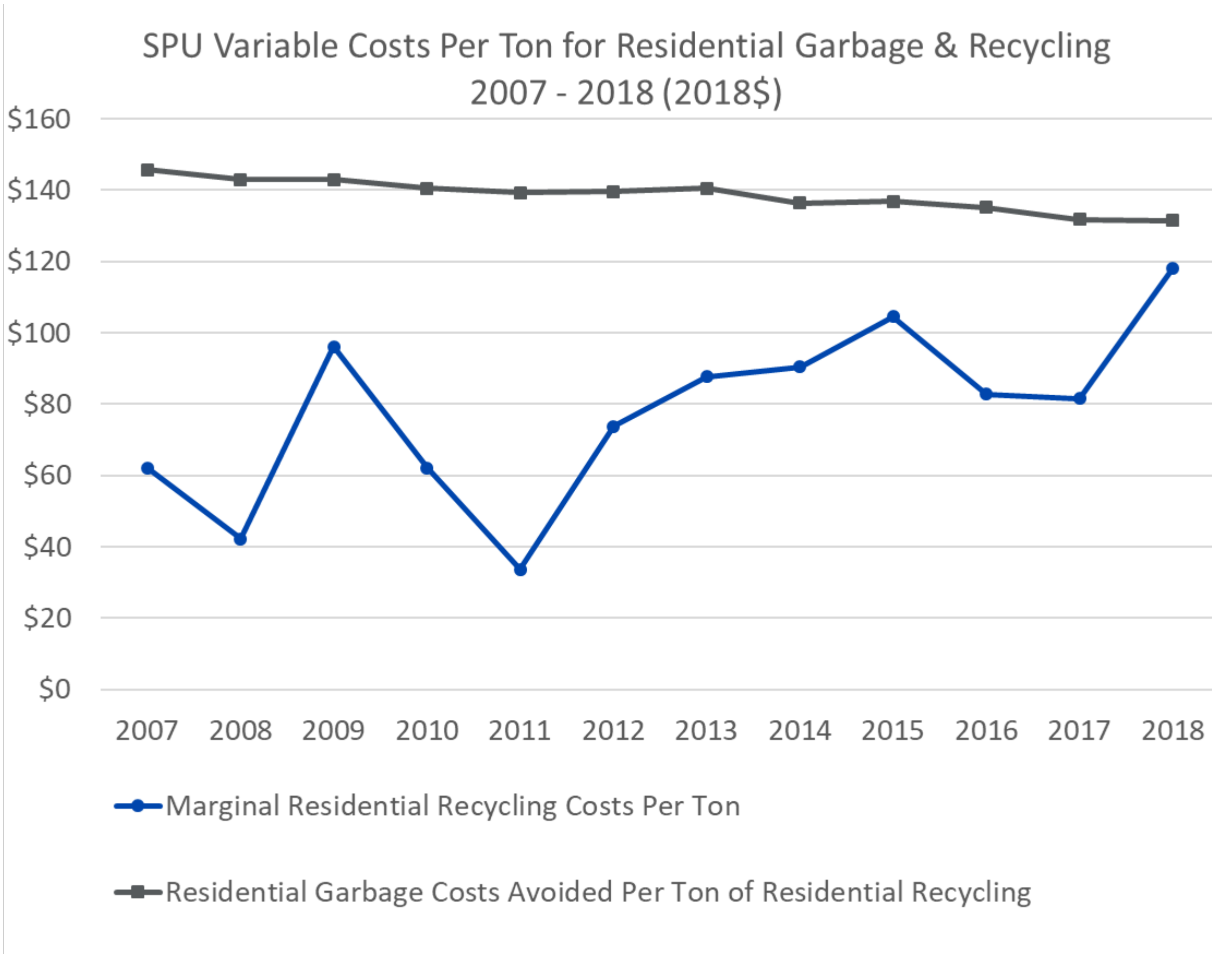
Recycling

Figure F.5 shows SPU residential garbage and recycling variable costs per ton in 2018$ for each year from 2007 through 2018. Avoided residential garbage disposal costs have been higher than residential recycling marginal costs for this 12-year period. In addition, 2018 is an anomalous year during this period, because of the depressed markets for recycled materials. In eight of these 12 years when recycling markets prices were strong, garbage costs avoided by recycling exceeded recycling marginal costs by over $50 per ton. In the other three years when recycling markets were less robust (but still better than in 2018), residential recycling was less costly than garbage by at least $32 per ton. In 2018, recycling profitability was just $13 per ton.

One way to evaluate the cost savings per ton of solid waste diverted to residential recycling in 2007–2018 is to sum the per-ton differences between avoided residential garbage disposal costs and residential marginal recycling costs. That sum is $728 (2018$). Another way to assess the cost savings is to calculate the net present value in 2007 of this 12-year diversion of a ton of garbage into residential recycling. At a discount rate of 2.5%, that 2007 present value in 2018 dollars (2018$) is $639. In 2019, this same stream of cost savings from one ton per year of residential recycling during the years 2019 through 2030 would also be worth $639 in 2018 dollars at 2.5% interest.

