Value Lost at the Landfill:

Metropolitan/Davidson County Region

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Executive Summary

This study estimates an appropriate disposal user fee of recoverable material for the Metro Government of Nashville and Davidson County (i.e., Metro). Landfilling recoverable material forfeits significant economic, human health, and environmental benefits recyclable material could otherwise provide taxpayers. Therefore, the authors assess the opportunity cost of landfilling such material by appraising the economic benefits and pollution damage avoided, representing human heath and environmental benefits, each material could provide. We also offer potential market values for plastic, paper, and metal and compare potential jobs created by material diversion to potential jobs created by material disposal. In conclusion, we reference the established opportunity costs to propose a specific user fee we believe will encourage recycling and successfully capture its benefits.

Introduction

Studies nationwide argue increasing diversion of recoverable material from landfills will yield significant economic opportunities. For instance, in Maryland, Platt, Bell, and Harsh (2013) find composting one million tons of organic material would create 1,360 jobs while landfilling the same material would yield a mere 220 jobs (Platt et al., 2013; Tennessee Department of Environment and Conservation [TDEC], 2015). Similarly, the Southeast Development Recycling Council (2013) claims diverting an additional 10,000 tons of single-stream recyclable material in Tennessee would create the need for an additional 68 jobs statewide (Southeast Development Recycling Council [SERDC], 2013). In South Carolina, Hefner and Blackwell (2014) claim the recycling industry has an outstanding $13 billion annual impact on the economy. With all of this in mind, it appears Tennessee, as a state, is not fully embracing the prospect for significant economic improvement. In fact, 36.4 percent of the material landfilled in Tennessee is recyclable, representing an economic value of over $180 million literally being thrown away (Coalition to Advance Recovery in Tennessee, 2015).

Boosting recycling rates might not only help to stabilize the local economy in the Metropolitan Government of Nashville and Davidson County (Metro) region, but it could also help state and municipal solid waste departments meet objectives at the same time. Under the Solid Waste Management Act of 1991, each solid waste planning region in Tennessee must divert 25 percent of municipal solid waste (MSW) from Class I landfills annually (TDEC, 2015). Achieving increased recycling rates would clearly aid Metro in meeting this goal. It would also assist TDEC in meeting several objectives delineated in the Tennessee Solid Waste and Materials Management Plan.

With all of the apparent advantages that an amplified recycling effort could offer to the Metro region, one would expect to see a highly visible effort to stimulate public participation. However, extended public services and public outreach efforts require money and, unfortunately, solid waste authorities have not been able to consider all costs associated with landfilling recyclable material until recently. Fortunately, on April 26, 2016, Governor William Haslam signed Tennessee Senate Bill 1049/House Bill 0857, effectively adding a new subsection to Tennessee Code Annotated 68-211-835, which authorizes metropolitan forms of government in Tennessee with a population of 500,000 or more to impose a fee on solid waste collection, processing, and disposal. Revenue earned from the fee can be used to recover, among other expenses, "the costs borne by a county as a consequence of disposal" (TDEC, 2016). This new amendment is significant as it effectively permits Metro to consider all expenses associated with landfilling recoverable material—not just the operational costs (e.g., collection, transport, and disposal) already reflected in existing fees.

In this report, the authors plan to examine the less overt opportunity costs associated with disposing of recyclable material in Class I and Class III/IV landfills. We hypothesize that landfilling such material relinquishes significant economic opportunities and environmental and health benefits from decreased pollution. As such, the objective of this report is to determine an adequate figure, which covers these postulated costs, for the prospective fee that Metro Public Works is now authorized to impose as a consequence of the above-referenced amendment to T.C.A. 68-211-835.

We understand the inevitable limitations to determining an accurate figure given certain parameters. With this in mind, we intend to provide comprehensive insight into the worth of recycling by analyzing recoverable material in three separate manners. We will provide the potential market value for paper, plastics, and metals. We will also provide the number of jobs that could have been created if each material had been recycled rather than disposed. Finally, we will appraise the overall opportunity cost of landfilling recoverable material by analyzing the economic impact, public health, and environmental benefits that each could have provided. We recommend the Metro Public Works Committee consider the opportunity cost analyses when reformulating an appropriate user fee on disposal.

Limitations

Our data sources represent snapshots in space and time. Market prices vary over time and economic performance of industries varies by region; therefore, the economic impact of recycling-supported industries should be expected to vary as well. More contemporary data focused specifically on the Metro region would give a more precise picture of the economic potential of recycling.

The studies utilized in this report do not distinguish very finely between materials, such as between PET and HDPE plastic or between different types of paper. Therefore, our figures represent averages across broad categories of material. We attempt to compensate for such limitations in calculating the total opportunity cost of landfilling recoverable material by using conservative estimates where possible.

We relax our assumptions for job creation and potential material value analyses. Such figures serve as supplementary data and are not incorporated into the final opportunity cost calculations. Potential job creation figures are calculated without consideration for existing reprocessing capacity and/or remanufacturing presence specific to the Metro region. The potential material value analysis assumes end markets for plastic exist in the region when secondary processors in neighboring states often profit from plastic material recovery (SERDC, 2013).

Methods

Waste Composition

To evaluate the recyclable material being landfilled, it is necessary to identify the composition of Metro's waste stream. In this study, we analyze two separate waste streams: municipal solid waste (MSW) and construction & demolition (C&D).

Municipal solid waste.

