Life Cycle Assessment (LCA) and Monetization for Nine Human and Environmental Health Impacts from Delaware County, Pennsylvania MSW Diversion & Disposal

2020 Baseline and Recommended Zero Waste Plan

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Table of Contents

Table of Contents (continued)

I. Introduction

This report details a life cycle assessment (LCA) and monetization of human and environmental health impacts from current diversion and disposal of municipal solid waste (MSW) generated in Delaware County, Pennsylvania in 2020. Similar analysis of projected diversion and disposal levels following implementation of a recommended Zero Waste Plan highlights the substantial human and environmental health benefits of the Zero Waste Plan recommendations.

Sound Resource Management Group's LCA tool, Measuring Environmental Benefits Calculator (MEBCalc), provides results. MEBCalc relies on a number of supporting tools, scientific research papers, and reliable data on MSW management systems and facilities as well as data estimates specific to Delaware County.

MEBCalc outputs cover nine different human and environmental health impacts, ranging from global climate health to local human health. Monetization in terms of environmental economic value (EEV) for each impact enables comparison among impact costs,[1] as well as calculation of a single indicator of overall EEV costs and benefits for MSW disposal and diversion. Global and local EEV benefits in this study flow from avoidance of two aspects of MSW materials' life cycles:

1. Upstream virgin-content manufacturing of materials and products using extracted ecosystem resources, and
2. Downstream disposal EEV cost impacts when MSW is not reduced, reused, recycled, or composted.

The report is divided into 10 main sections, of which this introductory section is the first. Section II summarizes LCA and monetization results. Sections III and IV, detail methodology and life cycle carbon accounting practices used by MEBCalc.

Section V describes general data and sources, as well as data and sources specific to Delaware County. Ruth Abbe (Zero Waste Associates), Alex Danovitch (Nothing Left to Waste), and Amanda Waddle (Zero Waste Associates) researched and cataloged the data and sources on Delaware County's current and recommended MSW management systems. These data provide the Delaware County specifics for LCA and monetization results reported herein.

Section VI details LCA results on pollutant emissions quantities in 2020 driving each of the nine human and environmental health impacts. Readers can skip directly to this section and Section VIII for more information and discussion regarding the LCA and monetization results briefed in Section II.

Section VII discusses MEBCalc methodology and estimates for monetizing LCA results on physical emissions for each of the nine human and environmental health impacts.

Section VIII brings the LCA physical emissions summary results and monetization thereof together to estimate overarching EEV benefits and costs for diversion and disposal of Delaware County generated MSW in 2020. Section IX discusses and compares specific EEVs for the Rolling Hills Landfill located in Earl Township (Berks County) and the Covanta Delaware Valley incinerator located in Chester City (Delaware County).

Section X details LCA results and monetization thereof for diversion and remaining disposal quantities once Zero Waste Plan recommendations are fully implemented.

Appendices A through E provide tables of supporting information for LCA and monetization findings.

[1] For example, the relative economic cost impact of one ton of greenhouse gas emissions on global climate health versus the economic cost impact of one ton of particulate or nitrogen oxides emissions on local human respiratory health.

II. Summary of LCA Results

This section summarizes eight major results from our LCA study on Delaware County MSW diversion and disposal.

1. Overall LCA and Monetization Results

Disposal of MSW generated in Delaware County in 2020 amounted to 467,770 tons. Disposal tons were almost entirely distributed among the four disposal facilities assessed in this LCA – Covanta Delaware Valley, Covanta Plymouth, Rolling Hills Landfill, and Fairless Landfill. Disposal facilities used for Delaware County (Delco) MSW and the proportions of the 467,770 tons received at each are detailed in the following chart:

Facility	Type	Owner/Operator	County	Municipality	Tons Delco MSW Received (2020)	% Delco MSW Received (2020)
Covanta Delaware Valley	Incinerator[2]	Covanta	Delaware	Chester City	380,122.7	81.3%
Covanta Plymouth	Incinerator[2]	Covanta	Montgomery	Plymouth Twp	5,032.1	1.1%
Rolling Hills Landfill	Landfill	Delaware County Solid Waste Authority	Berks	Earl Twp	1,187.1*	0.3%
Fairless Landfill	Landfill	Waste Management, Inc. (now "WM")	Bucks	Falls Twp	81,275.3	17.4%
Three other landfills	Landfill				152.7	0.0%

* Excludes Covanta Delaware Valley incinerator ash that is received at Rolling Hills Landfill.

Delaware County diversion of MSW from disposal in 2020 to recycling and composting totaled 218,599 tons. The diversion rate from disposal was 32% out of 686,369 tons MSW generated in 2020.

A. Carbon Emissions

Diversion in 2020 avoided emissions of 246,000 tons of carbon dioxide equivalents (eCO_2). This includes climate impacts of collecting, recycling markets preparation at a material recovery facility (MRF) that separates and bales mixed recyclables, composting of food scraps and yard wastes, and hauling and/or shipping prepared material to end users that make recycled-content products and materials from the diverted MSW materials. The 246,000 tons accounts for manufacturing of recycled-content products, as well as avoidance of virgin-content manufacturing of those products.

For biogenic (also known as "organic") materials diverted to composting, carbon emissions from petroleum-based fertilizers and pesticides production are avoided by soil amendments composted from biogenic materials. The total for avoided emissions of carbon dioxide equivalents also includes incremental carbon sequestration via healthier soils enhancing plant growth.

According to the U.S. Environmental Protection Agency (EPA), avoidance of 246,000 tons of carbon dioxide equivalents in 2020 provided the same climate benefit as taking 48,000 gasoline-powered passenger vehicles off the road in that year, or reducing annual miles driven by gasoline-powered passenger cars by 554 million miles.

Disposal of 467,770 tons of MSW in 2020 at landfills and incineration facilities, including landfill disposal of ash from incineration of Delaware County MSW, has a carbon footprint of 391,000 tons eCO_2 emitted into the atmosphere and contributing to climate change. This metric includes deductions of offsetting credits for displacement of fossil-natural-gas-based power by electricity generated at incinerators, as well as deductions for recovery and recycling of ferrous and

[2] EPA categorizes large municipal waste combustors (LMWCs) as non-hazardous solid waste incinerators burning on average more than 250 tons per day of MSW. Covanta Delaware Valley and Covanta Plymouth incinerators are LMWCs. This report mostly uses the term "incinerator" when referring to these two Covanta MSW incineration disposal facilities. The report occasionally uses "large municipal waste combustor" or its acronym "LMWC" instead of "incinerator" when referencing Covanta Delaware Valley or Covanta Plymouth incinerators. See U.S. Environmental Protection Agency (EPA) at: https://www.epa.gov/stationary-sources-air-pollution/large-municipal-waste-combustors-lmwc-new-source-performance .

non-ferrous metals from incinerator combustion ash residues. Delaware County's MSW 2020 disposal climate footprint is equivalent to annual carbon dioxide emissions from 76,000 gas-powered passenger vehicles driving 880 million miles.

B. Small Particulate Emissions

Small particulates no greater than 2.5 microns in diameter, including the many but very light nanoparticles, cause increases in morbidity and reduced life spans for humans impacted by those emissions. Diversion in Delaware County in 2020 avoided emissions of 294 tons of small particulates, while disposal of MSW that year increased particulate emissions by 12 tons. Virtually all particulate emissions avoidance due to recycling and composting is a benefit for households and businesses located outside of Delaware County, while particulate pollution health costs from 81% of Delaware County's MSW disposal at Covanta Delaware Valley impacts local households and businesses, especially in Chester where that incineration facility is located.

C. Monetization of Physical Emission Quantities

The disparity in absolute magnitudes between climate changing carbon emissions and human respiratory disease-causing emissions may seem to imply that particulate pollution is not a significant issue for Delaware County. However, particulate emissions have severe acute and long-term medical health effects on those living within the fallout zones of particulate pollutant emissions. Monetization of human health impacts due to respiratory and toxic pollutant emissions provides estimates for the economic costs of human respiratory and toxic emissions as compared to carbon emissions, as indicated in Table 1 of Section VII. Furthermore, human health costs of particulate and toxic emissions per ton of pollution for disposal facilities tend to be concentrated locally and occur in the near term, compared to the more globally dispersed and long-term costs of carbon emissions.

Figure S1 shows environmental[3] economic value (EEV) costs and benefits for Delaware County MSW 2020 disposal and diversion quantities. It shows EEVs in total for all nine impacts, as well as for several separate impacts of special significance.

The graph exhibits the well-recognized result that diversion from disposal to recycling and composting has substantial human and environmental health benefits. These EEV benefits total $399 million, with human health benefits alone accounting for $273 million, or 68%, of that EEV total.

Delaware County MSW disposal at Covanta Delaware Valley and Covanta Plymouth incinerators in 2020 incurred $104 million in net EEV costs after deductions for offsets from electricity generation and metals recycling by the two incinerators. Climate health and human health, respectively, accounted for $80 million and $23 million of those net costs.

The report dissects these results for diversion and disposal by separating local from global impacts, noting that both disposal and diversion activities depend on local collections for disposal, recycling and composting, as well as local transfer, hauling and processing activities. All of which impose EEV costs. In addition, over 81% of disposal takes place at the Covanta Delaware Valley trash incinerator located in the City of Chester. This incineration activity in the midst of a Delaware County population center has substantial local human health impacts with their attendant EEV costs.

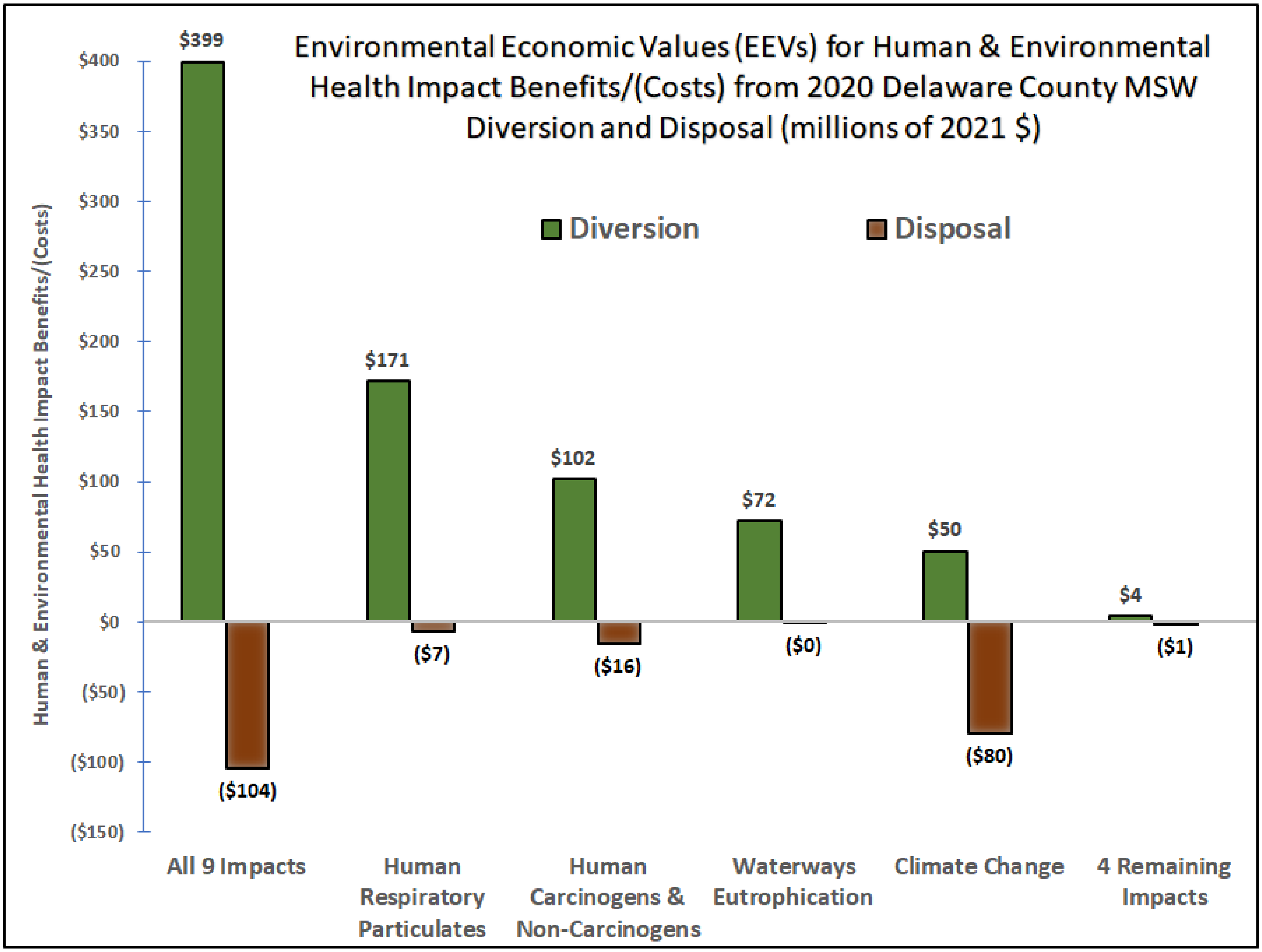
Human and environmental health benefits from recycling and composting are mostly due to displacement of products and materials manufacturing based on virgin resource and energy extraction from global ecosystems. This displacement, or avoidance, is achieved through diversion of discards from disposal to recycling and composting.

The avoided virgin manufacturing activities to produce new materials, products and soil amendments are widely dispersed across the U.S. and globally. There are some domestic manufacturing activities in Delaware County, such as Kimberly-Clark Tissue Corporation in Chester, oil refining in Trainer, and polypropylene manufacturing in Marcus Hook. Most displaced virgin manufacturing activities related to recyclables diversion from Delaware County MSW in this LCA,

[3] Note that the word "environmental" in the acronym EEV encompasses economic values for both human and environmental health.

however, occur outside of Delaware County. Most recycled-content manufacturing activities also likely occur outside of Delaware County, with notable exceptions such as Aero Aggregates in Eddystone.