From 2007 through 2018, residential recycling in total diverted more than a million tons, thus avoiding the greater costs of residential garbage by a net savings amounting to $61.1 million. In 2007, this would have represented a net present value at 2.5% discount rate of $53.6 million (2018$). These savings from recycling reduced the average monthly cost of a customer's garbage bill by $1.45 every month during the 12 years beginning 2007 and continuing through 2018.

Figure F.5 Residential Recycling Marginal Cost and Avoided Garbage Cost Per Ton 2007–2018 (2018$)

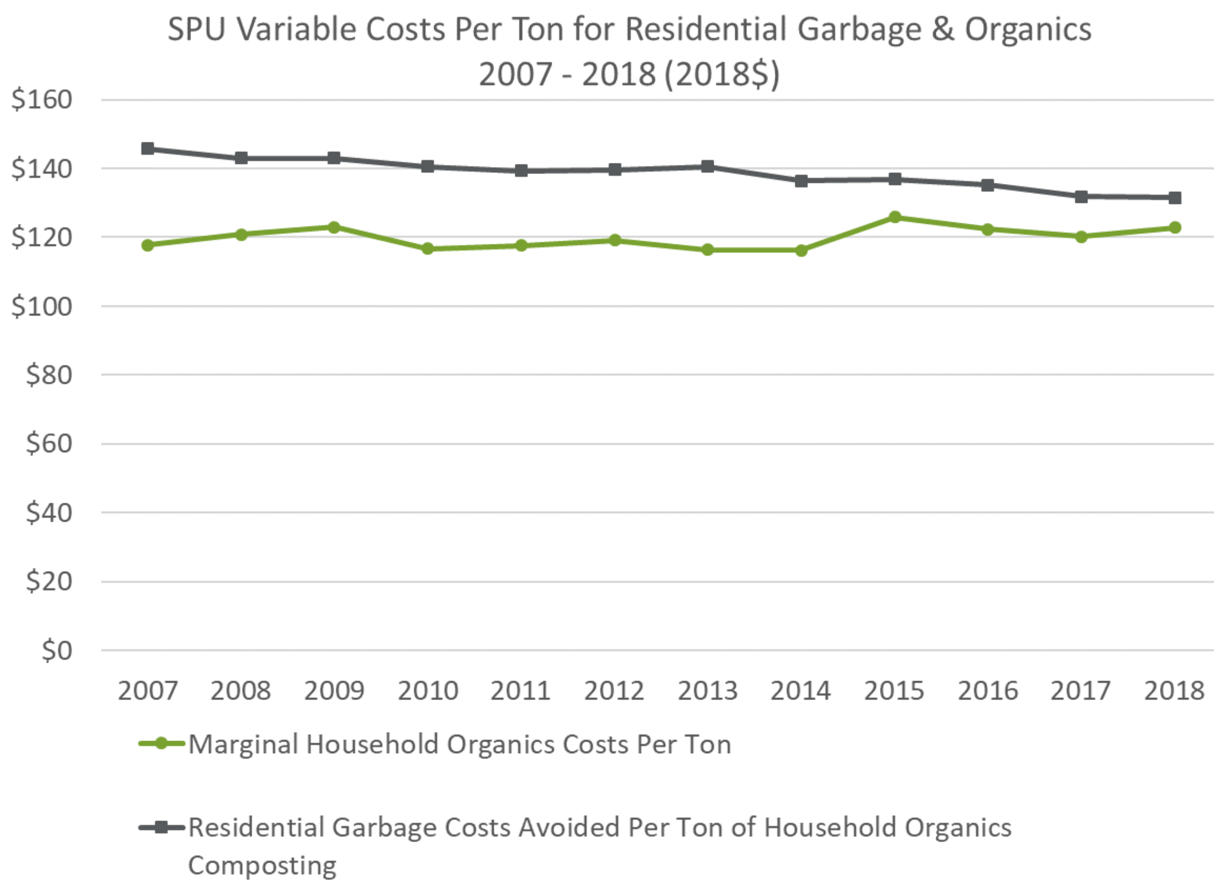


Food and Yard Waste

Figure F.6 shows SPU's curbside garbage and household food and yard waste composting variable costs per ton for the period 2007 through 2018. Avoided garbage disposal costs have been higher than household food and yard waste composting marginal costs throughout the past 12 years. However, the profitability margin has narrowed in the past five years primarily due to an increase in food and yard waste composting costs. In addition, avoided garbage costs have fallen slightly as garbage collection and rail-haul landfilling costs have decreased recently.

Cost savings per ton diverted to household food and yard waste composting (net of food and yard waste collection, transfer, haul and food and yard waste costs) in 2007–2018 amounted to $225 (2018$). The net present value in 2007 of this 12-year diversion of a ton of garbage into household food and yard waste was $197 (2018$). In 2019 this same stream of cost savings from one ton per year of composting household food and yard waste during the years 2019 through 2030 would also have a net present value of $197 in 2018 dollars. Furthermore, net household food and yard waste management financial costs savings reduced the average food and yard waste subscriber's monthly bill during the years 2007 through 2018 by $0.89 (2018$).