To determine general material composition, we apply waste composition percentages established by Painter and Watson (2008), which characterize Tennessee's Class I landfills, to the 757,332 tons of MSW reportedly landfilled in 2015 (Hand, 2016). After determining the general makeup of Metro's MSW waste stream, we apply subcategory values provided by Painter and Watson (2008) to determine the extent of recyclable material Metro landfilled in 2015, except where otherwise noted. We exclude wood from further analysis based negligible presence (1.34 percent).

Construction and demolition.

We apply the C&D waste characterization percentages obtained in a study by Painter and Smith-Walters (2007) to the weight of C&D debris landfilled as reported by Hand (2016), except where otherwise noted.

Total Economic Impact

Many studies have valued recycling by gauging direct, indirect, and induced impacts to the economy (R.W. Beck, Inc., 2001; Hefner & Blackwell, 2006; DSM Environmental Services, Inc., & MidAtlantic Solid Waste Consultants, 2009). Incorporating direct, indirect, and induced impacts into an economic impact analysis is a particularly effective way of assessing true worth of recoverable materials by providing more complete insight into the material's actual worth and avoiding a skewed analysis. We utilize figures from two studies using such an economic impact approach to assess the economic value of recycling materials Metro landfilled in 2015. The first is a study from DSM Environmental Services, Inc., and MidAtlantic Solid Waste Consultants (2009) analyzing the impacts recycling has on markets in Delaware, Maine, Massachusetts, New York, and Pennsylvania. The second is a study from DSM Environmental Services, Inc. (2010) analyzing markets in Illinois.

Economic benefits.

We apply values from the above-referenced studies to estimate impacts each recycled commodity has on the largest industry it supports. Some recycled commodities can support multiple industries; for example, recycled steel supports steel mills and iron and steel foundries. However, we count only one industry per commodity because counting multiple industries would likely double-count benefits (DSM Environmental Services, Inc. & MidAtlantic Solid Waste Consultants, 2009).

To obtain the economic impact values for each material we divide the total impact of the recycling-supported industry, including direct, indirect, and induced impacts as suggested by

Weisbrod and Weisbrod (1997), by the number of tons of recovered material it processes. The best measure of impact is the value added by the industry (DSM Environmental Services, Inc., 2010), but since our main data sources do not supply this information, we use payroll as a proxy. Please note payroll is likely to be a conservative estimate of impact, since SERDC (2013), which does give the value added by plastic reclaimers, aluminum smelters, and paper mills, gives higher values than used in this study. When data from both sources is available, we use the smaller value to make a conservative estimate.

Avoided pollution damage.

Pollution from solid waste can cause significant damage to the environment and human health. Data from Sound Resource Management (2009), however, indicate that recycling and/or composting can reduce such damage to human health and ecosystems. Therefore, we can assess the environmental value of recycling by monetizing the costs of these damages, which are prevented by diverting recoverable waste.

Avoided human health and ecosystem damages.

For many commodities, Sound Resource Management (2009) indicates the equivalent of the number of tons of the pollutants saved per ton of material recycled. Damages to human health are grouped together and expressed as the equivalent of toluene emissions, and ecosystem damages are lumped together and expressed as the equivalent of 2,4-D emissions. We first identify the toluene and 2, 4-D emissions equivalents that the recycling of each material in our study would prevent by using figures provided by Sound Resource Management (2009). We then can assess the monetary cost of these emissions using a study from Morris (2013), which estimates that toluene causes $118 of damage for every ton of emission, and 2,4-D causes $3280 per ton of emission, in order to gauge the extent of health and ecosystem benefits recycling this material would provide.

Data from the U.S. Environmental Protection Agency (2015b) Waste Reduction Model (WARM) indicate for most materials recycling or composting saves energy. Therefore, in cases where we lack pollution data specific to a commodity, we use energy savings as a proxy for the estimated environmental benefits of recycling by monetizing the cost of energy consumption avoided as a result of recycling using values provided by the National Research Council (2010).

Potential Market Value

We apply Recycle Markets Limited (RML) commodity pricing—as of August 1, 2016—to all possible materials within the plastic, paper, and metal categories determined in the MSW waste composition analysis ("Commodity pricing," 2016). We take special precaution to avoid overstating market values.

Job Creation

In this analysis, we analyze how recycling the recoverable material landfilled in 2015 might stimulate job creation compared to the job creation resulting from disposing of such material. We establish potential job creation figures for both material diversion and material disposal by utilizing multipliers provided by Goldstein and Electris (2011). We simply apply weights determined using the waste characterization percentages provided by Painter and Watson (2008) and data from the EPA (2015a), where noted, to the multipliers for this analysis. We also incorporate the C&D wood, cardboard, and steel categories into our analysis; however, we lack data necessary to evaluate potential job creation for other materials in the C&D waste stream.

Results and Discussion

Municipal Solid Waste

The MSW waste characterization results shown in Table A1 reveal considerable variation of recoverable material being landfilled. The tonnage of recyclable material landfilled ranges from wood at approximately 10,000 tons per year to paper at approximately 243,000 tons per year. Tables A2 through A7 provide detailed characterizations for each MSW material. Paper, plastic, and organic waste makeup 70 percent of the MSW waste stream.

The potential market value analyses for plastic, paper, and metal reveal considerable findings. The landfilled plastic material analyzed has $9.5 million in potential market value, which averages to $200 per ton. Results are shown in Table 3. The landfilled paper analyzed represents $17 million in potential market value, with an average value of $109 per ton. Table 4 displays the potential market value of paper. Finally, the landfilled metal analyzed represents $10 million in potential market value, with an average value of $713 per ton. Details are shown in Table 5.