Figure S1: EEVs for Benefits/(Costs) of All Nine Impacts and Separate EEVs for Climate Change, Human Respiratory Particulates, Human Carcinogens + Non-Carcinogens, Waterways Eutrophication, & the Remaining Four Impacts



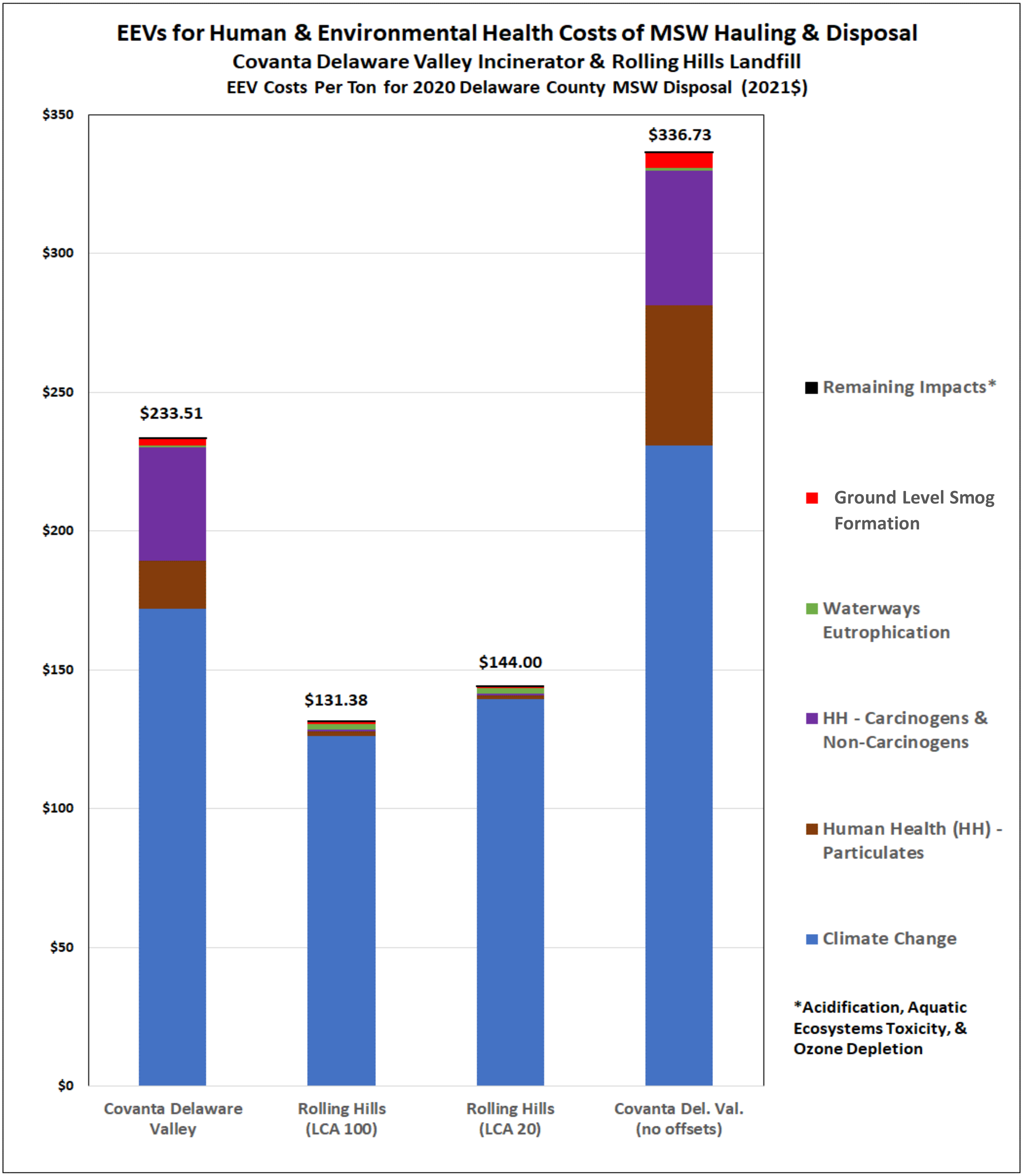
At the same time, even recycling has its own impacts. Both disposal and diversion activities such as collection, processing and hauling impose local human and environmental health costs caused by pollution from managing MSW generated in Delaware County. This finding puts emphasis on the need to minimize local human and environmental health costs from choices, especially for disposal, for managing Delaware County MSW.

2. Incineration and Landfilling EEV Cost Comparisons

Figure S2 shows additional detail on LCA disposal results that suggests an important avenue for reducing Delaware County local EEV costs. In Figure S2 EEV costs are shown as positive numbers for ease of presentation. The stacked bar labeled Covanta Delaware Valley on Figure S2 exhibits EEV costs per ton in 2020 for MSW hauling to, and disposal at, the Covanta Delaware Valley incinerator in Delaware County's City of Chester. The stacked bar labeled Rolling Hills (LCA 100) on Figure S2 portrays EEV costs per ton for hauling to, and disposal at, the Rolling Hills Landfill in Berks County, PA. The graph shows per ton EEV human and environmental health impacts in total, along with color bands in each stacked bar that detail the major human and environmental health impacts that encompass those EEV cost totals.

Covanta Delaware Valley incineration's total EEV cost is $234 per ton of Delaware County MSW burned. This cost is 78% higher than Rolling Hills Landfill's $131 total EEV cost per ton of Delaware County MSW buried there.

Figure S2: Stacked EEVs for Human and Environmental Costs Per Ton of 2020 MSW Hauling and Disposal: Covanta Delaware Valley Incinerator vs. Rolling Hills Landfill



Covanta Delaware Valley incinerator climate change EEV costs per ton burned exceed Rolling Hills Landfill climate EEV costs by 37%. Furthermore, Covanta Delaware Valley human health EEV costs are 23 times higher than Rolling Hills Landfill human health EEV costs, even though Rolling Hills EEV human health costs reflect a hauling distance from the Delaware County Solid Waste Authority's two garbage transfer stations for hauling MSW to Rolling Hills that is more than five times further than the hauling distance to Covanta Delaware Valley.

3. *Sensitivity of Rolling Hills EEV Cost to LCA Time Frame*

The two stacked bars on the right side of Figure S2 provide an indication of the effect of potential major sensitivities for existing EEV hauling and disposal costs for the Rolling Hills Landfill and Covanta Delaware Valley incinerator. The sensitivity comparison for Rolling Hills Landfill labeled Rolling Hills (LCA 20) exhibits the typical result that landfill climate impacts are higher over the first 20 years following MSW landfill disposal than they are over the first 100 years. This result is due to methane in landfill gas (LFG) emissions to the atmosphere. Blue-shaded bar sections of the stacked bar labeled Rolling Hills (LCA 20) portray the $139 20-year LCA climate impact EEV cost per ton landfilled at Rolling Hills Landfill. This is $13, or 10.6%, more than the $126 100-year LCA climate EEV cost for Rolling Hills Landfill portrayed by the stacked bar labeled Rolling Hills (100 LCA).

Section VIII discusses and explains details for this perhaps surprising result for readers expecting a larger difference in climate impacts. The United Nations Intergovernmental Panel on Climate Change (IPCC) 20-year global warming potential (GWP) characterization factor for methane is 81.2 carbon dioxide equivalents (eCO_2) versus IPCC's 100-year GWP climate impact characterization factor for methane of 27.9 eCO_2.

Rolling Hills Landfill EEVs for the other eight human and environmental health impacts decrease slightly when evaluated over 20 years instead of 100 years. This is because landfill pollutant emission quantities are all smaller in total over 20 versus 100 years, while impact characterization factors for each pollutant in each impact category are the same for both time periods for each impact other than climate change.

4. *Sensitivity of Covanta Delaware Valley EEV Cost Offsets for Electricity Generation & Metals Recycling*

Next, to more accurately portray the potential local human health impacts from incinerating MSW at Covanta Delaware Valley, we calculated that facility's pollution footprint excluding credits for offsets. The two EEV cost reductions included in Covanta Delaware Valley's $234 per ton EEV cost shown on the stacked bar labeled Covanta Delaware Valley on Figure S2 are for:

- Displacing fossil-natural-gas-generated electricity with power generated by burning MSW. This yields an offset EEV credit of $72 per ton of MSW burned.
- Recycling metals recovered from the combustion ash produced from burning MSW. Metals recycling yields an offset EEV credit of $31 per MSW ton incinerated.

The displaced natural gas power credit is based on assuming that when Covanta Delaware Valley partially or fully shuts down (e.g., for regular maintenance, operational difficulties, or other reasons), Pennsylvania electric power grid operators replace the decrease in electricity generation at Covanta Delaware Valley with electricity produced by standby peaking power natural-gas-fired generators. When Covanta Delaware Valley comes back online, its power output then replaces this short-term use of natural gas power.

If Covanta Delaware Valley were to permanently close down, the power source that would come online for the grid at this point in time likely would be natural-gas-based generation. In the future, that base load addition will increasingly be sourced from wind or solar generated electricity that has energy storage capabilities.

Removing these cost reduction credits increases Covanta Delaware Valley's human and environmental health EEV costs in total by $103 to $337 per ton of MSW incinerated, as indicated by the right-hand stacked bar labeled Covanta Del. Val. (no offsets) in Figure S2. This $103 total EEV cost increase per ton burned breaks down to increases of $59 for climate change, $41 for human health, and $3 for the remaining five environmental health impacts.

5. Local Human Health EEV Costs for Covanta Delaware Valley and Rolling Hills MSW Disposal

Human health EEV costs for MSW hauling and incineration at Covanta Delaware Valley, excluding offset credits, total $99 per ton burned. For comparison, human health EEV costs from hauling and landfilling MSW at Rolling Hills are $3 per ton.

The $99 per ton incinerated human health EEV costs for MSW hauling and disposal at Covanta Delaware Valley are portrayed on Figure S2 by brown and purple bands in the stacked bars. These human health costs are from particulates and toxics (non-carcinogens and carcinogens) emitted from incineration of MSW. At $99 per ton of MSW incinerated, local human morbidity and early mortality health costs from incinerating 380,000 tons of Delaware County MSW at Covanta Delaware Valley in 2020 total $38 million.

Delaware County MSW accounts for less than 31% of wastes burned at Covanta Delaware Valley. Including wastes from Philadelphia, New York City, New Jersey sources and elsewhere, local human health cost burdens from Covanta Delaware Valley operations total $123 million, most of which is borne by residents and workers in the City of Chester and nearby surrounding communities. Sections VII and VIII provide additional discussion on local human health costs from burning MSW at Covanta Delaware Valley.

6. Rolling Hills Landfill EEV Costs Sensitivity to LFG Capture Rate

This report also provides a sensitivity analysis for landfilling EEV costs for Rolling Hills Landfill at 70%, 30% and 0% landfill gas (LFG) capture rates. 70% is the LFG capture rate used for most LCA calculations in the report. Figure S3 exhibits landfill disposal impact EEV costs at a much lower 30% LFG capture rate, as well as disposal EEV costs if there were no LFG capture at all.

Figure S3 portrays estimates for MSW collection, hauling and disposal components of landfilling and incineration EEV costs, as well as indicating estimates for the local versus global impact EEV costs for just the disposal component.[4] Note that Figure S3 includes EEV costs for collection, whereas Figure S2 did not include collection EEV costs. Section VIII provides additional analysis and discussion regarding local versus global human and environmental health impacts and their EEV costs.

The sensitivity analysis shown on Figure S3 for Rolling Hills LFG capture rates indicates that regardless of LFG capture rate, MSW collection, hauling and landfilling at Rolling Hills have lower total human and environmental health EEV costs than collection, hauling and incinerating garbage at Covanta Delaware Valley, absent EEV cost offsets to that incinerator's impacts for electricity generation and metals recycling. Covanta Delaware Valley's total per ton EEV costs for MSW collection, hauling and disposal are $344 per ton excluding those offsets.

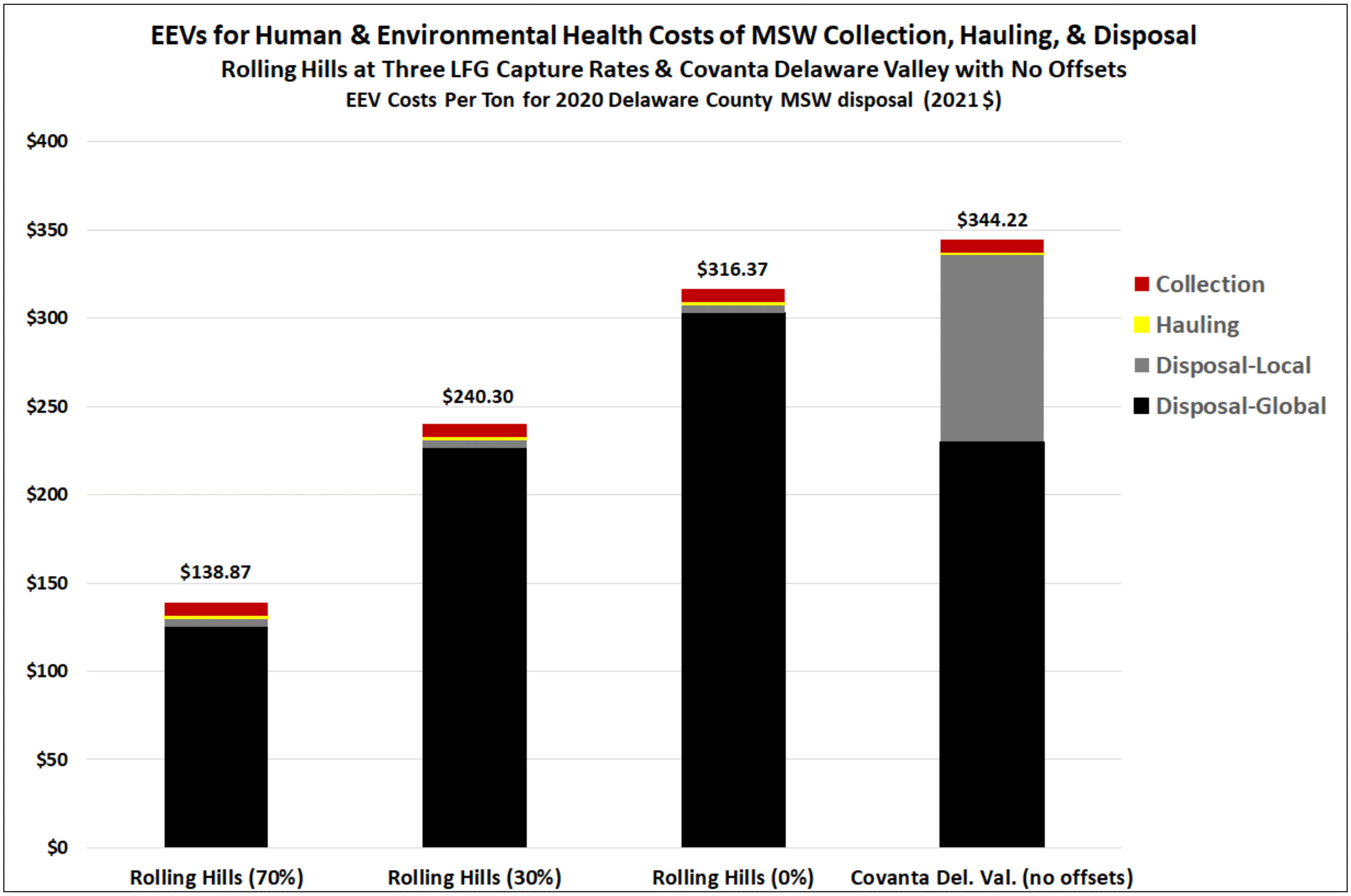
Total EEV costs for Covanta Delaware Valley including MSW collection costs as well as the offsets for electricity generation and metals recycling is $241.[5] At landfill gas capture rates of at least 30%, Rolling Hills total EEV cost is lower than Covanta Delaware Valley total EEV cost even when including cost offsets for Covanta Delaware Valley electricity generation and metals recycling.

Although not shown on Figure S3, it's also worth noting that when looking at only climate change, a 52% or higher LFG capture rate is sufficient for landfilling at Rolling Hills to have lower EEV costs than incineration at Covanta Delaware Valley even when including those Covanta Delaware Valley EEV cost offsets.

[4] Global impacts for disposal include climate change and stratospheric ozone depletion. Ozone depletion EEV costs for disposal are insignificant. Hence, EEVs for global disposal costs on Figure S3 are essentially equal to EEVs for climate change disposal costs.