Figure F.6 Household Food and Yard Waste (Organics) Marginal Cost and Avoided Curbside Garbage Cost Per Ton 2007–2018 (2018$)



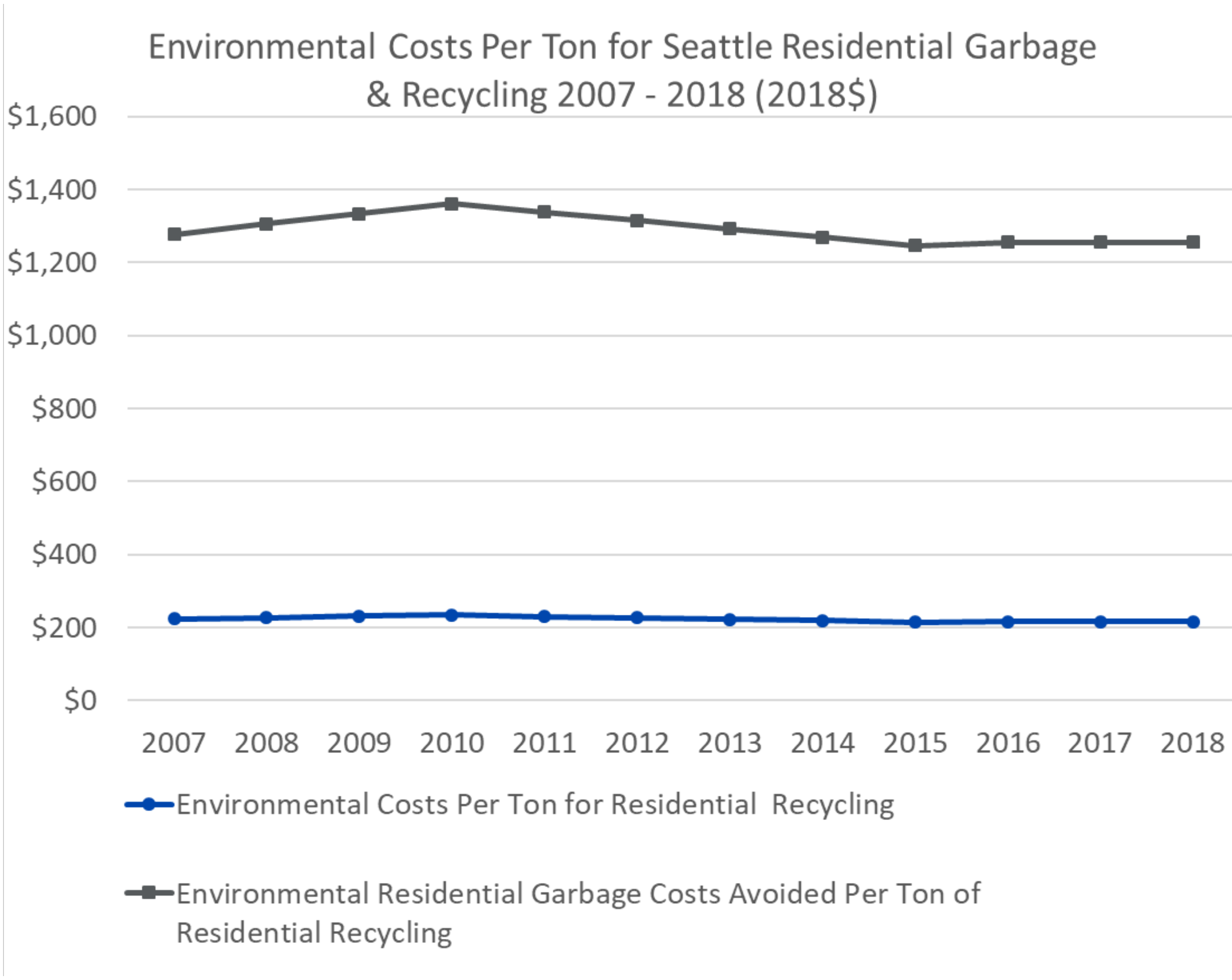
Environmental Benefits and Costs of Residential Recycling and Food and Yard Waste

Recycling

This section describes environmental costs and benefits of recycling calculated using MEBCalc (Measuring Environmental Benefits Calculator), described in Appendix E, *Recycling Potential Assessment Model and Environmental Benefits Analysis*.[1] Figure F.7 shows life cycle environmental costs for residential garbage and recycling per recycled ton in 2018$ for 2007–2018, according to the MEBCalc analysis. Garbage disposal environmental costs avoided by recycling were substantially higher than residential recycling environmental costs throughout the past 12 years. Environmental damage costs savings from recycling averaged $1,069 per ton during 2007–2018, avoiding the greater environmental cost of garbage disposal and saving a net $1.1 billion in environmental damage costs. If this global public health and environmental benefit were all paid to Seattle households, it would be equivalent to reducing monthly garbage bills by $25 (2018$) every month for 12 years.

[1] The development of life cycle analysis, life cycle environmental impacts monetization, and references for data and methodologies used in Sound Resource Management Group's tool Measuring Environmental Benefits Calculator (MEBCalc) are discussed in Appendix E, *Recycling Potential Assessment Model and Environmental Benefits Analysis*.