Table 1 displays the economic impact values, pollution damage avoided, and job creation figures for MSW side-by-side. The economic impact value for each material ranges from $35 per ton (organic waste) to $539 per ton (nonferrous metals). Benefits from pollution damage avoided range from $6 per ton (cotton textiles) to $1,196 per ton (aluminum). Potential job creation for material diversion ranges from 94 jobs to 1,297 jobs and exceeds every material category than the potential job creation from disposal, which ranges from 2 to 129 jobs.

Table 6 shows the total weighted average opportunity cost of landfilling one ton of MSW is $194.68. From the table, we can see that paper, which makes up the largest portion of the waste stream, has the highest weighted value, $113.92 per ton, of all materials in this analysis. Aluminum, which represents only one percent of disposed MSW, has the second highest weighted material value at $18.39. Polyethylene terephthalate (PET), representing only 2.17 percent of MSW waste and yielding a weighted value of $17.77, and high-density polyethylene (HDPE), representing only 2.90 percent of MSW waste and yielding a weighted value of $12, also stand out in this analysis.

Table 1 displays a summary of results for MSW.

Construction & Demolition

The C&D waste composition shown in Table A8 also reveals variation in the recyclable material being landfilled. C&D material ranges from asphalt being landfilled at the rate of 84 tons per year to wood being landfilled at the rate of 74,000 tons per year. Wood, concrete, drywall, roofing, and metal represent 85 percent of the entire C&D waste stream.

Table 2 displays the economic impact values, pollution damage avoided, and job creation figures for C&D debris side-by-side. The economic impact values range from $30 per ton (asphalt roofing and concrete) to $353 per ton (steel). Pollution damage avoided ranges from $1 per ton (cement concrete) to $48 per ton (cardboard). Potential job creation for diversion ranges from 39 jobs to 683 jobs and exceeds every material category than potential job creation from disposal, which ranges from 4 to 56 jobs.

Table 7 shows the total opportunity cost ton of C&D is $16.70 per ton, and Table 2 displays a summary of results for C&D.

The Appendices provide further detail methodological explanations for both MSW and C&D analyses.

Summary of Results for MSW

Table 1 Municipal Solid Waste Summary of Results					
Material	**Percentage of Waste Stream** (%)	**Economic Impact** (per 1,000 tons)	**Avoided Pollution** (per 1,000 tons)	**Job Creation - Material Diversion** (per 1,000 tons)	**Job Creation - Material Disposal** (per 1,000 tons)
Steel *(Ferrous Metals)*	3.66	$353,000	$33,000	770.60	21.07
Aluminum	1.06	$539,000	$1,196,000	331.56	6.10
Other Nonferrous	0.39	$539,000	-	121.87	2.24
Paper	32.09	$307,000	$48,000	1297.78	129.77
PET	2.17	$241,000	$578,000	558.32	12.49
HDPE	2.90	$241,000	$173,000	746.15	16.69
Other Plastic	12.01	-	$16,000	-	-
Glass	5.06	$0	$50,000	648.81	26.13

Cotton Textiles	1.20	-	$6,000	127.82	10.78
Food Scraps	15.28	$35,000	$20,000	251.11	87.95
Yard Trimmings	6.38	$35,000	$20,000	104.85	36.72
Wood	1.34	-	-	94.07	7.71
Other	16.47	-	-	-	-

* Analysis assumes capacity and industry presence for reprocessing, manufacturing, reuse/remanufacturing, and incineration in the Metro region necessary for job creation.
** Based on EPA's (2015a) proportion of total plastics by resin.
1. Steel represents the combination of the tin/steel cans and other ferrous metals categories from Painter and Watson (2008) analysis seen in Table A5.
2. About 35 percent of textiles are cotton (Textile Exchange, 2009).

Summary of Results for C&D

Table 2 Construction and Demolition Summary of Results					
Material	**Percentage of Waste Stream** (%)	**Economic Impact** (per 1,000 tons)	**Pollution Damage Avoided** (per 1,000 tons)	**Job Creation - Material Diversion** (per 1,000 tons)	**Job Creation - Material Disposal** (per 1,000 tons)
Wood	26.4	-	-	683.53	3.80
Cement Concrete	18.24	-	$1,000	-	-
Drywall	14.03	-	$4,000	-	-
Roofing *(Asphalt shingles)*	11.85	$30,000	$4,000	-	-
Other Metals	8.92	-	-	-	-

Asphalt Concrete	4.90	$30,000	$2,000	-	-
Cardboard	1.79	$307,000	$48,000	39.15	3.80
Steel	1	$353,000	$33,000	77.62	56.04
Plastics	0.29	-	$16,000	-	-
Other	12.58	-	-	-	-

* Analysis assumes capacity and industry presence for processing, manufacturing, reuse/remanufacturing, and incineration in the Metro region necessary for job creation.
1. For analysis, concrete is broken down into asphalt and concrete cement, using EPA (2015a) values.
2. Values derived using "Drywall and Plaster" from EPA (2015a).
3. For the economic calculation, asphalt shingles and asphalt pavement are combined and calculated using the Swenson (2013) study.
4. We lack data necessary to determine proportions of aluminum and copper present to evaluate these materials.
5. Assigned paper values from MSW analysis
6. Assuming steel proportions in C&D debris provided by EPA (2015a)

Potential Market Value Results

Table 3
Plastics
Potential Market Value

Subcategory	Percentage of Plastics Category (%)	Disposed (TPY)	Southeast Regional Commodity Price $/lb	Potential Market Value❖
PETE Containers	12.7	15,522.28	0.11	$3,337,290.89
HDPE Containers ‡	2.5	3,269.20	0.16	$1,046,142.86
#3 - #7 Containers ‡	10.5	13,546.61	0.02	$474,131.36
Trash Bags	6.5	8,407.90	-	-