[5] The $241 Covanta Delaware Valley total per ton EEV costs including offsets is higher than the $234 per ton costs shown on Figure S2 because the $241 estimate includes the EEV cost for garbage collection. In Figure S2 disposal costs include hauling costs but not collection costs. Figure S3 includes collection costs along with hauling and facility disposal costs to illustrate the point that collection and hauling human and environmental health impacts are much smaller than those impacts for disposal facility operations.

Figure S3: Stacked EEVs for Human & Environmental Health Costs Per Ton of MSW Collection, Hauling, and Disposal: Rolling Hills Landfill vs. Covanta Delaware Valley Incinerator



7. *Hauling: MSW to Covanta Delaware Valley & Rolling Hills; Ash Covanta Delaware Valley to Rolling Hills*

Figure S3 portrays MSW garbage EEV collection costs and hauling costs in addition to disposal EEV costs. This graphically shows that MSW collection and hauling for disposal account for a minor portion of human and environmental health impact costs for disposal of Delaware County garbage.

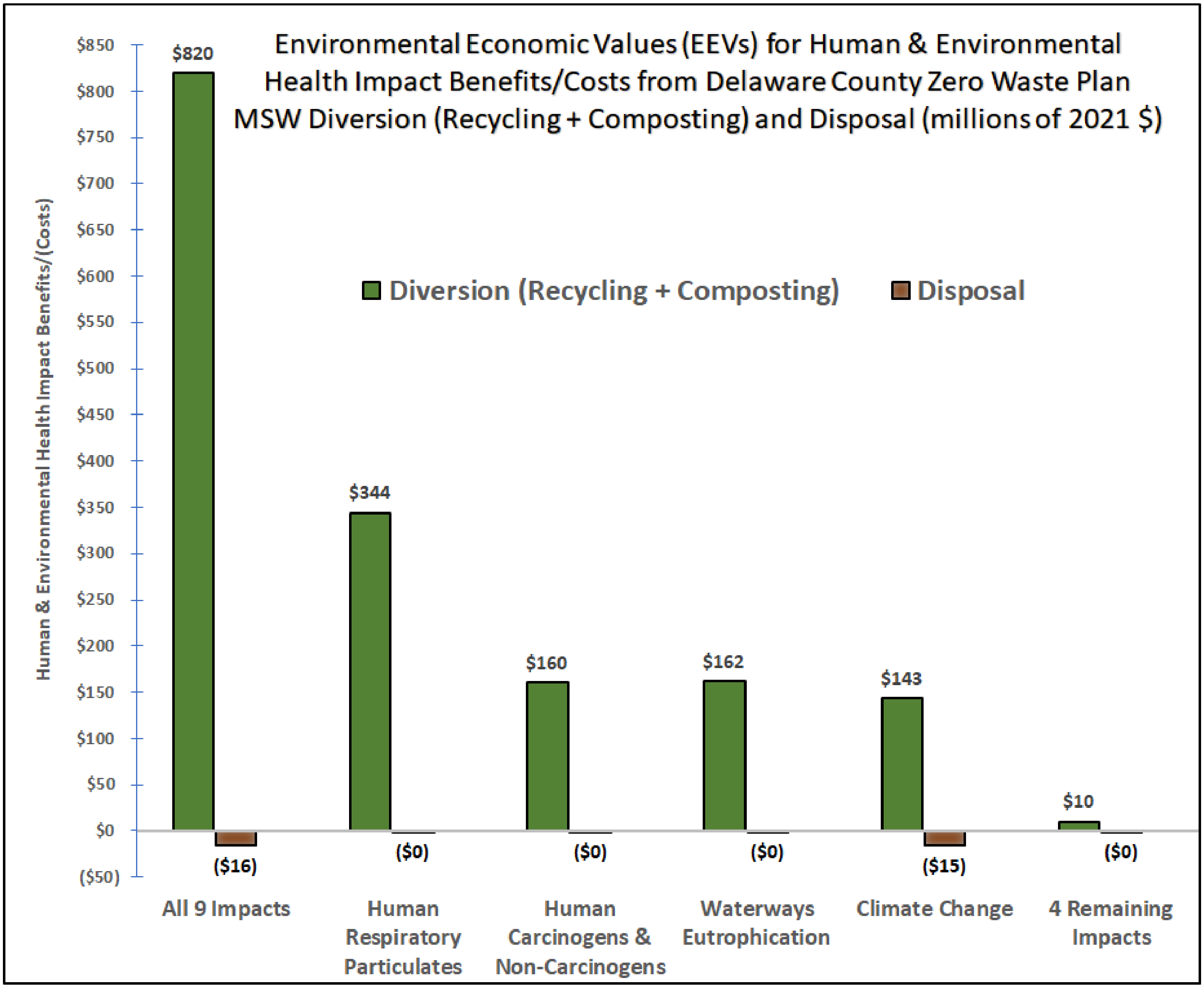
Specifically with respect to hauling, Rolling Hills Landfill is over 5 times more distant from Delaware County transfer stations than the Covanta Delaware Valley incinerator. Yet per ton EEV costs for hauling MSW to Rolling Hills Landfill account for just $1.52 of total per ton EEV costs. This compares to $0.76 per ton of MSW disposal for hauling MSW to Covanta Delaware Valley and hauling resultant combustion ash from Covanta Delaware Valley to Rolling Hills for burial.

8. *Summary of LCA and Monetization Results for the Recommended Zero Waste Plan*

Section X describes LCA results for diversion and disposal of Delaware County MSW assuming full implementation of Zero Waste Plan recommendations, as described in the *Delaware County, Pennsylvania Municipal Waste Management Plan 2023-2033*. Figure S4 portrays information similar to Figure S1, except that LCA results displayed on Figure S4 are based on disposal and diversion projections following full implementation of the Zero Waste Plan recommendations. Tables B1 and B2 in Appendix B show LCA results for the recommended Zero Waste Plan for Delaware County disposal and diversion to recycling and composting.

Following successful implementation of Zero Waste diversion and disposal programs, diversion from disposal to recycling and composting would total 522,126 tons, more than doubling 2020 diversion's 218,599 tons. Source reduction from potential waste generation would total 51,613 tons. Disposal would be reduced by 76% to 112,697 tons from 2020 baseline 467,770 tons. Waste requiring management by Delaware County would decrease to 634,823 tons due to source reduction. The County's diversion rate would increase to 82.2%.

Figure S4: EEVs for Zero Waste Plan Projected Benefits/(Costs) of All Nine Impacts and Separate EEVs for Climate Change, Human Respiratory Particulates, Human Carcinogens + Non-Carcinogens, Waterways Eutrophication, & the Remaining Four Impacts



As indicated on Figure S4, Zero Waste Plan diversion from disposal to recycling and composting has total EEV benefits of $820 million. Human health EEV benefits account for $504 million, or 61%, of total benefits.

Delaware County MSW disposal under the Zero Waste Plan would be entirely at Rolling Hills Landfill. It would incur $16 million in total human and environmental health EEV costs. All but 4% of that total EEV cost would be caused by climate changing GHG emissions.

III. Methodology for Indexing & Summarizing Pollutant Emissions Causing the Nine Impacts

There are thousands of potentially harmful substances involved in the production, consumption, and waste management activities associated with goods and services. Some of these substances are released to the environment during natural resource extraction and refining of energy and materials used to manufacture goods and offer services. Some are released during manufacturing.

Resource acquisition and manufacturing are the upstream phase of product life cycles. Consumption of goods and services is the use phase. Management of wastes, perhaps more accurately called discards, via activities such as collection, recycling, composting and disposal encompass the downstream life cycle phase. Chemical and non-chemical harmful substances can be released to the environment during activities, such as shipping and hauling or fuel combustion for heat and power, which may accompany any of these stages in the life cycle of a good or service.

The challenge is that policy makers cannot readily assess human and environmental health impacts when looking at a report listing releases of thousands of individual chemical and other harmful substances. Grouping pollutant releases into a small number of human and environmental health impact categories provides a partial solution to this conundrum. Monetizing the nine impacts goes further to provide a single index that summarizes benefits and costs in dollar terms for the nine categories of human and environmental health effects.

Initial sections of this report define the nine categories and the roots of their indexing methodologies, MEBCalc's carbon accounting methods for measuring climate change, and sources for measuring pollutant emissions across the life cycles of the many materials encountered in managing MSW. Subsequent sections discuss physical emissions results for the nine impacts, as well as monetization of the nine impact results into a single dollar benefit-cost index for environmental economic value (EEV).

1. IPCC Method for Indexing Greenhouse Gas Pollutants Causing Climate Change

The method that is used for assessing each greenhouse gas (GHG) pollutants' potential climate impact is an example of how research scientists can synthesize a large number of harmful emissions into an index number, in this case carbon dioxide emissions equivalents, that provides a metric for characterizing potential climate changing impacts from releases of GHG pollutants to the atmosphere. The United Nations Intergovernmental Panel on Climate Change (IPCC) popularized this index – carbon dioxide equivalents (denoted as eCO_2 or CO_2E) – that defines, in one number, the amount of climate forcing emissions released into Earth's atmosphere. The climate forcing strengths of GHG pollutants are characterized by global warming potentials (GWPs) for each atmospheric pollutant that contributes to trapping incoming solar radiation.

Examples from the IPCC's *2022 Sixth Assessment Report* (AR6) of GWPs for GHGs range from 1 for carbon dioxide (CO_2), 27.9 for methane (CH_4), and 273 for nitrous oxide (N_2O), up to 24,300 for sulfur hexafluoride (SF_6). These GWPs represent each GHG's average climate forcing effect over the 100 years following their release.

IPCC also publishes GWPs for climate forcing over 20 years and 500 years. This study uses the 100-year time frame for most LCA calculations presented herein. The exception is that LCA results are also provided for landfilled materials in 2020 over a 20-year time horizon to reflect especially the higher 20-year methane GWP of 81.2 versus its 100-year GWP of 27.9.[6]

[6] MEBCalc's modeling and peer-reviewed article sources mostly use the 100-year time frame for LCA calculations. Re-calculating results over the 20-year time horizon would reduce impacts for all but climate change. It would also reduce climate change impacts for landfilled materials such as wood, mechanically-pulped paper products, and other materials that generate methane and carbon dioxide very slowly. Wood and mechanically-pulped paper products contain lignin which is very resistant to formation of methane. Chemically pulped paper and paperboard products are chemically pulped to, in part, remove the lignin. Hence, they have much higher average climate impacts over 20-years. This report evaluated landfill impacts over both 20- and 100-years to check for sensitivity of results when comparing incineration to landfilling. Based on results shown on Figure S2, landfilling MSW is not very sensitive to whether the LCA time frame is 20 years instead of 100 years. See Section VIII for more on this issue.

GWPs are characterization factors that express the climate forcing potential of any greenhouse gas relative to that of carbon dioxide. GWP users calculate the climate change index eCO_2 by multiplying each GHG's GWP, its climate change characterization factor, by the amount of that GHG released to the atmosphere. Adding up these indexed emissions yields the summary number of carbon dioxide equivalents that represents climate forcing impacts over the subsequent 100 years.

2. *TRACI Tool for Indexing the Other Eight Human and Environmental Health Impacts*

In a similar vein, the U.S. Environmental Protection Agency (EPA) has a tool, TRACI (Tool for the Reduction and Assessment of Chemical and other environmental Impacts), that provides impact potential characterization factors for releases of nearly 4,000 chemicals and other substances for eight more human and environmental health impacts in addition to climate change.[7] For climate change, the TRACI characterization factors are the IPCC 100-year GWPs.

Many chemicals and substances have TRACI characterization factors of zero for some impacts, meaning that they do not contribute to damages for those particular impacts. For example, for climate change only 91 of the 3,944 chemicals and substances codified by TRACI 2.1 have GWP characterization factors greater than zero.

For each of the eight human and environmental health categories besides climate change, users of TRACI, such as MEBCalc, can select a particular pollutant to serve as the reference indicator for that impact, just as carbon dioxide equivalents (eCO_2) serve as the widely used climate impact potential indicator for GHG emissions. This means that all pollutants in each category are converted to the units of the reference indicator based on their characterization factors for each impact. Their releases, thus, can be multiplied by their reference indicator characterization factors, and added up to obtain an index of total impact from those releases for that category of human and environmental health impacts. Note, once again, that these eight human and environmental health impact categories have impact characterization factors for each pollutant in each impact category that are the same for 20-year and 100-year LCAs.

TRACI's characterization factors in some instances indicate that a pollutant has more than one human or environmental health impact. For example, sulfur dioxide, causes both environmental health acidification and human health respiratory damages. To prevent what might appear to be a potential for double counting in such instances, TRACI's nine categories assess mutually exclusive human and environmental health impacts. What might seem like a possibility for double counting is, thus, avoided using TRACI methodology for keeping impacts mutually exclusive.[8]

The nine human and environmental health impacts assessed by MEBCalc use the IPCC and TRACI 2.1 characterization factors. Brief comments on each of the nine categories of human and environmental health impacts, some of the pollutants that cause each impact, and the reference substance used to index each impact, follow:[9]

- **Climate change** – the potential increase in greenhouse effects due to anthropogenic atmospheric emissions. Carbon dioxide (CO_2) from burning fossil fuels is the most common source of GHGs. Methane (CH_4) from anaerobic decomposition of biogenic materials such as food scraps or discarded paper, say, from burial in a landfill, is another large source of GHG effects. Pollutants that have climate impacts are characterized by GWPs and converted into their reference substance impacts carbon dioxide equivalents, eCO_2.

[7] https://www.epa.gov/chemical-research/tool-reduction-and-assessment-chemicals-and-other-environmental-impacts-traci .
[8] More information on TRACI is provided in the following references: Bare J. C., *Developing a Consistent Decision-Making Framework by Using the U.S. EPA's TRACI,* U.S. Environmental Protection Agency, Cincinnati, OH, 2002; Bare J. C., Norris, G. A., Pennington, D. W., and McKone, T., TRACI: The Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts. *Journal of Industrial Ecology* 2003, 6(3-4): 49-78; and Bare, J. C., TRACI 2.0: the tool for the reduction and assessment of chemical and other environmental Impacts 2.0. *Clean Technologies and Environmental Policy*, 2011, 13(5) 687-696. These articles provide expositions on the original and more recent versions of the TRACI model.
[9] These nine human and environmental health impact categories match the impact categories used in TRACI, and are widely used in life cycle assessments and the scientific literature that assess damages from human and environmental health impacts.