Figure F.7 Residential Recycling Environmental Cost and Avoided Garbage Cost Per Ton 2007–2018 (2018$)



Garbage disposal environmental costs avoided by recycling in Seattle declined somewhat between 2007 and 2018, in part for three reasons:

- Contaminants thrown into recycling collection carts and dumpsters by Seattle households increased dramatically. In 2007, contaminants, on average, accounted for about 2% of the total weight recycled by households. By 2015, contamination averaged 10.5%. Collecting contaminants in recycling containers does not avoid garbage life cycle environmental costs, especially the upstream environmental costs of virgin-content material and product resource extraction and manufacturing.
- Glass in the recycling stream increased as a percentage of total weight from about 18% in 2007 to 26% by 2015. Glass has a lower virgin-content environmental cost than other materials, such as paper, plastics, and metals. Hence, the average virgin-content materials

production component of avoided garbage environmental costs per ton decreases when the relative amount of glass increases.

- One of Seattle's two mainstream newspapers ceased print publication in March 2009. This also reduced avoided garbage environmental costs, on average.

The decline in avoided garbage disposal environmental costs was somewhat reduced by increased diversion of metals, especially aluminum cans, beginning in 2010. Aluminum cans have much higher than average avoided environmental impacts from virgin-content manufacturing.

Decreased environmental costs of recycling offset some of the decline in avoided garbage environmental costs. Environmental costs of recycling dropped slightly mainly because of the increased proportion of glass in recycling carts and dumpsters. This decreased the average upstream environmental cost of recycled-content materials and products. As is true for virgin-content glass containers compared with virgin-content paper, plastics and metal products, recycled-content glass containers have a smaller environmental footprint than the average recycled-content product manufactured from other materials in the recycled discards stream.

Table F.3 shows residential recycling composition estimated from recycling stream sorts in 2005, 2010, and 2015 of recyclables collected curbside from single-family residences and smaller apartment buildings, as well as onsite from larger apartment buildings. For this study, recycling composition in the years between composition studies is based on linear interpolation during years between the waste composition studies.

Table F.3 Estimated Residential Recycling Composition Based on Studies of Curbside and Apartment Recycling Collections

Recycled Materials	Estimated Residential Recycling Stream Composition		
	2005	2010	2015
Cardboard	15.8%	17.8%	16.4%
Newsprint	33.0%	19.5%	13.9%
Mixed Paper	27.0%	32.2%	25.6%
PET	1.0%	2.0%	2.1%
HDPE	0.8%	1.1%	1.5%
PP	0.2%	0.6%	0.5%
LDPE	0.4%	0.6%	0.9%
Glass	18.2%	17.7%	26.1%
Aluminum	0.5%	0.9%	0.9%
Tin Cans	0.8%	1.2%	1.1%
Other Ferrous Scrap	0.3%	0.4%	0.4%
Contaminants	2.1%	5.9%	10.5%
Total	100.0%	100.0%	100.0%

Table F.4 shows the changes over time in the composition of commingled materials collected for residential recycling that affected environmental costs of recycling and avoided garbage disposal. Table F.4 also shows the net effects on residential recycling's environmental benefits. Environmental costs of contamination in materials collected are allocated proportionately to the actual recyclables collected. Given this assumption, one might expect benefits of recycling to decline for all nine environmental impacts as contamination rates increase. However, climate change, human health, and water eutrophication impacts all increased between 2005 and 2010. One driving force was the decline in newspaper recycling that followed the closure of the *Seattle Post Intelligencer* in 2009. Fewer newspapers printed meant fewer newspapers to recycle. Recycling newspapers has a lower net environmental benefit than the average recycled material. A decline in newspaper recycling, all other things constant, increases recycling's net environmental benefits per ton of commingled material.

For climate change, an additional driver is that the costs of carbon dioxide emissions increase as the time approaches when the environmental impacts of climate change will begin to increase, perhaps precipitously. This is reflected in the social costs of carbon estimates by the U.S. Interagency Working Group on the Social Cost of Carbon (IWGSCC) as detailed in Appendix E, *Recycling Potential Assessment Model and Environmental Benefits Analysis*.

Table F.4 Residential Recycling Net Environmental Benefits, Recycling Costs and Avoided Garbage Disposal Costs

Environmental Impacts	Environmental Benefits and Costs of Residential Recycling Per Commingled Ton Collected								
	2005			2010			2015		
	Net Recycling Benefit	Avoided Garbage Cost	Recycling Cost	Net Recycling Benefit	Avoided Garbage Cost	Recycling Cost	Net Recycling Benefit	Avoided Garbage Cost	Recycling Cost
	(a = b - c)	(b)	(c)	(a = b - c)	(b)	(c)	(a = b - c)	(b)	(c)
Climate Change	$101	$166	$65	$109	$176	$67	$100	$166	$66
Human Health									
Respiratory	$525	$622	$97	$590	$711	$121	$562	$674	$112
Toxicity	$37	$61	$24	$38	$58	$20	$33	$49	$16
Carcinogenicity	$5	$9	$4	$5	$12	$7	$5	$12	$7
Water Eutrophication	$324	$334	$10	$375	$383	$8	$326	$333	$7
Acidification	$7	$18	$11	$4	$10	$6	$1	$3	$2
Ecosystems Toxicity	<$1	<$1	<$1	<$1	<$1	<$1	<$1	<$1	<$1
Ozone Depletion	<$1	<$1	<$1	<$1	<$1	<$1	<$1	<$1	<$1
Smog Formation	$5	$11	$6	$5	$11	$6	$5	$9	$5
Total	$1,005	$1,222	$217	$1,126	$1,361	$235	$1,032	$1,247	$215