Grocery Bags	3.7	4,786.04	-	-
Commercial Film	11.4	14,746.17	0.16	$4,571,312.40
Other Film	3.8	4,915.39	-	-
Durable Items	9.1	11,771.06	-	-
Composite Plastic	20.8	26,905.29	-	-
Diapers	19.7	25,482.41	-	-
TOTAL		**129,352.36**		**$9,428,877.51**

❖Numbers may not add due to rounding
‡ HDPE proportion of plastics determined using data from EPA (2015a).
1.Values represent present commodity values as of August 1, 2016, taken from Recycling Markets Index ("Commodity pricing," 2016).
2.Assigned to A Grade Film category for analysis

Table 4
Paper
Potential Market Value

Subcategory	Percentage of Paper Category (%)	Disposed (TPY)	Southeast Regional Commodity Price $/lb	Potential Market Value❖
Corrugated Cardboard	30.0	72,908.39	0.05	$7,290,839.00
Paper Bags/ Kraft	3.9	9,478.09	-	-
Newspaper	10.4	25,274.91	0.02	$1,200,558.23
White Ledger	11.2	27,219.13	0.10	$5,307,730.35

Color Ledger	2.8	6,804.78	0.07	$1,003,705.05
Magazines	9.9	24,059.77	0.05	$2,225,528.73
Phone Books, etc.	3.0	7,290.84	-	-
Other Paper	2.9	7,047.81	-	-
Composite Paper	25.8	62,944.24	-	-
TOTAL		**243,027.96**		**$17,028,361.35**

❖ Numbers may not add due to rounding
1. Values represent present commodity values as of August 1, 2016, taken from Recycling Markets Index ("Commodity pricing," 2016).
2. Assigned to the "Sorted Office Paper" category for analysis

Table 5
Metals
Potential Market Value

Subcategory	**Percentage of Metal Category (%)**	**Disposed (TPY)**	**Southeast Regional Commodity Price $/lb**	**Potential Market Value❖**
Tin/Steel Cans	13.8	5,988.53	0.04	$523,996.32
Other Ferrous	50.1	21,740.97	-	-
Aluminum	18.5	8,028.10	0.59	$9,473,159.06
Other Non-Ferrous	6.8	2,950.87	-	-
Composite Metal	10.8	4,686.68	-	-
TOTAL		**43,395.14**		$9,997,155.38❖

❖ Numbers may not add due to rounding
1. Values represent present commodity values as of August 1, 2016, taken from Recycling Markets Index ("Commodity pricing," 2016).

Total Opportunity Cost Results-MSW

Table 6
Opportunity Cost of Landfilling Recoverable MSW Material

Material	Percentage of Waste Stream (%)	Economic Impact per ton	Avoided Pollution Damage per ton	Material Weighted Value❖
Steel *(Ferrous Metals)*	3.66	$353	$33	$14.12
Aluminum	1.06	$539	$1,196	$18.39
Other Nonferrous	0.39	$539	-	$2.10
Paper	32.09	$307	$48	$113.92
PET	2.17	$241	$578	$17.77
HDPE	2.90	$241	$173	$12.00
Other Plastic	12.01	-	$16	$1.87
Glass	5.06	$0	$50	$2.53
Cotton Textiles	1.20	-	$6	$0.07
Food Scraps	15.28	$35	$20	$8.40
Yard Trimmings	6.38	$35	$20	$3.51
Wood	1.34	-	-	-
Other	16.47	-	-	-
Total Cost per ton				**$194.68**

❖ Numbers may not add due to rounding
* Based on EPA's (2015a) proportion of total plastics by resin.
1. Steel represents the combination of the tin/steel cans and other ferrous metals categories from Painter and Watson (2008) analysis seen in Table A5
2. About 35 percent of textiles are cotton (Textile Exchange, 2009).

Total Opportunity Cost- C&D

Table 7 Opportunity Cost of Landfilling Recoverable C&D Material				
Material	**Percentage of Waste Stream (%)**	**Economic Impact per ton**	**Avoided Pollution per ton**	**Weighted Value**
Wood	26.4	-	-	-
Asphalt Concrete	4.90	$30	$2	$1.57
Cement Concrete	18.24	-	$1	$0.18
Drywall	14.03	-	$4	$0.56
Roofing *(Asphalt shingles)*	11.85	$30	$4	$4.03
Steel	1	$353	$33	$3.86
Other Metals	8.92	-	-	-
Plastics	0.29	-	$50	$0.15
Cardboard	1.79	$307	$48	$6.35
Other	12.58	-	-	-
Total Cost per ton				$16.70

** For analysis, concrete is broken down into asphalt and concrete cement, using EPA (2015a) values.
1. Values derived using "Drywall and Plaster" from EPA (2015a)
2. Assuming steel composition of C&D provided by EPA (2015a)
3. We lack data necessary to determine proportions of aluminum and copper present to evaluate these materials.
4. Assigned paper values from MSW analysis

Conclusion and Recommendations

This report reveals Metro is currently landfilling recoverable material with an opportunity cost of approximately $195 per ton. Much of the material represents potential feedstock, which local facilities can reprocess and local industries can remanufacture. The Metro region has industrial capacity for certain materials like paper (WestRock) and aluminum (Siskin Steel), which results in a greater probability of realizing most of the materials' benefits. However, the presence of feedstock does not necessarily guarantee that reprocessing or remanufacturing industries will appear within Davidson County to process it. For instance, Tennessee must currently export recovered glass cullet and plastic to neighboring states for secondary processing, increasing the likelihood other states reap the economic gains from recovered material. While we do not make such assumptions in our opportunity cost calculations, SERDC (2013) argues that increasing the local supply may attract new plants to Tennessee. The following two recommendations cover potential methods for increasing material diversion and feedstock to expand opportunities for existing plants and attract new industries to the Metro region.