- **Human respiratory disease and death from particulates** – potential human health impacts from anthropogenic atmospheric releases of coarse particles known to aggravate respiratory conditions such as asthma, fine particles that can lead to more serious respiratory symptoms and disease such as lung cancer, and particulate precursors such as nitrogen oxides (NO_x) and sulfur dioxide (SO_2). Activities that are large sources of particulate emissions include combustion of fuels such as coal, natural gas, wood, and petroleum diesel. Grinding, combusting, or otherwise processing municipal solid wastes also generates particulate emissions. Emissions of pollutants that have respiratory health impacts are characterized and converted into reference pollutant equivalents, $ePM_{2.5}$, where $PM_{2.5}$ is particulate matter 2.5 microns or less in diameter.[10]
- **Human disease and death from non-carcinogenic toxics** – potential human health impacts (other than particulates' respiratory and toxics' carcinogenic impacts) from releases of chemicals that are toxic to humans. There are many chemical and heavy metal pollutants that are toxic to humans, including 2,4-dichlorophenoxy acetic acid (2,4-D), benzene, dichloro-diphenyl-trichloroethane (DDT), formaldehyde, permethrin, toluene, chromium, copper, lead, mercury, silver, and zinc. Examples of these pollutants' human toxicity effects include heart diseases, kidney failure, reproductive disorders, cognitive effects, and disruption of the endocrine system. MEBCalc uses TRACI characterization factors to convert emissions of pollutants that have human health non-carcinogenic toxicity impacts into reference pollutant equivalents, eT, where T is toluene.
- **Human disease and death from carcinogenic toxics** – potential human health impacts from releases of chemicals that are carcinogenic to humans (other than particulates respiratory cancers impact). There also are many chemical and heavy metal pollutants that are carcinogenic to humans, including 2,4-D, benzene, DDT, dioxins and furans, formaldehyde, kepone, permethrin, chromium, lead, and mercury. MEBCalc's reference substance for human carcinogenic potential is benzene. MEBCalc aggregates the pollutants that have human carcinogenic impacts into benzene equivalents, eB.
- **Eutrophication** – potential environmental impacts from the addition of macro nutrients to soil or water resulting from emissions of eutrophying pollutants to air, soil or water. The addition to soil or water of mineral nutrients, such as nitrogen and phosphorous, can yield generally undesirable shifts in the number of species in ecosystems and a reduction in ecological diversity. In water, nutrient additions tend to increase algae growth, which can lead to reductions in oxygen and death of fish and other species. Pollutants that have waterways eutrophying impacts are characterized by nitrogen equivalents, eN.
- **Acidification** – potential environmental impacts from anthropogenic releases of acidifying compounds, principally from fossil fuel and biomass combustion, which affect trees, soil, buildings, animals and humans. The main pollutants involved in acidification are sulfur, nitrogen and hydrogen compounds – e.g., sulfur dioxide, sulfuric acid, nitrogen oxides, hydrochloric acid, and ammonia. The pollutants that have acidifying impacts are characterized and referenced by sulfur dioxide equivalents, eSO_2.
- **Aquatic ecosystems toxicity** – the relative potential for chemicals released into the environment to harm aquatic ecosystems, including wildlife. There are many chemical and heavy metal pollutants that are toxic to ecosystems, including 2,4-D, benzene, DDT, dioxins and furans, ethyl benzene, formaldehyde, kepone, permethrin, toluene, chromium, copper, lead, silver, and zinc. Pollutants that have toxicity impacts to aquatic ecosystems are characterized and referenced by 2,4-dichlorophenoxy acetic acid equivalents, e2,4-D.
- **Ozone depletion** – the relative potential for chemical compounds released into the atmosphere to cause degradation of the Earth's ozone layer. The reference substance for ozone depletion potential (ODP) is

[10] For comparison a human hair's diameter is about 75 microns on average.

trichlorofluoromethane, CFC-11, where CFC is the acronym for chlorofluorocarbon. CFC-11 is sometimes called R-11. Pollutants that have ozone depletion potential are characterized and referenced by CFC-11 equivalents eCFC-11.

- **Ground level smog formation** – the relative potential for chemical compounds released into the atmosphere to react with sunlight, heat and fine particles to form ozone (O_3). For example, nitrogen oxides (NO_x) and volatile organic compounds (VOCs) released during fuel combustion are some of the chemical compounds that contribute to ground level smog formation. Smog forming pollutants are characterized by ozone equivalents, eO_3.

IV. MEBCalc LCA Accounting Methodology for Climate Changing Carbon Emissions

MEBCalc calculations for climate change impacts count all GHG emissions, including carbon dioxide (CO_2) and other GHGs that have more substantial climate warming impacts than CO_2, such as methane (CH_4), carbon tetrachloride (CFC-10), and dichlorodifluoromethane (CFC-12). MEBCalc does not give credits for previously sequestered carbon that may remain stored for a time, short or long, in biogenic- or fossil-carbon based materials discarded into landfills, processed into composts, or processed into reused or recycled-content products. Nor does MEBCalc count regrowth of plants and trees as an offset for carbon emissions from waste management system activities and facilities.

In addition, MEBCalc tracks the timing of carbon releases from current year handling of wastes. Biogenic materials such as paper products, food scraps, yard maintenance grass clippings and plant prunings buried today in a landfill, for example, release carbon dioxide, methane and other GHGs from their anaerobic biodegradation slowly over many years. Fossil carbon-based materials such as most plastics do not biodegrade in landfills. In contrast, combustion of burnable biogenic- or fossil-carbon based materials releases the carbon in those materials all at once, and virtually all as CO_2 assuming the combustion process is efficient. MEBCalc uses dynamic carbon accounting methods to account for the difference in climate impacts between the GHGs released all at once today versus more slowly over time, for example throughout the typical 100-year LCA timeframe,[11] or the shorter 20-year timeframe.

There are several important reasons for MEBCalc's accounting methodology for biogenic CO_2:

1. Companies that own or manage MSW incinerators often make the claim that their current biogenic CO_2 emissions can be ignored due to those emissions being re-sequestered during future plant and tree growth. However, if these incineration disposal facilities use future plant and tree growth CO_2 sequestration as offsets when calculating their climate footprint, then recycling, composting and landfilling could use that same quantity of future CO_2 sequestration credits when they manage the same quantity and composition of biogenic discards. The result is that an LCA comparison of climate impacts for recycling, composting, landfilling, and incinerating MSW would each be subtracting the same CO_2 credit from their climate impacting carbon emissions. This leaves rankings in terms of climate impacts the same regardless of whether the regrowth credit is applied to all or none. Hence, to avoid unnecessary and complicated tracking and responsibility verification accounting to measure regrowth that may occur in future years to offset today's mix of biogenic materials treated by a waste management method, MEBCalc's analysis instead focuses on tracking all carbon emissions, including both biogenic and fossil CO_2.

   Another way of coming to the same conclusion is to note that according to climate change accounting rules for allocating regrowth credits, if the regrowth will happen ***anyway***, regardless whether the biogenic discards are burned for energy or managed by some other waste management method, then no offset for that regrowth should be awarded to incinerators.[12]

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[11] MEBCalc uses DYNCO2 for dynamic carbon accounting, Dynamic Carbon Footprint - Life Cycle Assessment Tool - CIRAIG.

[12] See, for example, the discussion on additionality in Broekhoff *et al*, 2019. *Securing Climate Carbon Offsets*, Stockholm Environmental Institute & Greenhouse Gas Management Institute. Available at https://www.offsetguide.org.

2. Sequestration of carbon into plants and trees from CO_2 in the atmosphere occurs through photosynthesis when plants and trees are growing. Continued storage of biogenic carbon in products and materials produced from those plants and trees is not sequestration. Continued storage of fossil carbon, for example, in fossil-carbon-based plastics buried in landfills, does not accrue CO_2 emissions reduction credits. Why should storage of biogenic carbon be treated differently than storage of fossil carbon in LCA calculations? Counting biogenic carbon storage as a credit against current releases of CO_2 also could double count CO_2 sequestration if that sequestration was already registered in climate accounting when plants and trees were growing or at the time of their harvest.[13]

3. Concentrations of CO_2 in the atmosphere continue to increase. Oceans absorb about 30% of CO_2 released to the atmosphere, and increased CO_2 emissions are likely a substantial cause of currently-observed increases in ocean acidification. Both trends suggest that current plant and tree CO_2 sequestration from the atmosphere may not be keeping up with growth of human-driven emissions. As a result, plant and tree sequestration of CO_2 from the atmosphere to offset CO_2 emissions to the atmosphere may fall short of what is necessary to prevent further climate change. This potential imbalance between regrowth demand needed for offsets and actual regrowth supply necessary to offset planetary GHG emissions means that carbon dioxide polluters cannot legitimately claim that undesignated planetary regrowth automatically offsets their particular carbon emissions. The total supply of undesignated regrowth credits may be insufficient to meet total demand for such credits. Furthermore, credits for continued plant and tree growth and regrowth should go first to those doing the growing – for example, private and public entities that sustainably manage forests and parks.[14]

V. MEBCalc Sources for Pollutant Emissions Over the Life Cycle of Material Discards

Sound Resource Management Group (SRMG) found inspiration, research results, and preliminary data for initial development of MEBCalc from several ground-breaking studies on conservation versus incineration – where incineration is meant to encompass pseudonyms such as combustion, waste-to-energy (WTE), pyrolysis, and gasification. These studies included Tellus Institute's Packaging Study,[15] SRMG's Recycling Versus Incineration,[16] and Washington State Department of Ecology's Issue Paper 10.[17]

For emissions from material and fuel resources extracted and refined from ecosystems, from manufacturing virgin-content products using those refined resources, from manufacturing recycled-content products using recycled materials, and from waste management system facilities and activities, SRMG and MEBCalc initially relied significantly on two waste management LCA models – EPA/Research Triangle Institute's Decision Support Tool (RTI DST)[18] and EPA's WARM tool.[19]

Note also that earlier versions of MEBCalc did not assess the use phase for materials and products handled by waste management systems, just as EPA's RTI DST and WARM decision support tools do not. This was not

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[13] EPA's WARM tool is an example of a 100-year timeframe climate impacts accounting tool that gives credit for storage of biogenic carbon in composts and landfills, but no such credit for storage of fossil carbon in landfills or products.

[14] For discussion and references on verification issues even with purchases of carbon offset credits see, Guizar-Coutino, *et al*, 2022, A global evaluation of the effectiveness of voluntary REDD+ projects at reducing deforestation and degradation in the moist tropics. *Conservation Biology*. 36:e13970.

[15] CSG/Tellus Institute, 1992. *Assessing the Impacts of Production and Disposal of Packaging and Public Policy Measures to Alter Its Mix*, prepared for Council of State Governments (CSG), prepared by Tellus Institute, Boston, MA.

[16] Morris, J., Canzoneri, D., 1992. *Recycling Versus Incineration: An Energy Conservation Analysis*, prepared for Pollution Probe (Toronto, Ontario) and Work on Waste USA (Canton, NY), Sept. 1992. Seattle, WA. Also, summarized in Morris, J., 1996. Recycling versus incineration: an energy conservation analysis. *Journal of Hazardous Materials* 47(1-3) 277-293.

[17] Washington State Department of Ecology, 2002. *Beyond Waste Washington State Solid Waste Plan, Issue Paper 10, Solid Waste Costs and Barriers to Recycling.* Publication no. 02-07-030, August 2002. Olympia, WA.

[18] See downloadable resources on the DST at: RTI International.

[19] See U.S. Environmental Protection Agency (EPA) at: Waste Reduction Model (WARM) | US EPA.

because the use phase is not a significant and important part of the life cycle of products and services. Rather, it is because the use phase impacts of recycled-content and virgin-content products or materials typically are assumed to be the same.

Like WARM and RTI DST tools, MEBCalc always has accounted for the upstream impacts for products and materials produced from virgin raw materials and fuels as compared to recycled products and materials. In fact, it is the upstream differences in human and environmental health impacts between virgin- and recycled-content products, materials and services that provide most of recycling's human and environmental health benefits.

In addition, earlier versions of MEBCalc did not account for the upstream differences in human and environmental health impacts between soil amendments produced from composts and their competing products produced from petroleum and other virgin resources. Also, the use phase for soil amendments produced by composting biogenic MSW materials such as yard debris, food scraps and soiled compostable paper products has different impacts than the use phase for virgin resource and petroleum-based soil amendments.

To correct these shortcomings, the current version of MEBCalc, version 7.2, assesses human and environmental health for both upstream and use phase differences between composted biogenic material soil amendments and their virgin resource and petroleum-based counterparts. These differences result in lower upstream impacts for soil amendments produced from composts, lower use phase soil runoffs of nitrates and phosphorus, and enhanced use phase plant growth with its related additional carbon sequestration due to healthier soils.[20]

Furthermore, since developing the first version of MEBCalc, Sound Resource Management Group has continually revised emissions profiles and other LCA input data using updates from EPA's WARM and RTI DST models, as well as substantial new data from a wide variety of peer-reviewed scientific journal articles and other well-regarded sources. These latter sources include publications by organizations such as The Association of Plastic Recyclers (APR), Environmental Paper Network (EPN), Oregon Department of Environmental Quality (DEQ), Washington State Department of Ecology (DOE), National Renewable Energy Laboratory (NREL), and U.S. Department of Energy's Energy Information Administration (EIA). Relevant peer-reviewed scientific articles often appear in journals such as *Environmental Science & Technology* published by the American Chemical Society (ACS), the *Journal of Industrial Ecology* published at Yale University, and *Waste Management* published by Elsevier.[21]

Sources for Input data specific to Delaware County are discussed in the following six subsections.

1. *Landfill Emissions*

For landfill air emissions from the Fairless and Rolling Hills landfills used for disposal of some Delaware County MSW, MEBCalc relies on EPA's Landfill Gas Emissions Model (LandGEM),[22] and MSW disposal composition estimates from a 2022 report for the Pennsylvania Department of Environmental Protection that provides 2020-2021 data specific to the southeastern region (Philadelphia and its suburbs). The EPA LandGEM model projects anaerobic generation of both GHG and non-GHG pollutants over the subsequent 20 or 100 years.

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[20] Morris, J., Flammer, R., and Soylu, T. M., 2022, Environmental Dollars and Sense of Composting in San Diego County. *BioCycle Connect*, January 25, 2022; and Morris, J., 2021, *The Environmental Economics Dollars and Sense of Composting in San Diego County.* Prepared for City of Chula Vista (CA) Economic Development Dept. by SRMG.

[21] For example, De la Cruz, F.B., Barlaz, M.A., 2010, Estimation of waste component-specific decay rates using laboratory-scale decomposition data, *Environmental Science & Technology 44 (12): 4722-4728;* Morris, J., 2017, Recycle, bury, or burn wood waste biomass? LCA answer depends on carbon accounting, emissions controls, displaced fuels, and impact costs, *Journal of Industrial Ecology*, 21 (4) 844-856; and De la Cruz, F. B., *et al*, 2016, Comparison of field measurements to methane emissions models at a new landfill, *Environmental Science & Technology*, 50: 9432-9441.

[22] See U.S. EPA at: [Emissions Estimation Tools | US EPA]

For landfill water emissions from MSW disposal, MEBCalc relies on RTI DST emission factors. For landfill air and water emissions from disposal of ash outputs from Covanta Delaware Valley and Covanta Plymouth, MEBCalc also relies on RTI DST emissions factors.

2. *Incinerator Emissions*

For the Covanta Delaware Valley and Covanta Plymouth incinerators used for disposal of MSW from Delaware County in 2020, MEBCalc input data for incineration air emissions rely on Covanta's reports to the Pennsylvania Department of Environmental Protection (DEP). Continuous emissions monitoring at those two incineration facilities is compiled for four pollutants: carbon monoxide, nitrogen oxides, sulfur oxides, and hydrochloric acid. Estimated emissions for other air pollutants are based on annual stack emissions tests for release rates of those pollutants, and estimated total annual emissions are calculated by Covanta for their yearly reporting to DEP. Annual air emissions data for continuously monitored pollutants and pollutants with annual emissions estimates based on periodic tests for emissions rates are both publicly available through PA DEP's website. [23] Data on dioxins/furans and polycyclic aromatic hydrocarbons are not reported in DEP's online air emissions data report. Annual reports for those pollutants had to be requested from DEP.