The final important conclusion from examining recycling's environmental benefits and costs is that upstream costs account for a major portion of total environmental costs for both recycling and disposal. For example, in 2015, the distribution of recycling's life cycle environmental costs was:

- 79% from upstream recycled-content production
- 14% from contaminants management, including the upstream portion of their garbage disposal life cycle
- 5% from MRF processing
- 1% from hauling processed recyclables from the MRF to recycled-content product manufacturers
- 1% for collection from single-family and multifamily households

For avoided garbage disposal, the distribution of environmental costs in 2015 was:

- 97% for avoided upstream manufacturing of virgin-content materials
- 2% for avoided landfilling
- Much less than 1% for avoided garbage collection and avoided hauling of garbage to Columbia Ridge landfill

For net environmental costs of recycling, the upstream recycled-content versus virgin-content manufacturing mainly determines the net footprint for recycling. At the same time, collection and hauling of recyclables and garbage have significant local environmental impacts. Processing recycling by sorting them into individual material types in the material recovery facility also affects the local environment, especially for workers in the facility itself. However, recycling solid waste materials provides its greatest benefits to regional, national, and global environments by avoiding the extraction and refining of virgin resources and use of those resources for virgin-content product and material manufacturing.

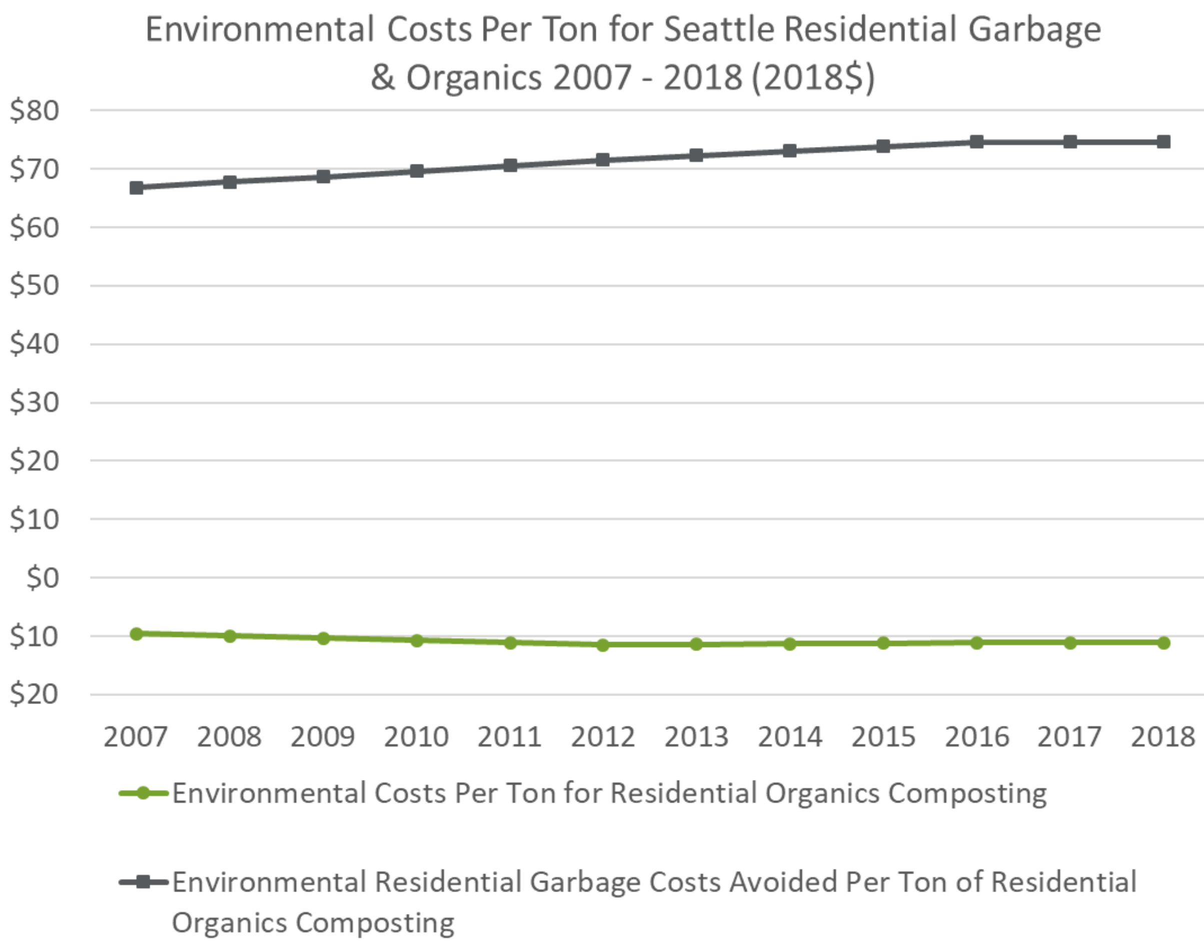
In addition, environmental impacts of recycled-content manufacturing are most often a fraction of the environmental impacts of virgin-content production, which disrupt ecosystems to obtain resources. Examining residential recycling in Seattle in 2015, for example, shows that upstream recycled-content product and material manufacturing environmental costs were just 16% of what environmental costs would have been if the same quantities of products and materials were manufactured from virgin ecosystem resources.