Recommendations

Recommendation 1: Metro should consider a landfill user fee

Since disposal of solid waste carries costs, as outlined above, Metro should consider a fee on waste disposal that will capture such costs. Our analysis has suggested appropriate fees by material. If it is not feasible to assess fees by material, then Metro should assess a fee of $195 per ton to cover the local economic and environmental losses that result from disposal.

The new fee schedule is expected to lead to high rates of material recovery. Therefore, the fee should go into effect 18 to 24 months after its passage into law, to allow the waste handling industry sufficient time to construct the infrastructure for additional recovery. We expect that in response to the fee and with more accurate measurement of Davidson County's waste stream, adjustment to the fee schedule will be appropriate. However, this must be balanced against the industry's need for predictive certainty in pricing.

To what extent will a landfill fee based on opportunity costs of disposal actually encourage recycling? Bartelings, van Beukering, Kuik, Linderhof, and Oosterhuis (2005) find that most European countries have landfill fees at $60 per on or below, well below our estimated opportunity costs of disposal, and still see high recycling rates as a result. Fischer, Lehner, and McKinnon (2012) survey European countries in 2012 and find that a landfill tax of about $100 per ton may be the level at which most landfilling ceases. The Netherlands has used landfill fees effectively to divert material away from landfills (Bartelings et al., 2005), and a fee of about $80 per ton was sufficient to stimulate diversion.

Tipping feels are generally lower in the United States. CalRecycle (2015) reviews the 50 states and finds that, on average, an increase in the tipping fee of $10 per ton results in a 7 percent decrease in the landfill rate. Extrapolating, if Metro assesses a user fee of $100 per ton on top of the $40 per ton tipping fees in Tennessee, then landfilling should mostly cease.

Recommendation 2: Metro should consider public investment

Metro could finance upgrades to recycling facilities. An effective system could collect wet-dry separated waste and transport it to a state of the art material recovery facility (MRF), which sorts the inorganic (dry) for reprocessing and sends the organic (wet) for anaerobic digestion. Public financing of recycling recognizes that recycled material is a merit good (Economics Online, n.d.), in that its value to Davidson County taxpayers exceeds its market value.

SERDC (2013) estimates that the capital costs for building the recycling infrastructure around an advanced MRF in Tennessee are estimated at $28 per ton of waste for collection, $50 for carts, and $40 for the MRF, which totals to $118 per ton. Operating costs for a MRF are less clear, but Kessler Consulting, Inc. (2009) estimates them at about $60 per ton for a MRF that processes over 218 tons per day, a level that an advanced recycling program in Davidson County should easily surpass. Older study include Roy F. Weston, Inc. (1992), which gives an operating cost of $85 per ton, and Dubanowitz (2000), which gives a total cost (capital and operating) of $175 per ton.

Increasing the waste disposal fee sufficiently should quickly expand feedstock of recyclable material and, in turn, benefit public and/or private reprocessing operations in the Metro region. About two-thirds of MRFs in the United States are privately owned and operated and as with remanufacturing industries, the most important step in attracting such facilities is for Metro to insure a reliable supply of feedstock (Kessler Consulting, Inc., 2009). However, the results of this study indicate if Metro invests in the discussed upgrades for publicly owned MRFs, the amount of money required for such upgrades should fall well below the estimated economic gain of recycling.

Appendix A

Waste Composition Data

Municipal solid waste.

Table A1

Metro-Davidson County Municipal Solid Waste (MSW) 2005 Waste Characterization Values Applied to 2015 Class I Landfill Disposal Weight

Material	Percentage of Waste Stream (%)	Disposed (TPY)
Paper	32.09	243,027.95
Plastics	17.08	129,352.36
Food Scraps	15.28	115,720.38
Yard Trimmings	6.38	48,317.80
Metals	5.73	43,395.14
Rubber, Leather & Textiles	5.35	40,517.28
Glass	5.06	38,321.02
Wood	1.34	10,148.25
Other	11.70	88,607.88
Total		**757,408.07**

1. Percentages of waste stream based on 2005 waste disposal collected from Bi-County Landfill and Cedar Ridge Landfill
2. Disposed weight taken from Metro's 2015 Annual Solid Waste Progress Report (Hand, 2016).

Table A2 MSW Paper			
Material	**Subcategory**	**Percentage of Paper Category (%)**	**Disposed (TPY) ❖**
Paper	Corrugated Cardboard	30.0	72,908.39
	Composite Paper	25.8	62,701.21
	White Ledger	11.2	27,219.13
	Newspaper	10.4	25,274.91
	Magazines	9.9	24,059.77
	Paper Bags/ Kraft	3.9	9,478.09
	Phone Books, etc.	3.0	7,290.84
	Other Paper	2.9	7,047.81
	Color Ledger	2.8	6,804.78
TOTAL			**243,027.95**

1. Subcategories paper values based on 2005 waste disposal collected from Bi-County Landfill and Cedar Ridge Landfill
❖ Figures may not add in exact amounts due to rounding

Table A3 MSW Plastics			
Material	**Subcategory**	**Percentage of Plastics Category (%)**	**Disposed (TPY)**
Plastic			