Solid waste disposal quantities handled at each of the two landfills and two incinerators used for Delaware County MSW disposal in 2020 are also available through PA DEP's website.[24]

SRMG used five-year averages over the years 2017 through 2021 for air emissions per ton handled at Covanta Delaware Valley and Covanta Plymouth incinerators. Use of these averages is for three main reasons:

- Delaware County MSW composition data had to be estimated from the PA DEP waste composition study that was conducted during July 2020 through June 2021 to coincide with the Pennsylvania Commonwealth's fiscal year. This did not coincide exactly with this study's 2020 baseline year.
- The two years 2020 and 2021 seemed unreliable as a basis for typical emissions from each of the two incinerators due to disruptions during the COVID pandemic.
- Averages for disposal tons over the five years 2017-2021 showed substantially lower variation than averages for emissions of many pollutants listed in the PA DEP air emissions database. For example, disposal tons for Covanta Delaware Valley had a five-year standard deviation that was 2.5% of the five-year average for disposal at that incinerator. Annual emissions of the heavy metals cadmium, chromium, lead, mercury, and nickel had standard deviations for 2017-2021 that were between 33% and 78% of their respective 5-year averages for Covanta Delaware Valley disposal emissions. The standard deviation for $PM_{2.5}$ was 80% of its average during 2017-2021. Even the continuously monitored sulfur oxides pollutants had a 5-year standard deviation that was 29% of its average. These results suggested that using one or two years as the basis for air emissions from Covanta Delaware Valley would be an unreliable basis for emissions factors when emissions for many pollutants varied so much from year to year while total tons burned stayed very stable.

There are some exceptions to the five-year average emissions procedure for several pollutants – carbon dioxide, dioxins/furans, and polycyclic aromatic hydrocarbons (PAHs). Carbon dioxide emissions for this study's 2020 baseline waste composition tons are a straight forward calculation from each waste stream material's carbon content and the assumption that each combustible material's carbon content is essentially all converted to carbon dioxide and water vapor when combusted. Hence, 2020 carbon dioxide emissions at each of the two incinerators are based just on Delaware County MSW disposal using the southeast region's waste composition.

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23 Pennsylvania Department of Environmental Protection Air Emissions Report (Detail Report tab) available at: http://cedatareporting.pa.gov/reports/powerbi/Public/DEP/AQ/PBI/Air_Emissions_Report.

24 Pennsylvania Department of Environmental Protection Solid Waste Disposal Information available at: http://cedatareporting.pa.gov/reports/powerbi/Public/DEP/WM/PBI/Solid_Waste_Disposal_Information.

Note that 81.3% of 2020 MSW disposal for Delaware County was sent to the Covanta Delaware Valley incinerator located in the City of Chester.

Neither dioxins/furans nor polycyclic aromatic hydrocarbons (PAHs) are codified in DEP's online annual air emissions database. That database reports annual tons. Annual emissions for these pollutants are below DEP's reporting threshold. Data for estimating annual emissions of these pollutants was acquired from DEP based on Pennsylvania Right-To-Know Law requests. These data sources are available by contacting the SWMP Update and LCA study team. Emissions for dioxins/furans are represented as 2,3,7,8-TCDD TEQs (2,3,7,8-tetrachlorodibenzo-p-dioxin toxicity equivalents). Emissions of PAHs are represented as benzo(a)pyrene equivalents.

Table C1 in Appendix C lists Covanta Delaware Valley and Covanta Plymouth atmospheric pollutant emission factors per metric ton that are used in MEBCalc to calculate pollution emissions for Delaware County MSW burned at the two incinerators.

3. *Disposal Facility Air Emissions Offsets*

MEBCalc evaluation of incineration disposal facility human and environmental health impacts includes offsets (i.e., emissions deductions) for emissions from natural-gas-fired power production equal in power output amounts to electricity generated and distributed to the PA electrical grid from Delaware County MSW burned at incinerators in 2020.

MSW disposal managed at the two landfills used for burying Delaware County MSW in 2020 captured landfill gas (LFG) released from this buried MSW. However, captured LFG was not used to generate energy. Instead that captured LFG is burned in flares located at the two landfill sites and does not accrue air emissions offsets for displacing other electricity generation sources.

The emissions profiles for natural gas power production and landfill flares are from EPA AP-42 compilations.[25]

4. *Diversion Quantities and Composition*

Baseline 2020 diversion quantities are based on actual materials recycled in 2020, as reported by Delaware County in its 2020 Act 101 County Recycling Report.[26] Recommended Zero Waste diversion projections were developed for the 10-year solid waste management plan and added to baseline diversion quantities. Both diversion composition tables are detailed in Table D1 of Appendix D.

5. *Disposal Quantities and Composition*

Baseline 2020 disposal composition is from the Pennsylvania DEP Waste Characterization Study, prepared by MSW Consultants, September 2022, and is based on data collected in the PA DEP's Southeast Region between November 9, 2020 and May 26, 2021 from three facilities – Covanta Plymouth, and two MSW transfer stations in Philadelphia.[27] Zero Waste Plan disposal projections were calculated by subtracting the Zero Waste Phase 1 and Phase 2 diversion projections from the baseline disposal compositions for each material enumerated in the 2020 composition table. Both disposal composition tables are detailed in Table E1 of Appendix E.

Table E2 in Appendix E summarizes Delaware County actual diversion and disposal tons for 2020, as well as projected diversion and disposal tons after implementation of Phase 1 and Phase 2 of Zero Waste programs recommended for Delaware County.

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[25] See U.S. Environmental Protection Agency at: AP-42: Compilation of Air Emissions Factors | US EPA.
[26] See: https://files.dep.state.pa.us/Waste/Recycling/RecyclingPortalFiles/Documents/2023/2020_County_Recycling_Data.pdf,
[27] See: https://files.dep.state.pa.us/Waste/Recycling/RecyclingPortalFiles/Documents/2022/PA_DEP_Report_FINAL_10-04-2022.pdf.

6. *Hauling Distances*

Truck travel distances from garbage collection routes to the midpoint between the Solid Waste Authority's two garbage transfer stations are based on the population center point (i.e., centroid) for Delaware County.[28] Distances to disposal facilities are measured from the midpoint between those two transfer stations.

Shipping distances to recycling markets are based on actual distances from that same Delaware County population center point to known markets. In cases where end markets or an end market are not disclosed by private businesses, an estimate was based on the Northeast Recycling Council (NERC) 2020 report Recycling Businesses in the NERC Region That Process or Use Post-Consumer "Blue Bin" Materials after MRF Processing.[29]

VI. LCA Results from Baseline Delaware County 2020 MSW Management Practices

Disposal of MSW generated in Delaware County in 2020 amounted to 467,770 tons. These disposal tons were almost entirely distributed among four disposal facilities. The proportion of those MSW tons received at each disposal facility is indicated in parentheses – two incinerators: Covanta Delaware Valley (81.3%) and Covanta Plymouth (1.1%); and two landfills: Fairless (17.4%) and Rolling Hills (0.3%).

Delaware County diversion of MSW from disposal that same year to recycling (including wood wastes used as industrial fuels displacing natural gas)[30] and composting totaled 218,599 tons, a diversion from disposal rate of 32%.

Tables A1 and A2, respectively, in Appendix A show LCA results for 2020 Delaware County disposal and diversion. These tables exhibit reference substance indicators for MEBCalc's nine human and environmental health impact categories for total tons disposed and total tons diverted, as well as on a per ton basis for disposal and diversion.[31]

Some of the specific human and environmental health impacts from MSW management choices in Delaware County in 2020 are worth mentioning separately due to their magnitude, especially for local human health impacts and global climate change effects. Their environmental economic value (EEV) benefits and costs are discussed in subsequent sections of this report. Here we focus on the reference substance emissions quantities that summarize the pollutants causing six of the nine human and environmental impacts assessed by MEBCalc: climate change, human health respiratory effects, human health effects from non-carcinogens, human health effects from carcinogens, waterways eutrophication, and ground level smog formation. These emissions quantities are reported separately for disposal and diversion for each of the six human and environmental health impacts discussed in the following subsections of this report. For emissions causing the remaining three impacts – acidification, aquatic ecosystems toxicity, and ozone depletion, reference substance impact indicator quantities are reported separately in Tables A1 and A2 of Appendix A.

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[28] Census Bureau population centroids for Pennsylvania counties are listed in https://www2.census.gov/geo/docs/reference/cenpop2020/county/CenPop2020_Mean_CO42.txt. Website for converting population centroid latitude and longitude is at https://gps-coordinates.net/gps-coordinates-converter.

[29] See NERC website resource at: Recycling Businesses in NERC Region using Post Consumer Recycled Content Dec 20.pdf

[30] Burning wood wastes in place of natural gas to generate power or heat energy is sometimes referred to as "beneficial use" rather than recycling. This is because the human and environmental health impacts of wood combustion are worse than those impacts from natural gas combustion. At the same time some believe burning wood scraps for energy is a better use than disposal in a landfill or incinerator. Hence, the use of the term "beneficial use" as a descriptor for diversion of a material to a non-recycling use. This is based on the belief that, although the use has negative environmental impacts, it is a use that is somehow not a typical waste disposal method. See Morris, J., 2017: Recycle, Bury or Burn Wood Waste Biomass? LCA Answer Depends on Carbon Accounting, Emissions Controls, Displaced Fuels, and Impact Costs. *Journal of Industrial Ecology* 21(4) 844-856 (available at: (https://onlinelibrary.wiley.com/doi/full/10.1111/jiec.12469), for LCA results that illustrate the human and environmental health harms from burning wood instead of natural gas to generate electricity or provide heat energy.

[31] Note that incinerators in the appendices are sometimes denoted as LMWCs, the acronym for large municipal waste combustors, which is one of EPA's categories of incinerators for emissions standards.

1. Climate Change

A. Diversion

Diversion of 218,599 tons of MSW from disposal to recycling and composting in 2020 avoided emissions of 246,000 tons of carbon dioxide equivalents (eCO_2). This metric accounts for the climate impacts of collecting, MRF processing, composting, and hauling and shipping diverted materials. It also accounts for upstream manufacturing of recycled-content products, as well as displacement of virgin-content manufacturing of the same quantities and types of products.

In addition, for biogenic materials diverted to composting, the metric accounts for the upstream displacement of petroleum-based fertilizers and pesticides by soil amendments composted from diverted biogenic materials such as food scraps and yard maintenance debris. The total for avoided carbon dioxide equivalent emissions also includes incremental carbon sequestration due to healthier soils from organic soil supplements enhancing plant growth.

Displacement and avoidance of upstream resource extractions from ecosystems, as well as of virgin-content product and materials manufacturing, enabled by diversion of MSW materials from disposal to recycling and composting provide climate benefits. Collection, hauling, shipping, MRF processing, composting, and diversion-based upstream manufacturing impacts associated with diversion to recycling and composting increase climate changing carbon emissions. These negative upstream and downstream impacts totaled 68,000 tons eCO_2 for recycling and composting. The benefits of diversion amounted to 314,000 tons of eCO_2 avoided through displacement of virgin-content manufacturing by recycled-content products and displacement of petroleum-based fertilizers and pesticides by organic soil amendments, plus the use phase incremental carbon sequestration due to healthier soils resulting in enhanced plant growth.

According to EPA, avoidance of 246,000 tons of carbon dioxide equivalent carbon emissions in 2020 provides the same climate benefit as taking 48,000 gasoline-powered passenger vehicles off the road in that year, or reducing annual miles driven by gasoline-powered passenger cars by 554 million miles.[32]

B. Disposal

Disposal of 467,770 tons of MSW in 2020 at landfills and incinerators, including landfill disposal of ash from incineration of Delaware County MSW, has a carbon footprint of 391,000 tons eCO_2 emitted into the atmosphere and contributing to climate change. This metric is reduced by offsetting credits for displacement of fossil-natural-gas-based power by electricity generated at the incinerators, as well as offsetting credits for recovery and recycling of ferrous and non-ferrous metals from incinerator ash residues. Based on the same EPA GHG equivalence calculator, Delaware County's MSW 2020 disposal climate footprint is equivalent to annual carbon dioxide emissions from 76,000 gas-powered passenger vehicles driving 880 million miles.

2. Human Health Respiratory Particulate Emissions

Small particulates no greater than 2.5 microns in diameter, including the many but very light nanoparticles, cause increases in morbidity and reduced life spans for humans impacted by those emissions. Diversion in Delaware County in 2020 avoided emissions of 294 tons $ePM_{2.5}$, while disposal of MSW that year increased particulate emissions by 12 tons $ePM_{2.5}$. One should note that virtually all particulate emissions avoidance due to recycling and composting is a benefit for households and businesses located outside of Delaware County, while the particulate pollution health costs of 81% of Delaware County's MSW disposal at Covanta Delaware Valley impact local households and businesses, especially in Chester where that incinerator is located.

The disparity in absolute magnitudes between climate changing emissions of eCO_2 and human respiratory disease-causing emissions of $ePM_{2.5}$ may seem to imply that particulate pollution is not a significant issue for Delaware County

[32] U.S. Environmental Protection Agency, Greenhouse Gas Equivalencies Calculator, available at https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator.

locally. However, particulate emissions have severe acute and long-term medical health effects on those living within the fallout zones of particulate pollutant emissions. The discussion and results for monetization of human health impacts due to respiratory and toxic pollutant emissions in subsequent sections of this report will provide estimates for the human health costs of respiratory and toxic emissions as compared to the environmental health costs of carbon emissions. Furthermore, human health costs of particulate and toxic emissions per ton of pollution for disposal facilities tend to be concentrated locally and occur in the near term, compared to the more globally dispersed and long-term environmental health costs of carbon emissions.

3. Human Health Non-Carcinogenic and Carcinogenic Toxic Emissions

Diversion in 2020 resulted in avoidance of both non-carcinogenic and carcinogenic toxics due to upstream virgin-content materials and products displacements. The specifics are 305,000 tons of toluene equivalent (eT) non-carcinogenic toxic emissions and 465 tons of benzene equivalent (eB) carcinogenic emissions avoided due to diversion programs. Upstream avoidance is greater than the pollution from local collection and management facilities for recyclables and compostables. Yet, as indicated for particulate pollution, the human health benefits from diversion are realized in many cases far from Delaware County, whereas the human health costs of MSW recycling and composting collection and processing activities occur in Delaware County.

Emissions of human health toxics associated with MSW disposal amounted to 47,200 tons eT and 99 tons eB for non-carcinogens and carcinogens, respectively. Due to the reliance on the Covanta Delaware Valley incinerator for disposal of 81% of garbage generated in Delaware County, the vast majority of the human health impacts of garbage management in Delaware County falls on Delaware County residents, especially those living in the fallout zone of pollution released through the Covanta Delaware Valley incinerator's smoke stack in Chester.