Composting

Figure F.8 displays residential garbage and household food and yard waste life cycle environmental costs per ton in 2018$ for 2007–2018. Avoided residential garbage disposal environmental costs have been higher than household food and yard waste environmental costs throughout the past 12 years. Collecting and composting food and yard waste had a beneficial environmental impact of $11 per ton without even taking avoided garbage disposal impacts into account. This is due to soil carbon storage and above-ground biomass enhancement benefits from applying compost to garden and agricultural soils. The monetary value of these climate benefits from composting exceeds the monetary costs for all nine environmental damage categories from impacts of collection and composting operations themselves. The avoidance of synthetic fertilizer and pesticides production, which is the equivalent of virgin-content production in the case of compost, as well as avoidance of garbage collection and landfill emissions, provide additional benefits for composting averaging $71 per ton, as shown by the top line on Figure F.8.

Environmental damage costs savings from food and yard waste composting averaged $82 (2018$) per ton during 2007–2018. Household food and yard waste composting avoided the greater environmental cost of garbage disposal, saving a net $78.1 million in environmental damage costs. If this global public health and environmental benefit were all paid to Seattle subscribers for curbside food and yard waste collection, it would reduce their monthly collection bills by $4 (2018$) for 12 years.

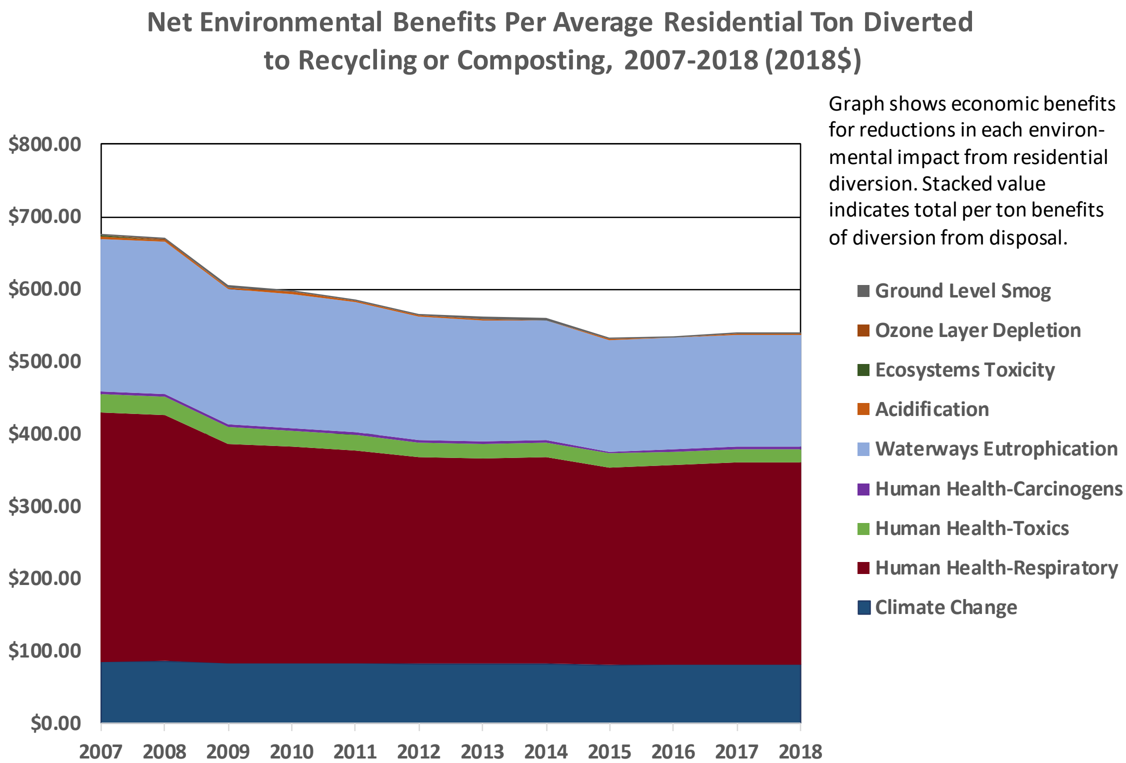
Figure F.8 Residential Food and Yard Waste (Organics) Environmental Cost and Avoided Garbage Cost Per Ton 2007–2018 (2018$)



Environmental Cost Savings Details

Figure F.9 shows weighted average net environmental cost savings per ton diverted by residential recycling and food and yard waste composting for each of nine environmental impacts evaluated by the MEBCalc tool over the 12-year period 2007 through 2018. Benefits are stacked so that the line across the top of the stack measures benefits in total from all nine.

Figure F.9 Residential Diversion Program Environmental Cost Savings Per Ton Details 2007–2018 (2018$)



Benefits through reductions in potential human health respiratory mortality and morbidity, waterways eutrophication, and climate change predominate. Smaller benefits result from reductions in human health toxicity and from even smaller human health carcinogenic impact reductions. Emissions reductions per ton of recycling and of food and yard waste for the remaining four environmental impacts (1) acid rain, (2) ecosystems toxicity, (3) ozone layer depletion, and (4) ground level smog formation are relatively insubstantial.