	Composite Plastic	20.8	26,905.29
	Diapers	19.7	25,482.41
	#2 - #7 Containers	13.0	16,815.81
	PETE Containers	12.0	15,522.28
	Commercial Film	11.4	14,746.17
	Durable Items	9.1	11,771.06
	Trash Bags	6.5	8,407.90
	Other Film	3.8	4,915.39
	Grocery Bags	3.7	4,786.04
TOTAL			**129,352.36**

Table A4: MSW Organics *(Food Scraps & Yard Trimmings)*			
Material	**Subcategory**	**Percentage of Organics Category (%)**	**Disposed (TPY)❖**
Organics			
	Food Scraps	70.6	115,773.83
	Leaves and Grass	20.6	33,868.39

	Prunings and Trimmings	8.8	14,471.73
TOTAL			**164,038.18**

❖ Figures may not add due to rounding.
1. "Leaves and Grass" & "Prunings and Trimmings" are synonymous with "Yard Trimmings" in Table A1

Table A5:
MSW Metals

Material	Subcategory	Percentage of Metal Category (%)	Disposed (TPY)
Metal			
	Tin/Steel Cans	13.8	5,988.53
	Other Ferrous	50.1	21,740.97
	Aluminum	18.5	8,028.10
	Other Non-Ferrous	6.8	2,950.87
	Composite Metal	10.8	4,686.68
TOTAL			**43,395.14**

Table A6
MSW Rubber, Leather & Textiles

Material	Subcategory	Percentage of Category (%)	Disposed (TPY)❖
	Rubber & Leather	33.55	13,593.55
	Textiles	66.44	26,919.68

TOTAL			**40,513.23**

❖ Figures may not add due to rounding.
1. Values derived from EPA (2015a) data.

Table A7 MSW Glass			
Material	**Subcategory**	**Percentage of Glass Category (%)**	**Disposed (TPY)**
Glass			
	Clear Glass	47.0	18,024.51
	Green Glass	11.9	4,543.99
	Brown Glass	30.8	11,814.39
	Composite Glass	10.3	3,938.13
TOTAL			**38,321.02**

Construction and demolition composition.

Table A8

**Metro-Davidson County Construction & Demolition Waste
Characterization Percentages from 2005 Applied to 2015 Class III/IV Landfill Disposal Tonnage**

Material	Percentage of Waste Stream (%)	Disposed (TPY)
Wood	26.4	73,735.46
Concrete	23.14	64,630.25
Drywall	14.03	39,185.93
Roofing	11.85	33,097.17
Metals	9.92	27,706.66
Brick	5.53	15,445.35
Cardboard	1.79	4,999.49
Plastics	0.29	809.97
Asphalt	0.03	83.79
Misc.	7.02	19,606.93

Appendix B

Economic Impact and Avoided Pollution Damage

Table B1
Economic Impact and Avoided Pollution Damage
Municipal Solid Waste

Material	Percentage of Waste Stream (%)	Economic Impact per Ton	Avoided Pollution per Ton
Steel *(Ferrous Metals)*	3.66	$353	$33
Aluminum	1.06	$539	$1,196
Other Nonferrous	0.39	$539	$0
Paper	32.09	$307	$48
PET	2.17	$241	$578
HDPE	2.90	$241	$173
Other Plastic	12.01	$0	$16
Glass	5.06	$0	$50
Cotton Textiles	1.20	$0	$6
Food Scraps	15.28	$35	$20
Yard Trimmings	6.38	$35	$20
Wood	1.34	$0	$0
Other	16.47	$0	$0

* Based on EPA's (2015a) proportion of total plastics by resin.
1. Steel represents the combination of the tin/steel cans and other ferrous metals categories from Painter and Watson (2008) analysis seen in Table A5
2. About 35 percent of textiles are cotton (Textile Exchange, 2009).

Table B2 Economic Impact and Avoided Pollution Damage Construction & Demolition (C&D)			
Material	**Percentage of Waste Stream (%)**	**Economic Impact per ton**	**Avoided Pollution per ton**
Wood	26.4	-	-
Asphalt Concrete	4.90	$30	$2
Cement Concrete	18.24	-	$1
Drywall	14.03	-	$4
Roofing *(Asphalt shingles)*	11.85	$30	$4
Steel	1	$353	$33
Other Metals	8.92	-	-
Plastics	0.29	-	$50
Cardboard	1.79	$307	$48
Other	12.58	-	-

** For analysis, concrete is broken down into asphalt and concrete cement, using EPA (2015a) values.
1. Values derived using "Drywall and Plaster" from EPA (2015a)
2. Assuming steel composition of C&D provided by EPA (2015a)
3. We lack data necessary to determine proportions of aluminum and copper present to evaluate these materials.
4. Assigned paper values from MSW analysis

Economic Impact and Pollution Damage by Material

Steel

We estimate the economic value of recovering ferrous metals by the impact of the steel mills that would be supported by a local supply of feedstock. The figure is taken from DSM

Environmental Services, Inc. (2010). Recycling a ton of ferrous metal saves the equivalent of 239 kilograms (kg) of toluene emissions (Sound Resource Management, 2009), and we lack data on ecosystem toxicity.

Example of standard economic impact calculation:

Steel Mills (DSM 2010):

Annual payroll listed for steel mills in Illinois: $880,592,000

Annual estimated throughput of steel: 2,898,000 tons

Economic impact per ton (2007): $303.86

After CPI adjustment: $352.67

Aluminum

We estimate the economic value of recovering all nonferrous metals, including aluminum, by the impact of nonferrous secondary smelters and refining mills, as given in DSM Environmental Services, Inc. (2010). Recycling a ton of aluminum saves the equivalent of 39.18 kg of 2,4-D and 7624 kg of toluene (Sound Resource Management, 2009).