4. Eutrophication Emissions Impacts on Waterways

Diversion of Delaware County MSW provided a waterways nutrification avoidance of 3,000 tons of nitrogen equivalents, compared to emissions from MSW disposal amounting to 16 tons nitrogen equivalents (eN). As is the case for all nine human and environmental health impacts assessed by MEBCalc, these estimates for diversion and disposal include all emissions associated with collection, transportation, processing, and disposal, including emission offsets for fossil-gas powered electricity generation displaced on the grid by Covanta Delaware Valley and Covanta Plymouth electricity generation, as well as offsets from recycling of metals recovered from ash residues generated by incineration of Delaware County MSW at both incinerators. For diversion, they also include the net benefits of recycled-content over virgin-content upstream manufacturing, as well as the use phase benefits of lower nutrient runoffs for compost-based soil amendments and incremental carbon sequestration from healthier soils.

5. Ground Level Smog Formation

Diversion avoided ground level smog formation from management of 2020 Delaware County MSW for 13,700 tons of ozone equivalents (eO_3). Disposal exacerbated ground level smog by 4,800 tons eO_3. Benefits from avoidance of pollution impacts due to diversion mostly occur elsewhere than in Delaware County. Costs of diverted materials collection and processing activities and most disposal impacts occur locally. The exacerbation of ground level smog formation in Delaware County is likely to fall especially on households and businesses located in and around the environs of the Covanta Delaware Valley incinerator's smoke stack.

VII. Monetizing Physical Emissions Data to Estimate & Summarize Damage Costs for the Nine Impacts

This section's discussion and the following section's graphs illustrate how environmental economic values (EEVs), estimated by monetizing costs for the nine physical human and environmental health reference substance impacts from pollutant emissions, simplify comparisons between diversion and disposal for managing Delaware County discards. Otherwise, the physical quantity estimates themselves for the nine pollution impacts are so disparate in absolute physical quantities and impact severities that they defy readily understandable comparisons of relative importance for physical pollution increases or decreases for those nine impacts.

Another reason for monetizing human and environmental health impacts is to provide dollar costs for pollution impacts that can be compared to solid waste management system accounting revenues and costs. This provides a metric for human and environmental health impact costs of pollution that may help in the ongoing debate about how to balance pocketbook costs, pollution costs, environmental preservation, and conservation costs.

An important aspect of this need for balance arises because facilities, activities and other sources producing pollution may not have to pay for some or all of the damages caused by their releases of pollutants to the environment. In that case, the costs for damages will be reflected in:

- Higher health care costs for humans impacted by those pollutants
- Lower property values
- Lower agricultural productivity
- Damages to wildlife habitats
- Lower plant and tree growth
- Other dis-amenities in the fallout zones of pollutant releases imposed on the more-than-just-human entities within Earth's planetary ecosystems.

From the perspective of economics, the problem for a free-markets-based economy is that, if those producing pollution associated with a good or service do not pay full costs for their pollution, that good or service most of the time will be sold at a price that does not cover these human and environmental health damage costs. That, in turn, may cause more of society's resources to flow toward production and consumption of this good or service than would be the case if the price for that good or service were higher due to inclusion of these damage costs.

One might regard these situations as free disposal of pollutants to air, water and land. Economists refer to these damages as external diseconomies or externalized costs. Research on externalized economic damage costs from releases of pollutants to the environment leads to our ability to assign externality costs, also known as impact monetization factors or environmental economic values (EEVs), to the reference substances for the nine human and environmental health impacts assessed by MEBCalc.

Table 1 lists these damage costs per ton of reference substance emitted for each of MEBCalc's nine human and environmental health impacts. These damage costs are based on more than 30 scientific studies reviewed by Sound Resource Management Group in a 2019-20 study and report for Oregon Department of Environmental Quality (DEQ) and Oregon Metro (Metro).[33]

[33] Morris, J., *Economic Damage Costs for Nine Human Health and Environmental Impacts*, prepared for Oregon Department of Environmental Quality and Oregon Metro, July 2020.

Table 1: Reference Substance Damage Costs Per Ton for Each of the Nine Human & Environmental Health Impacts

Impact Category (Reference Substance)	Damage Costs (2021 $) Per Ton of Reference Substance
Climate Change (CO_2)	$204
Human Health:	
Respiratory Effects from Particulates ($PM_{2.5}$)	$583,449
Non-Carcinogenic Effects from Toxics (T)	$330
Carcinogenic Effects from Toxics (B)	$2,360
Waterways Eutrophication (N)	$23,995
Acidification (SO_2)	$395
Aquatic Ecosystems Toxicity (2,4-D)	$4,021
Ozone Layer Depletion (CFC-11)	$54,673
Ground Level Smog Formation (O_3)	$235

A summary of research for SRMG's report to DEQ and Metro on damage costs follows:

- ***Climate Change*** – Integrated assessment models (IAMs) are used by research agencies, such as the U.S. Interagency Working Group on the Social Cost of Carbon (IWGSCC) and economists including William Nordhaus of Yale University, to estimate economic damage costs from climate change. IAMs, such as the dynamic integrated climate-economy (DICE) model developed by Nordhaus, assess current year carbon emissions and the damages caused by those current year emissions for all future years through at least 2300. This long assessment timeline is because some GHGs, e.g., carbon dioxide, released in the current year remain in the atmosphere for hundreds of years. Current, future and far-future damage costs from GHG emissions in the present are typically stated as present value dollar costs per metric ton of carbon dioxide emissions in the current year. These estimates for a given year of carbon emissions are often called the social cost of carbon (SCC) for that year.

  Long lasting climate impacts from current GHG emissions raise the problem of how to compare climate change damages in the future against the costs of lowering GHG emissions in the present. Economists and others use discount rates to measure the present value of future damages to compare against the current cost of GHG emissions reductions.

  Estimating an appropriate discount rate involves making judgments or having estimates on time preference for income now versus the future, how those preferences change as income grows or declines, expected growth rates for the economy over extended future years, and valuations of probabilities for drastic climate impacts from current year carbon emission levels.

  SCC estimates at any given discount rate have tended to increase since initial studies that estimated them. This is because IAMs have become more accurate and comprehensive, and because of the lack of sufficient actions to limit climate change by countries around the world as yet. The increasing accuracy of IAMs is associated in part with observed data indicating that some effects of climate change – such as the collapse of polar-region ice sheets and glaciers – are occurring faster and with greater intensity than earlier models predicted. Thus, additional years of observation have persuaded scientists to recalibrate IAMs for increasing damage costs.

- ***Human Health Respiratory Effects from Particulates*** – There are few comprehensive peer-reviewed studies on human health damage costs from emissions of particulates to the atmosphere. An EPA technical support document (TSD) published in 2013 is the most comprehensive and robust of studies reviewed.[34] That reference incorporates U.S. geographic-region-specific damage cost estimates for 17 economic/industrial sectors for the human respiratory health cost of direct PM2.5 emissions.[35] These EPA data enabled SRMG to calculate a 17-sector weighted average cost, using as weights the direct fine particulate emissions from each of those sectors.

  Costs to human health per ton of fine particulate emissions is high for several reasons – (1) fine and ultrafine particulates are very small and light, so that a ton of particulates may be widely dispersed and have serious health impacts for a large population, (2) it doesn't take much particulate matter to have serious health consequences when inhaled, and (3) particulate emissions are widely dispersed due to their generation from combustion of various materials and fuels by sources providing heat, energy and/or transportation services.

  Because the impacts of particulate emissions affect human health in future years as well as the current year, there are issues regarding the ethics of discounting even near-term future human health costs, just as there are for long-term climate change economic damages from current GHG releases. Furthermore, as the economy grows and population increases, the number of impacted people and the fine particulates they breathe both go up. Hence, what seems a very high damage cost for particulates compared with damage costs for the other eight impacts could still underestimate the human health damages from current year particulate emissions.

- ***Human Health Non-Carcinogenic Effects from Toxic Pollutants*** – Most references for non-cancer human health impacts base their cost estimates on mercury emissions to air, some of which deposit in water. Once in water, microbes convert mercury to methylmercury, making it fat soluble, which works its way up the food chain to contaminate fish species that are consumed by people. Hence, human exposures can occur both directly from air emissions and indirectly from the cascading effect of air emission deposits on waterways.

  Mercury impacts on human health are both neurological and cardiovascular. The latter is not as well studied, so the estimates of mercury's cardiovascular impacts are more uncertain. There are also uncertainties in health impact estimates that arise from observed mercury dose-health response data. Observations can measure health responses only down to the lowest level of observed doses. Hence, when extrapolating a dose-response relationship to an entire population exposed to mercury emissions, one must decide whether to project observed dose-response relationships further down to low and very low doses below observed dose levels. The estimate for human non-carcinogenic toxicity cost shown in Table 1 provides a balance between the low cost and more certain neurological health effects and the much higher cost but more uncertain cardiovascular effects of mercury, as well as between the threshold versus no threshold effects of mercury exposure.

- ***Human Health Carcinogenic Effects from Toxic Pollutants*** – Several studies reviewed for cancer damage costs were focused on heavy metals. Some heavy metals have both carcinogenic and non-carcinogenic impacts, and reviewed studies did not always distinguish between these two impacts when estimating human health costs.

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[34] U.S. Environmental Protection Agency (EPA), *Technical Support Document: Estimating the Benefit Per Ton of Reducing PM2.5 and PM2.5 Precursors from 17 Sectors,* January 2013.

[35] Indirect particulate emissions are caused by gaseous emissions of pollutants such as nitrogen oxides (NO_x) and sulfur dioxide (SO_2) that react with other compounds in the atmosphere to form particulate matter. Such gaseous emissions are often termed particulate precursors.

It is also worth noting the substantial increase in carcinogenic damage costs for arsenic and cadmium between estimates published in 2000 and estimates published in 2016. Both studies had the same scientist as one of the two co-authors for each study. This is another example of the tendency for damage costs for environmental impacts to increase over time due to better and more comprehensive emissions data, better modeling of dispersion and exposure from emissions sources to impacted populations, better data on health effects of exposure, and economic and demographic growth that tend to increase fugitive emissions quantities and numbers of people exposed to emissions. To reflect this uptrend in cost estimates, The Table 1 2021-dollar figure for benzene damage costs from cancers uses the midpoint between the sample mean and the upper end of a 90% confidence interval for estimates given in studies reviewed for the Oregon DEQ and Metro project.

- ***Waterways Eutrophication*** – Damage costs for deposition of nitrogen in surface waters depend on costs for, among other effects, algae blooms in freshwaters or coastal waters from nitrogen loadings to surface waters either from direct emissions of nitrogen to water or of cascading nitrogen emissions to water from releases to air or land. Algae blooms and other impacts of nitrogen loadings can cause fisheries decline due to eutrophication of surface waters. An example is the annual dead zone in the Gulf of Mexico at the mouth of the Mississippi River.

- ***Acidification*** – Sulfur dioxide (SO_2) emissions were one target of the 1970 Clean Air Act (CAA), and more especially of the Acid Rain Program established under Title IV of the CAA Amendments of 1990. Under Title IV, EPA has regulated SO_2 emissions since 1993 using a cap-and-trade system of tradable emissions allowance permits, and facilitates annual auctions for those permits. EPA publishes the spot clearing price reached during those auctions.

  Average prices in the spot auctions have recently dropped below $1 per metric ton of SO_2 emissions compared with nearly $400/MT in earlier years. Causes for this decrease likely include:
  - The decline in demand for coal-fired power,
  - The Great Recession (2008-2009) which substantially reduced overall demand for energy in general,
  - The availability of cheap natural gas due to fracking technology and the consequent decline in costs of natural gas-fired power, and,
  - The continued growth of solar and wind power and their falling prices.

  The EPA auction spot clearing prices may represent abatement costs more closely than damage costs. Yet abatement costs also may reflect damage costs. Their decline may be indicative of a decrease in SO_2 emissions. At the same time, estimates in the reviewed scientific literature provide scant information on damage costs for SO_2 releases onto agriculture and forest lands. Considering the possibility of either decline or increase in future damage costs for sulfur dioxide, the Table 1 estimate reflects the midpoint of the low and high ends of a 65% confidence interval for the sample mean of auction prices (excluding the high average auction prices during 2001-2010). The high end may help account for the lack of estimates in much of the literature for damage costs from forestry and agriculture impacts of SO_2 emissions.[36]

[36] A 65% confidence interval around the sample mean provides the low- and high-end costs for those environmental impact categories where there appear to be trends in emissions and damage costs that in future years could move in either direction from the sample mean. In order to maintain some similarity to the 0.65 probability width of those 65% confidence intervals, for some impact categories SRMG used the upper end of a 90% confidence interval to stretch the probability width to 0.45 for an interval stretching from the sample mean to the high-end cost calculated using the upper end for a 90% confidence interval. The midpoint between the reviewed studies' sample mean and the upper end of a 90% confidence interval for that sample mean provides damage costs for impact categories where there appears to be a substantial likelihood of continuing increases in damage costs, and little probability of decreases.

- ***Aquatic Ecosystems Toxicity*** – The Table 1 estimate for aquatic ecosystem toxicity damages from 2,4-D deposition on freshwater represents the midpoint between low and high ends of a 65% confidence interval about the sample mean for estimates in reviewed studies. With very few studies in this sample, the 65% confidence interval may mitigate against underestimating or overestimating aquatic toxicity impacts, while also providing mitigation against the lack of data on aquatic ecosystem costs from pollutant releases.

- ***Ozone Layer Depletion*** – Only four studies were found that provide damage costs for stratospheric ozone layer depletion. Two are based on the same source. The highest estimate is based on politically developed ecotaxes in Sweden. Hence, the midpoint of the range between the 65% confidence interval low end and the sample average may prevent overestimating ozone layer depletion impact costs, while also recognizing the lack of data on ozone layer depletion costs from ozone depleting pollutant releases.

- ***Ground Level Smog Formation*** – The damage cost estimate for ozone in Table 1 is the midpoint between the mean of reviewed studies and the upper end of a 65% confidence interval. The prevalence of NO_x emissions in some geographic areas combined with the likelihood of higher temperatures and sunny skies during certain weeks or months of the year as our climate warms justifies using the high end of the 65% confidence interval.

VIII. LCA Monetization Results for the Nine Human and Environmental Health Impacts

In addition to physical quantity impacts for reference substances, Tables A1 and A2 in Appendix A provide monetized total and per ton LCA damage benefits and costs. Benefits in Tables A1 and A2 are displayed as positive values. Damage cost increases are displayed as negative values. These values are presented in 2021 dollars.

One of the advantages of monetizing physical impacts is that monetized results for each of the nine impacts can be added together to produce an overall environmental economic value (EEV) benefit/(cost) score for 2020 diversion and disposal. Figure 1 graphically displays EEV totals (millions of 2021$) for Delaware County 2020 diversion and disposal from the nine human and environmental health impacts.