The net environmental benefits of recycling are substantially larger on a per ton basis than are food and yard waste composting's benefits. For food and yard waste, the big three benefits, in order, are from (1) climate change, (2) human health respiratory, and (3) human health toxicity reductions. Climate change accounts for up to 75% of total food and yard waste composting's benefits compared with about 10% for recycling. On the other hand, human respiratory impact reductions account for over 50% of recycling's benefits versus about 15% for food and yard waste. Furthermore, food and yard waste diversion has net environmental costs rather than benefits for waterways eutrophication due to ammonia, nitrogen oxides, and phosphates emissions from composting operations. These eutrophying damage costs are relatively small compared with the environmental benefits of composting for the other eight impacts. In the graphs shown for Figure F.9 and Figure F.10, the eutrophication damage costs from food and yard waste composting are overwhelmed by the eutrophication benefits from recycling.

The decline in total net environmental benefits per ton during 2007 through 2018 shown on the graph in Figure F.9 occurred due to:

- Increased contamination in collected recyclables
- The closing of the Seattle Post Intelligencer newspaper
- Relative increases in the amount of glass recycling, and
- Much faster growth of food and yard waste compared to recyclables diversion over the period (combined with the lower net benefits from food and yard waste versus recyclables diversion)

Growth in tonnage diverted offset most of the decline in per ton environmental benefits during the 2007 through 2018 period, as shown by total environmental benefits from residential recycling and food and yard waste diversion on the graph in Figure F.10.

Figure F.10 Residential Diversion Program Total Environmental Cost Savings Details 2007–2018 (2018$)

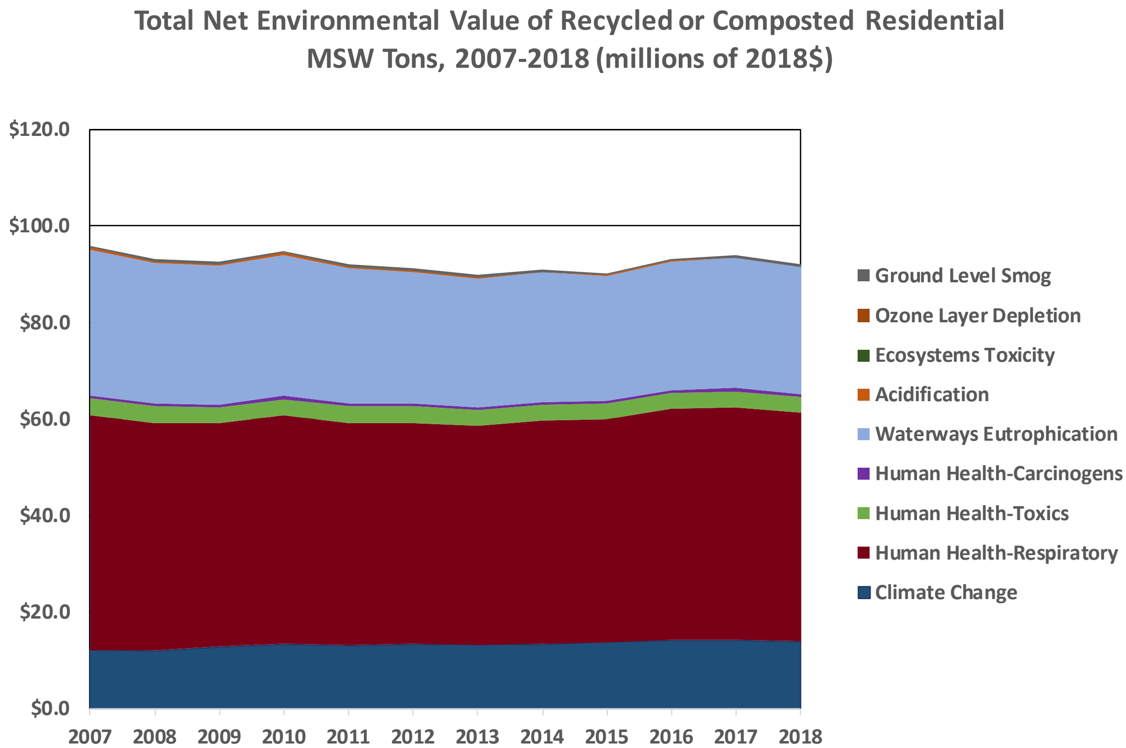


Chart note: MSW in this chart refers to solid waste.

Social Benefits and Costs of Residential Recycling and Food and Yard Waste Composting

This report does not quantitatively evaluate the social costs of the economics of recycling. The comparative impacts of diversion versus disposal on social inequities among Seattle households has not been well-researched, although there are certainly inequities among Seattle households. However, whether diversion programs, collection practices, and processing facilities have greater or lesser effects on such inequities than disposal programs, collection practices, and garbage handling facilities has not been studied.