Example of standard pollution damage calculation:

[7.624 ton of eToluene * $118/ton eToluene] +

[0.03918 tons of 2,4-D * $3,280/ton of 2,4-D] =

$1,028.14 (2007)

After CPI adjustment: $1,193.29 of eToluene and e2,4-D savings per ton of aluminum recycled

Other Nonferrous Metals

Aside from aluminum, nonferrous metals in MSW include copper, tin, zinc, lead, and others. As noted above, we assess the economic impact of all nonferrous metal recycling based on nonferrous secondary smelters and refining mills, as given in DSM Environmental Services, Inc. (2010). We lack data on environmental impacts of recycling.

Paper

We estimate the economic value of paper recycling by the impact of pulp and paper mills, as report in DSM Environmental Services, Inc. and MidAtlantic Solid Waste Consultants (2009). Sound Resource Management (2009) estimates that recycling a ton of mixed paper saves the equivalent of 0.29 kg of 2,4-D and 341 kg of toluene.

Plastics: PET and HDPE

Polyethylene terephthalate (PET) and high-density polyethylene (HDPE) are the most widely recycled plastic resins. For these two resins, we assess the economic impact of recycling on the value of plastic reclaimers, as reported in DSM Environmental Services, Inc. (2010). Plastic product manufacturers produce greater impact per ton of feedstock (DSM Environmental Services, Inc., 2010), but since we are not aware of plastic remanufacturing in Davidson County, we base our estimate on the value of plastic reclaimers instead. Sound Resource Management (2009) estimates that recycling a ton of PET saves the equivalent of 0.35 kg of 2,4-D and 4212 kg of toluene emissions, while the figures for HDPE are 0.08 kg of 2,4-D and 1262 kg of toluene.

Other Plastics

Plastics other than PET and HDPE are not widely recycled, and so we assess their economic value based on conversion into liquid fuel via pyrolysis. A pyrolysis facility might create a significant economic impact, such as the Enerkem plant under construction in Edmonton, Canada (Enerkem, n.d.), but we do not have a sufficiently reliable estimate of the economic impact for this study. We assume the output of pyrolysis displaces heavy fuel and so the estimated environmental value, which excludes climate change impacts from consideration, of these energy savings is $16 per ton of feedstock.

Glass

The authors are not aware of glass product manufacturers operating in Davidson County that use recycled glass. Instead, Tennessee exports recovered cullet to other states for reprocessing (SERDC, 2013). Therefore, the economic value of glass recycling is not captured in Davidson County, and we use assign glass an economic value of 0. Since recovered glass is ultimately recycled, though, we do consider its environmental value. Sound Resource Management (2009) estimates that recycling a ton of glass saves the equivalent of 1.73 kg of 2,4-D and 316 kg of toluene emissions.

Textiles

We do not have a reliable estimate for the economic impact of cotton fiber recycling, and so that figure is not included. Sound Resource Management (2009) estimates that textile recycling saves the equivalent of 1.45 kg of 2,4-D per ton of recycled material, while we have no figure for reduction of human health impacts.

Food Scraps and Yard Trimmings

The economic value of both food and yard waste composting is based on the impact of composters and organics producers, as given in DSM Environmental Services, Inc. and MidAtlantic Solid Waste Consultants (2009). As noted above, paper plates, cups, towels, and napkins are classified as yard waste for the purposes of this study. Sound Resource Management (2009) estimates the environmental benefits of composting to be the equivalent of 2.02 kg of 2,4-D and 165 kg of toluene emissions.

Wood

There are several ways in which wood waste can be recovered, including lumber reuse, recycling into paper pulp, gasification, combustion, or mulching. The environmental benefits of the first two methods are outlined in Morris (2008). However, for this analysis we assume that recovered wood is mulched, since mulching is the method used by the Bordeaux mulching facility, which processes most publicly recycled wood (Hand, 2016). However, we do not have a reliable estimate of economic value of mulching, so none is used. Sound Resource Management (2009) gives environmental benefits to wood waste recycling, but not mulching in particular.

Other MSW

We attribute no economic or environmental value to recovering the remainder of the waste stream.

Construction and Demolition

Based on an analysis by Swenson (2013) in the Houston-Galveston area, we estimate an economic benefit of $30 per ton for recovering asphalt concrete and asphalt shingles. We have no estimate of the economic value of recycling drywall and plaster, or brick and clay tile. For asphalt shingles and for drywall, we estimate the local environmental value of recycling by the benefit of energy savings, with energy savings estimated from U.S. Environmental Protection Agency (2015b). The environmental benefit of recycling asphalt concrete is based on the equivalent of reducing 0.44 kg of 2,4-D emissions, as in Sound Resource Management (2009).

We lack data for the environmental benefit of recycling brick and clay tile.

Appendix C

Recycling, eToluene Reduction, and Human Health Benefits

Table C1 Human Health Benefits of Recycling: eToluene Reduction per Tonne	
Product / Material	**kg eToluene / Tonne Recycled or Composted**
Aluminum	-7,646
PET	-4,212
Cardboard	-2,802
Electronics	-1,830
Newspaper	-1,598
HDPE	-1,262
Recycling/Composting Average (MSW & DLC)	-591
Re-refined Lubricating Oil	-549
Mixed Paper	-341
Glass	-316
Ferrous	-239
Compostables	-165
Wood	-8

Credit: Sound Resource Management (2009)