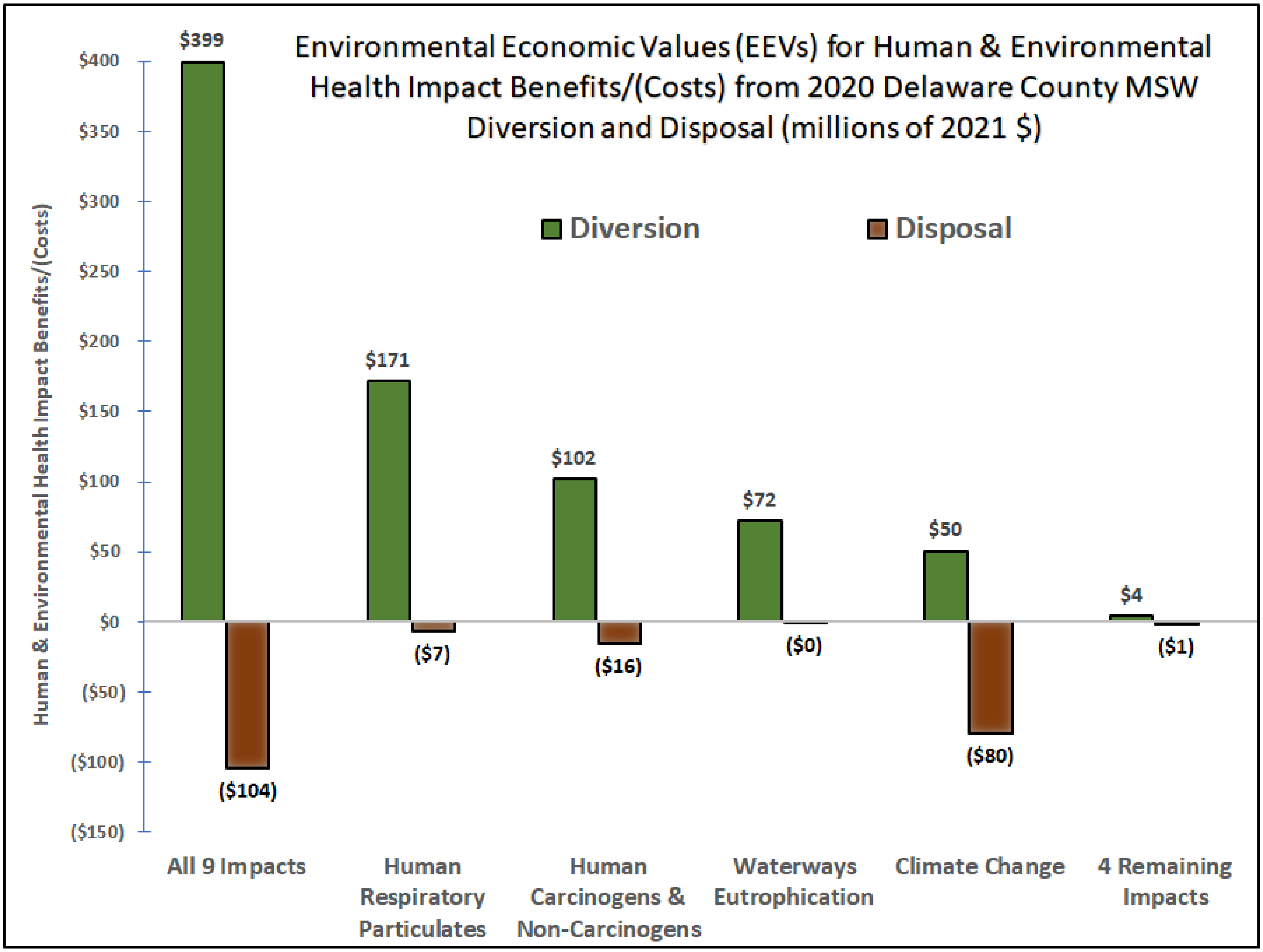
Figure 1 indicates that diversion avoids a substantial amount of EEV costs for human and environmental health emissions by substituting upstream production using diverted materials for upstream production based on extracting virgin resources from ecosystems. The margin between EEV costs from using diverted materials versus EEV costs from using virgin resources outweighs damage costs for collection, transfer and hauling/shipping activities, and composting or material recovery facility (MRF) processing of diverted MSW materials. The net human and environmental health monetized benefits of diverting 2020 MSW in Delaware County to recycling and composting total $399 million.

By contrast Delaware County MSW disposal has substantial human and environmental health EEV costs. These costs for 2020 total $104 million (2021 $), as indicated on Figure 1.

In addition to total benefits and costs for diversion and disposal, Figure 1 also exhibits EEV diversion and disposal details for human health respiratory, human health non-carcinogenic plus carcinogenic toxicity, waterways eutrophication, and climate change. These details show that the same preferential relationship for diversion over disposal holds for these separate impacts. Furthermore, Tables A1 and A2 in Appendix A exhibit the same preferential outcomes for diversion versus disposal for acidification, aquatic ecosystems toxicity, ozone depletion, and ground level smog formation. In other words, diversion has better outcomes in total, and for all nine separate human and environmental health impacts, versus disposal for managing Delaware County MSW in 2020.

Furthermore, the only impact for which diversion EEV benefits are less than EEV disposal costs is climate change. There the $50 million in EEV benefits from diversion are outweighed by $80 million in EEV costs for disposal. Diversion EEV benefits in total exceeds disposal's overall EEV costs by $296 million. This despite Delaware County MSW disposal in 2020 totaling 467,770 tons, more than twice times as much as 2020 diversion of 218,599 tons.

Figure 1: EEVs for Benefits/(Costs) of All Nine Impacts and Separate EEVs for Climate Change, Human Respiratory Particulates, Human Carcinogens + Non-Carcinogens, Waterways Eutrophication, & the Remaining Four Impacts



However, these totals for human and environmental impact net monetized benefits from diversion and monetized costs for disposal don't exactly illuminate many important aspects of the story regarding human and environmental health impacts from choices made by Delaware County in managing MSW in 2020. The next section delves more deeply into LCA results by dissecting and discussing local versus global human and environmental health impacts of MSW management outcomes for Delaware County during 2020.

IX. Comparison of EEVs for Incineration vs. Landfilling for Disposal of Delaware County MSW

Table A3 in Appendix A exhibits human and environmental health costs per ton of Delaware County MSW disposal in 2020 for the Covanta Delaware Valley incinerator and for the Rolling Hills Landfill. EEV costs shown in Table A3 include impacts from MSW hauling from transfer stations to these disposal facilities, hauling of incinerator ash from Covanta Delaware Valley to landfill disposal, ash landfilling, disposal facility operations, and impact offsets for electricity generation from MSW incineration and metals recycling from combustion ash. That table indicates that the net human and environmental health costs total $234 per ton of MSW disposal at the Covanta Delaware Valley incinerator versus $131 per ton of MSW disposal at the Rolling Hills Landfill. For both disposal facilities, the costs for climate change per ton of MSW disposal account for the largest share of their human and environmental health impact EEV costs.

Figure 2: Stacked EEVs for Human and Environmental Health Costs Per Ton of 2020 MSW Hauling and Disposal: Covanta Delaware Valley Incinerator vs. Rolling Hills Landfill exhibits the disparity in EEV costs (in 2021 dollars) between incineration and landfilling for Delaware County in 2020. Covanta Delaware Valley incineration's total EEV cost, shown on the stacked bar labeled Covanta Delaware Valley in Figure 2, was $234 per ton. This total EEV cost for MSW disposal is 78% higher than Rolling Hills Landfill's total EEV cost per ton of $131 for Delaware County MSW disposal, shown on the stacked bar labeled Rolling Hills (LCA 100) on Figure 2.

The stacked bars for EEV costs indicate that global climate change costs account for 74% of total human and environmental health economic costs for Covanta Delaware Valley incineration, compared with 96% for Rolling Hills Landfill. Yet Rolling Hills Landfill's climate cost itself at $126 per ton is 27% lower than the climate cost of $172 per ton for MSW disposal at the Covanta Delaware Valley incinerator.

The remaining eight human and environmental health EEV costs total $61 per ton of MSW disposal at Covanta Delaware Valley incinerator and $5 per ton of MSW disposal at Rolling Hills Landfill. In other words, Rolling Hills EEV cost for the eight non-climate changing human and environmental health impacts is 91% lower than Covanta Delaware Valley EEV cost.

Another way to look at these EEV cost disparities is that the Covanta Delaware Valley incinerator's global climate change impact EEV cost is 37% greater than the Rolling Hills Landfill's global climate change EEV cost. In addition, Covanta Delaware Valley's other eight human and environmental health EEV costs are 11.6 times higher than Rolling Hills Landfill's other eight EEV costs. That is, incineration is worse for the global climate than landfilling. Furthermore, the Covanta Delaware Valley incinerator in Chester is dramatically much worse than landfilling at Rolling Hills in terms of local impacts, most of which are for increased human health morbidities and mortalities from disposal of Delaware County MSW, even after accounting for longer hauling distances to reach the Rolling Hills Landfill.

1. *20-Year LCA Result for Rolling Hills Landfill*

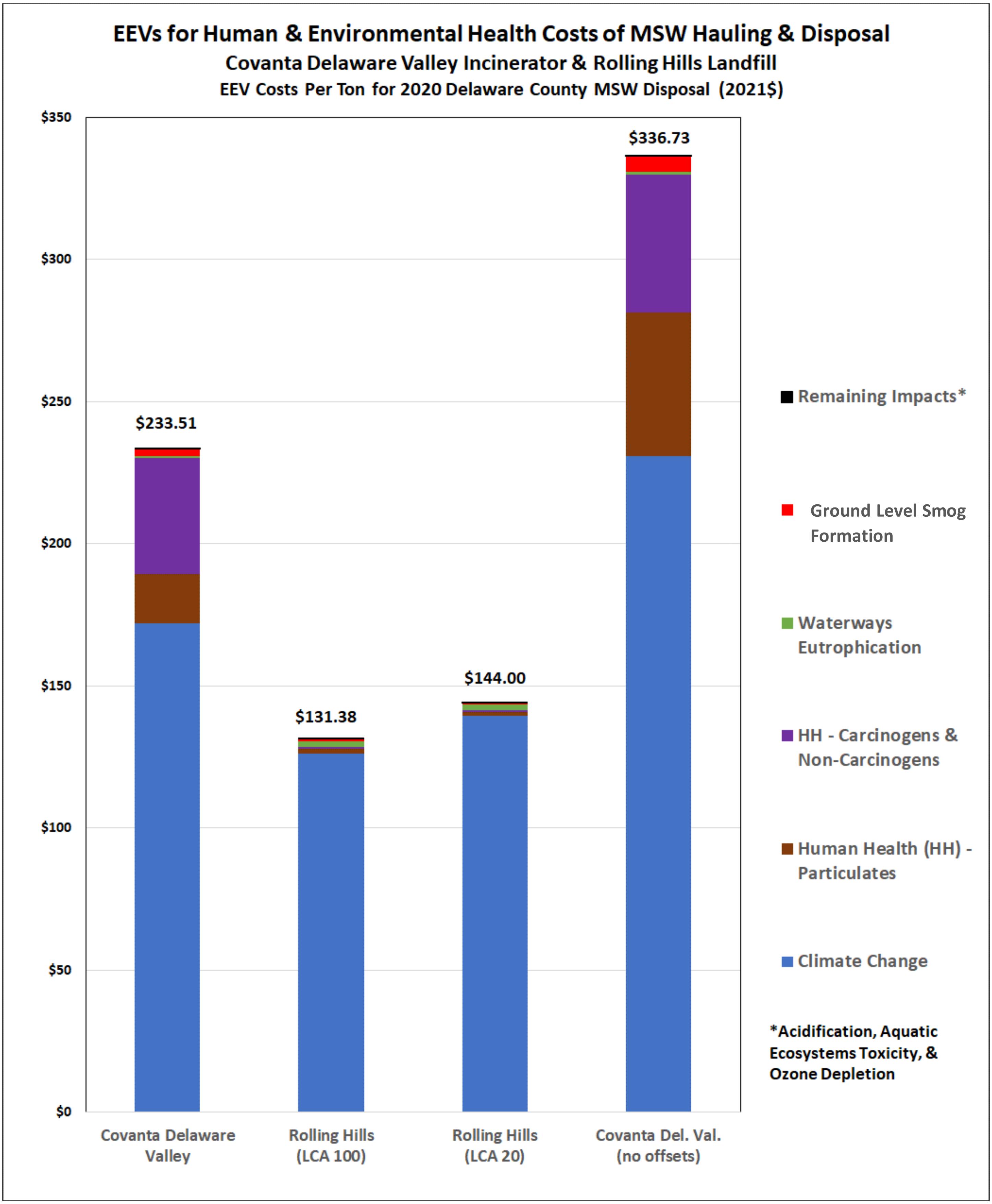
Figure 2 also displays LCA EEV cost results for Rolling Hills Landfill's 20-year impacts on the stacked bar labeled Rolling Hills (LCA 20). The 20-year human and environmental health LCA for Rolling Hills results in a 9.6% higher total EEV at $144 per ton landfilled compared against the 100-year LCA EEV of $131 per ton shown on Figure 2. This increase is due to an increase of more than $13 in EEV costs for Rolling Hills Landfill's 20-year climate impacts.

Total EEV for the other eight human and environmental health impacts decreased by less than a dollar. The fact that EEV costs decrease for the 20-year LCA is not surprising. All impact characterization factors for pollutants driving these eight impacts are the same for both 20- and 100-year LCAs. Landfills continue generating and then releasing non-captured (also known as, "fugitive") pollutants for many years beyond the 20 years following burial of wastes. Hence, cumulative impacts and their EEV costs are lower for the 20-year LCA for non-climate impacts versus the 100-year LCA.

However, the 10.6% increase of $13 for the climate EEV per ton landfilled could seem surprising since landfilled biogenic wastes have a 20-year global warming potential (GWP) characterization factor for methane emissions of 81.2 versus 27.9 for their 100-year GWP, a 2.9 multiple for climate impacts per ton of methane landfill emissions when evaluated over just the 20-year interval. Methane is the most concerning of near-term landfill pollutant releases because of its high generation amounts relative to most GHGs other than carbon dioxide, and the much higher climate impacts over 20 years for methane emissions to the atmosphere versus methane emission impacts over the longer 100-year time horizon.

One reason for the disparity in 20- versus 100-year climate impacts for methane is that, once released to the atmosphere, methane oxidizes to carbon dioxide within about 12 years. This tends to make its average climate impact over 100 years lower, depending on the time profile of methane emissions from the landfill.