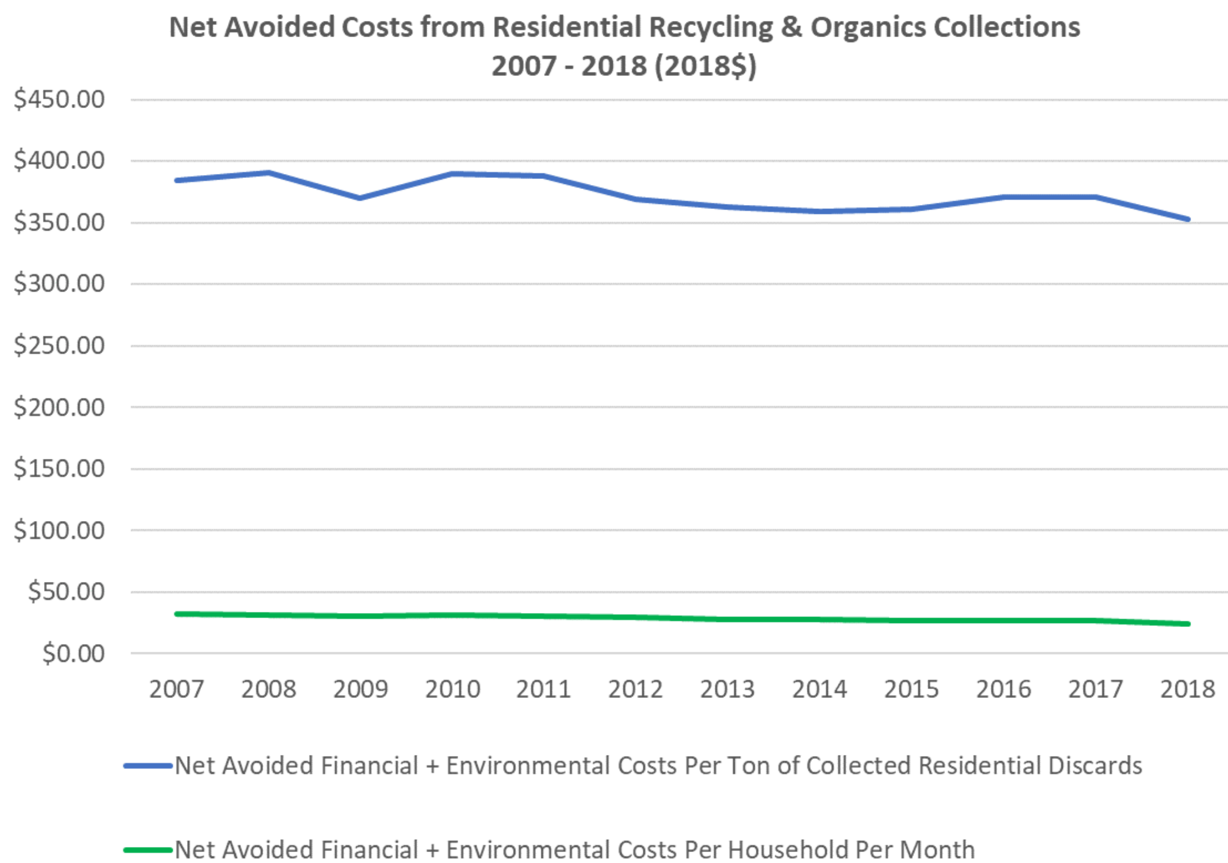
Transfer station operations create social impacts, such as collection truck and self-haul vehicle traffic. However, whether these negative effects are more associated with handling garbage versus handling food and yard waste and recyclables is unknown. Seattle's transfer stations handle substantial quantities of both garbage and diverted food and yard waste, as well as some quantities of diverted recyclables, which suggest that there may not be too much difference in between diversion and disposal in terms of social impacts from the transfer stations.

Food and yard waste composting and garbage landfilling facilities are located outside of Seattle and do not cause disparate social impacts on Seattle residents. The environmental life cycle assessment of diversion versus disposal detailed in this report addresses the potential global public health impacts from composting and landfilling. Seattle's contracted composting and garbage landfilling facilities may have additional impacts on regional or global social inequities. Such potential effects are not analyzed here.

Total Financial and Environmental Cost Savings of Recycling and Food and Yard Waste Collection

Figure F.11 depicts net financial and environmental cost savings per household per month and per ton of collected residential discards (garbage + recycling + food and yard waste) through SPU residential recycling and food and yard waste collection programs for 2007–2018. The chart demonstrates the success of SPU programs at diverting residential discards from disposal to financially less costly and environmentally preferable uses, either as recovered materials for manufacturing recycled-content products or as soil amendments composted from household food and yard waste. This diversion saved $1.2 billion (2018$) over the 12 years from 2007 through 2018. Those savings averaged $372 per ton of residential wastes generated for collection and $29 per month per household.

Figure F.11 Residential Diversion Program Financial Plus Environmental Cost Savings 2007–2018 (2018$)



Increasing contaminants (especially in the recycling discards stream), increases in composting fees, and an increasing proportion of glass and decreasing proportion of newspapers in recycled materials are the major causes of the downtrends in both per household and per ton net avoided cost savings. Despite these challenges, and the challenge of low recycling market prices at the time of this writing (2018), Seattle's recycling and composting diversion programs continue to pay generous dividends to SPU solid waste collection rate payers, global public health, and the global environment. In 2018, these programs avoided financial and environmental garbage disposal costs of $353 per ton of residential discards generated for collection, which amounts to avoided costs of $24 per household per month.