Recycling, e2,4-D Emissions, and Environmental Benefits

Table C2 Environmental Benefits of Recycling: e2,4-D Reduction per Tonne	
Product / Material	**kg e2,4-D / Tonne Recycled or Composted**
Aluminum	-39.18
Electronics	-6.35
Cardboard	-3.65
Newspaper	-3.45
Compostables	-2.02
Recycling/Composting Average (MSW & DLC)	-1.53
Glass	-1.73
Asphalt/Concrete	-0.44
PET	-0.35
Mixed Paper	-0.29
Wood	-0.1
HDPE	-0.08
Re-refined Lubricating Oil	4.1

Credit: Sound Resource Management (2009)

Appendix D

Job Creation Data

Table D1 Potential Job Creation: Material Diversion MSW and C&D						
Material	**Subcategory**	**Disposed (TPY)**	**Collection** *(Jobs per 1,000 tons)*	**Processing** *(Jobs per 1,000 tons)*	**Manufact-uring** *(Jobs per 1,000 tons)*	**Reuse/ Remanufacture** *(Jobs per 1,000 tons)*
Paper/ Paper-board						
	Corrugated Cardboard	72,908.39	121.76	145.82	303.30	N/A
	Cardboard (C&D)	4,999.49	8.35	10.00	20.80	N/A
	Paper Bags/ Kraft	9,478.09	15.83	18.96	39.43	N/A
	Newspaper	25,274.91	42.21	50.55	105.14	N/A
	White Ledger	27,219.13	45.46	54.44	113.23	N/A
	Color Ledger	6,804.78	11.36	13.61	28.31	N/A
	Magazines	24,059.77	40.18	48.12	100.09	N/A
Glass						
	Clear Glass	18,024.51	30.10	36.05	141.49	132.48
	Green Glass	4,543.99	7.59	9.09	35.67	33.40
	Brown Glass	11,814.39	19.73	23.63	92.74	86.84
Metals						

	Ferrous (MSW)	27,729.49	46.31	55.46	114.25	554.59
	Ferrous (C&D)	2,793.01	4.66	5.59	11.51	55.86
	Aluminum	8,028.10	13.41	16.06	141.54	160.56
	Other Non-Ferrous	2,950.87	4.93	5.90	52.02	59.02
Plastics						
	PETE Containers	16,435.76	27.45	32.87	169.29	328.72
	#2 - #7 Containers	21,964.83	36.68	43.93	226.24	439.30
Rubber Leather & Textiles						
	Rubber & Leather	13,504.41	22.55	27.01	124.78	99.26
	Textiles	27,012.87	45.11	54.03	67.53	198.54
Wood						
	Wood (MSW)	10,148.25	16.95	20.30	28.42	28.42
	Wood (C&D)	73,735.46	123.14	147.47	206.46	206.46
Organic Waste						
	Food Scraps	115,720.38	193.25	57.86	N/A	N/A
	Yard Trimmings	48,317.80	80.69	24.16	N/A	N/A
Subtotal			**957.69**	**900.88**	**2,122.23**	**2,383.43**
TOTAL						6,364.23

1. For each material, analysis assumes reprocessing, manufacturing, and reuse/remanufacturing infrastructure and presence in Davidson County necessary for local job creation.

Table D2
Potential Job Creation: Material Disposal
MSW and C&D

Material	**Subcategory**	**Disposed (TPY)**	**Collection** *(Jobs per 1,000 tons)*	**Landfill** *(Jobs per 1,000 tons)*	**Incineration** *(Jobs per 1,000 tons)*
Paper & Paperboard					
	Corrugated Cardboard	72,908.39	40.83	7.29	7.29
	Cardboard (C&D)	4,999.49	2.80	0.50	0.50
	Paper Bags/ Kraft	9,478.09	5.31	0.95	0.95
	Newspaper	25,274.91	14.15	2.53	2.53
	White Ledger	27,219.13	15.24	2.72	2.72
	Color Ledger	6,804.78	3.81	0.68	0.68
	Magazines	24,059.77	13.47	2.41	2.41
Glass					
	Clear Glass	18,024.51	10.09	1.80	1.80
	Green Glass	4,543.99	2.54	0.45	0.45
	Brown Glass	11,814.39	6.62	1.18	1.18
Metals					
	Ferrous (MSW)	27,729.49	15.53	2.77	2.77

	Ferrous (C&D)	2,793.01	1.56	0.28	0.28
	Aluminum	8,028.10	4.50	0.80	0.80
	Other Non-Ferrous	2,950.87	1.65	0.30	0.30
Plastics					
	PETE Containers	16,435.76	9.20	1.64	1.64
	HDPE containers	21,964.83	12.30	2.20	2.20
Rubber, Leather & Textiles					
	Rubber & Leather	13,504.41	7.56	1.35	1.35
	Textiles	27,012.87	15.13	2.70	2.70
Wood					
	Wood (MSW)	10,148.25	5.68	1.01	1.01
	Wood (C&D)	73,735.46	41.29	7.37	7.37
Organic Waste					
	Food Scraps	115,720.38	64.80	11.57	11.57
	Yard Trimmings	48,317.80	27.06	4.83	4.83
Subtotal			**321.14**	**57.35**	**40.94**
TOTAL					419.43

1. Metro currently has no incineration capacity (Hand, 2016); however, based on the material diversion assumptions noted above, incineration is included in this analysis.

Appendix E

Terminology

Direct impact: the impact to the recycling-supported industry

Indirect impact: the impact to industries related to the recycling-supported industry, such as suppliers

Induced impact: the impact that results from personal spending of employees of recycling-supported and related industries.

Recycling: the transformation of discarded material into an economically useful product. This includes reuse, pyrolysis, and composting.

Reprocessing: the conversion of recovered material into a form that is usable by a manufacturer

Remanufacturing: the conversion of recovered material into a finished product

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