Figure 2: Stacked EEVs for Human and Environmental Costs Per Ton of 2020 MSW Hauling and Disposal: Covanta Delaware Valley Incinerator vs. Rolling Hills Landfill

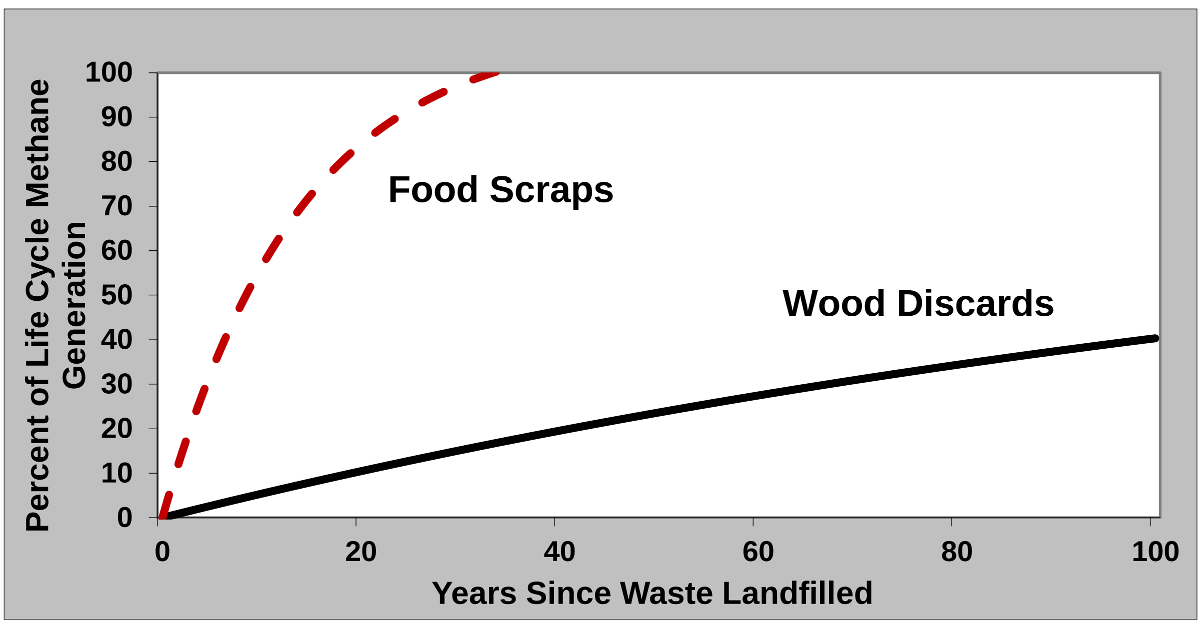


Moreover, the actual increase in climate impacts is driven by important additional factors. For one, not all carbon in MSW is biogenic. Some, for example carbon content in most plastics wastes, is of ancient fossil origin and does not biodegrade to methane under the anaerobic conditions of landfills. For Delaware County MSW in 2020, about 43% of carbon in materials in the County's disposal stream was fossil carbon.

In addition, methane generation inside a landfill sometimes comes quickly after burial of a material and sometimes quite slowly, as exhibited in Figure 3. Carbon in landfilled food scraps biodegrades to methane much faster than carbon in landfilled wood discards. In fact, carbon in landfilled wood biodegrades to methane so slowly that methane generation in a landfill in years 1 through 20 following burial of wood amounts to only about 10% of wood's potential lifetime methane generation. This contrasts with about 40% of lifetime potential generation over the first 100 years following burial. That means that the climate impact of methane releases from landfilled wood discards is less over 20 years than its climate impact over 100 years, assuming the same rate of capture versus non-capture for landfill gases over those years.[37]

Compare this LCA result for wood discards to LCA results for methane's generation over time from landfilled food scraps. As portrayed by Figure 3, about 85% of lifetime methane generation potential for food scraps occurs in the first 20 years following burial in an anaerobic landfill. 100% of potential methane generation occurs within less than 35 years. This makes the average potential climate impact of methane emissions from food scraps over 20 years almost 2.5 times greater than its average potential impact over 100 years.

Figure 3: Cumulative Percentage of Life Cycle Methane Generated Since Material Landfilled



Sources: U. S. Environmental Protection Agency, 2005. *Landfill Gas Emissions Model (LandGEM) Version 3.02 User's Guide.* EPA-600/R-05/047, EPA: Washington, DC; De La Cruz, F. B., Barlaz, M. A., 2010. Estimation of waste component-specific landfill decay rates using laboratory-scale decomposition data. *Environmental Science & Technology* 44 (12): 4722-4728; Morris, J., 2010. Bury or burn North American MSW? LCAs provide answers for climate impacts & carbon neutral power potential. *Environmental Science & Technology* 44 (20): 7944-7949; Wang, X., Padgett, J. M., De la Cruz, F. B., Barlaz, M. B., 2011. Wood biodegradation in laboratory-scale landfills. *Environmental Science & Technology* 45: 6864-6871, and Morris, J., 2017. Recycle, bury, or burn wood waste biomass? LCA answer depends on carbon accounting, emissions controls, displaced fuels, and impact costs. *Journal of Industrial Ecology*, 21 (4) 844-856.

[37] The 20-year methane release is only 25% pf the 100-year release. So even though the 20-year GWP for wood discards is almost 3 times the 100-year GWP, the impact over 20 years is less than 0.25 * 3 = 0.75 as a proportion of the 100-year impact.

Other materials such as mechanically pulped paper products like newsprint and catalog paper have landfill methane generation profiles that resemble the Figure 3 profile of wood discards. Leaves are more like wood than food in their landfill methane generation behavior. On the other hand, chemically pulped virgin-content paper products such as printing and writing papers, and the linerboard inside and outside parts of corrugated cardboard boxes behave more like food scraps than wood. This is because chemical pulping removes the lignin from tree wood. Lignin inhibits the generation of methane from mechanically-pulped paper and paperboard products. Based on composition of disposed MSW in 2020, Delaware County garbage has more biogenic materials that behave like wood scraps than it does materials behaving like food scraps.

Lastly, notice that the 20-year LCA total EEV cost for Rolling Hills is $144 per ton MSW landfilled, less than the EEV cost of $234 per ton MSW incinerated at Covanta Delaware Valley. Municipal waste combustion is not sensitive to whether emissions are evaluated by a 20-year or 100-year LCA. One reason is that Covanta Delaware Valley stack emissions all occur as MSW is fed into the incinerator in year one of the 20-year or 100-year LCA time frame. The other reason is that incinerator atmospheric emissions contain only trace amounts of short-run climate sensitive GHGs such as methane. Virtually all incinerator GHG emissions are carbon dioxide with its GWP characterization factor of 1 over both 20 and 100 years. Hence, there is no significant difference in climate impacts over a 20- or 100-year LCA time frame for the Covanta Delaware Valley incinerator.

Although not portrayed on Figure 2, we also calculated EEVs for Rolling Hills at landfill gas (LFG) capture rates less than the 70% capture rate used to evaluate landfill disposal for Delaware County MSW in Figures 1 and 2. More about those LCA monetization results in Subsection 3. First, we discuss local versus global impacts for the Covanta Delaware Valley incinerator in the next subsection to showcase implications of dividing Covanta Delaware Valley human and environmental health impacts into local versus global amounts.

2. LCA Results for Incineration Without Offsets for Natural Gas-Fueled Electricity and Metals Recycled from Ash

Figure 2 also shows LCA results for the Covanta Delaware Valley incinerator without emissions offsets (i.e., deductions) for fossil natural gas electricity generation displaced by electricity generated from burning Delaware County MSW, and without emissions avoidance credits from recycling metals recovered from that incinerator's bottom ash. These results are portrayed by the stacked bar labeled Covanta Del. Val. (no offsets).

One possible scenario yielding vastly reduced offsets is that solar and wind energy sources could at some point in the future become predominant generators of power for the Pennsylvania power grid. At the same time, Delaware County's implementation of Zero Waste programs could become highly effective at diverting metals from disposal. In that case, the no offsets scenario could approximate human and environmental health EEV costs for Covanta Delaware Valley.

Perhaps a more important reason for examining this no offsets scenario is that it facilitates dissecting local versus global pollution impacts from Covanta Delaware Valley stack emissions by eliminating offsets for upstream metals recycling and power offsets from displacing natural-gas-fueled electricity generation. These two pollution sources likely occur mostly outside of the City of Chester where Covanta Delaware Valley is located. Hence, avoiding these two outside of Delaware County pollution sources by burning MSW at Covanta Delaware Valley does not actually change human and environmental health costs in Chester and nearby areas of Delaware County.

There are two large natural gas power plants in nearby boroughs. There is no guarantee that one of these would not be the source for replacement power when Covanta Delaware Valley shuts down for either routine maintenance or unanticipated upsets. Whether one or both of these plants are used for meeting short-term peaking electricity demand on the Pennsylvania power grid, or whether such peaking power needs are met by more distant natural-gas-fired power plants that come on and off the grid on a regular basis, is unknown. At the same time, the no offsets scenario for Covanta Delaware Valley may approximate improvements in local pollution impacts in the future should Delaware County MSW no longer be sent to the Covanta Delaware Valley incinerator for disposal due to the typically lower human health impacts of natural-gas-fired power versus MSW-fired power.

As shown on Figure 2 Covanta Delaware Valley's human and environmental health impacts, absent offsets, have EEV costs totaling $337 per ton of Delaware County MSW burned at that facility. $99 per ton burned of this no offsets EEV total are costs for human health respiratory, non-carcinogenic toxicity and carcinogenic toxicity impacts that fall in large part on the health and lifespans of persons in households and workplaces in Delaware County, especially in the City of Chester where the Covanta Delaware Valley incinerator's smoke stack is located.

Human and environmental health costs for waterways eutrophication and smog formation amount to $6 per ton from Covanta Delaware Valley emissions. These impacts also are mostly incurred by residents and workers in Chester and nearby neighborhoods in Delaware County. Added to human health costs of $99 per ton, LCA and monetization results from this study suggest that local EEV costs from burning MSW at Covanta Delaware Valley amount to $105 per MSW ton disposed at that incinerator.

The majority of Delaware County MSW EEV impacts costs associated with the Covanta Delaware Valley incinerator are related to climate changing carbon emissions. Excluding offsets, climate change EEV cost is $231 per ton of MSW combusted at the Covanta Delaware Valley incinerator. EEV costs for stratospheric ozone depletion emissions from the Covanta Delaware Valley incinerator are not substantially different from zero. Climate change and ozone depletion together account for what might be termed the global impacts of emissions from disposal facilities used for Delaware County MSW. Keep in mind that this global EEV costs figure of $231 per ton ignores upstream climate change and ozone depletion benefits related to Covanta Delaware Valley's offsets for its electricity generation and metals recycling.

The above discussion supports using $105 per ton for incineration's local Delaware County human and environmental health EEV costs plus $231 per ton for global EEV costs. Acid rain, aquatic ecosystems toxicity, and rounding account for the missing dollar from the total $337 EEV cost for Covanta Delaware Valley absent any EEV credits for offsets.

Covanta Delaware Valley incinerated somewhat over 380,000 tons of Delaware County MSW in 2020. At $105 for local human and environmental costs per ton, local EEV costs for disposal at Covanta Delaware Valley imposed nearly $40 million of human and environmental health costs on Chester City and nearby residents and workers, of which nearly $38 million is human health costs.

It should also be mentioned that Delaware County MSW tons burned at the Covanta Delaware Valley incinerator made up less than 31% of tons incinerated at that incinerator in 2020. Hence, the total local human health impact costs of $38 million from burning Delaware County MSW at Covanta Delaware Valley underestimates total local human health costs by a factor larger than three. Local human health costs imposed on Chester City and environs for all wastes burned at Covanta Delaware Valley in 2020 total $123 million.

Importantly, there could be additional local impacts as a result of Covanta Delaware Valley's CO_2 emissions. There is peer-reviewed research suggesting that carbon dioxide emissions can form CO_2 domes over cities and other geographic areas having high levels of carbon emissions.[38] Such an occurrence would result in additional local human morbidity and mortalities from enhanced impacts of particulate emissions and smog formation. This means that local human health impacts of the Covanta Delaware Valley incinerator could well be higher than $123 million.

3. Rolling Hills Landfill EEV Cost Sensitivity to Landfill Gas (LFG) Capture Rate

As far as we are aware there has never been an actual tracking of landfill gas (LFG) generation and emissions to the atmosphere over 20 years or 100 years following burial of one year's MSW in a landfill. Most empirical data on landfill emissions comes from various methods for measuring those emissions on a spot check basis periodically over the years as new batches of MSW continue to be buried on top of previous batches. This makes it essentially impossible to track landfill emissions from any single year of MSW burial. Changing compositions and burial quantities for MSW over the years compound difficulties in tracking emissions from MSW buried in a particular year.

[38] Jacobson, Mark Z, 2010, Enhancement of Local Air Pollution by Urban CO_2 Domes. *Environmental Science & Technology 44(7) 94305-94020.*

Generation of landfill gases (LFGs), including methane, from biodegradation of biogenic carbon containing materials buried in the landfill has, to our knowledge, not been empirically measured at all. What has been done is to track and evaluate methane generation under laboratory simulations of landfill conditions for individual materials commonly found in MSW.[39] That research yields models of LFG methane generation over time such as those shown in Figure 3 for wood and food scraps. This research supports modeling of MSW LFG generation in software such as EPA's LandGEM model used in MEBCalc.[40]

For this LCA study we needed to know what the LFG capture rate was for just the particular cohort of Delaware County MSW disposal buried at Rolling Hills and Fairless landfills in 2020. Delaware County MSW disposal composition for 2020 was estimated from the Pennsylvania composition study completed in 2022. Carbon content for major biogenic materials is available in literature on MSW management. EPA's LandGEM model provided projections for LFG generation in each future year based on the composition of MSW landfilled in 2020.

However, we were still left with the problem of projecting the LFG capture rate in each future year for the 100-years following MSW burial in 2020. Hence, we assumed a capture rate of 70%, which is somewhat less than the 75% capture rate widely used in LCA studies on landfill emissions.

Figure 2 compared human and environmental health impact costs for Rolling Hills Landfill versus the Covanta Delaware Valley incinerator. The discussion in the previous subsection on EEV costs for these two disposal facilities also delved into human and environmental health impacts incurred locally in the environs around each disposal facility from its emissions of particulates, toxics and smog forming compounds. The costs for these local human and environmental health impacts can be distinguished to a reasonable extent from the more global human and environmental health costs from emissions of pollutants causing climate change and stratospheric ozone depletion. The discussion of results portrayed by Figure 2 along with the uncertainties regarding whether the actual LFG weighted average capture rate that will be achieved at Rolling Hills in the 100 years between 2020 and 2119 will approximate 70% mandates an analysis of Rolling Hills EEV costs for human and environmental health impacts at LFG capture rates lower than 70%.

Figure 4: Stacked EEVs for Human & Environmental Health Costs Per Ton of MSW Collection, Hauling and Disposal: Rolling Hills Landfill vs. Covanta Delaware Valley Incinerator addresses this uncertainty on Rolling Hills LFG capture rates. Figure 4 portrays Rolling Hills EEV costs at 70%, 30% and 0% capture rates, along with the Covanta Delaware Valley no offsets EEV costs scenario. The figure shows stacked bars of EEV costs for MSW collection, MSW and ash hauling, and disposal facility impacts, with the disposal facility human and environmental health impacts separated into mostly local impacts versus mostly global impacts.

What Figure 4 clearly shows is that regardless of LFG capture rate, landfilling at Rolling Hills is less costly for human and environmental health than incineration at Covanta Delaware Valley when looking at direct impacts without granting offsets for metals recycling and displaced electricity generation. This result is mainly due to the much greater local human health costs of incineration compared to those local human health costs for landfilling. Those local human health costs for incineration outweigh the greater climate changing costs of landfill methane and carbon dioxide emissions even when the landfill gas capture rate is zero.

Adding Covanta Delaware Valley offsets back into the comparison, incineration's total EEV costs drop to $241 per ton compared to the $344 per ton shown on Figure 4 for Covanta Delaware Valley excluding those offsets.[41] Rolling Hills LFG capture rate needs to be at least 30% to reduce its total EEV costs to $240.

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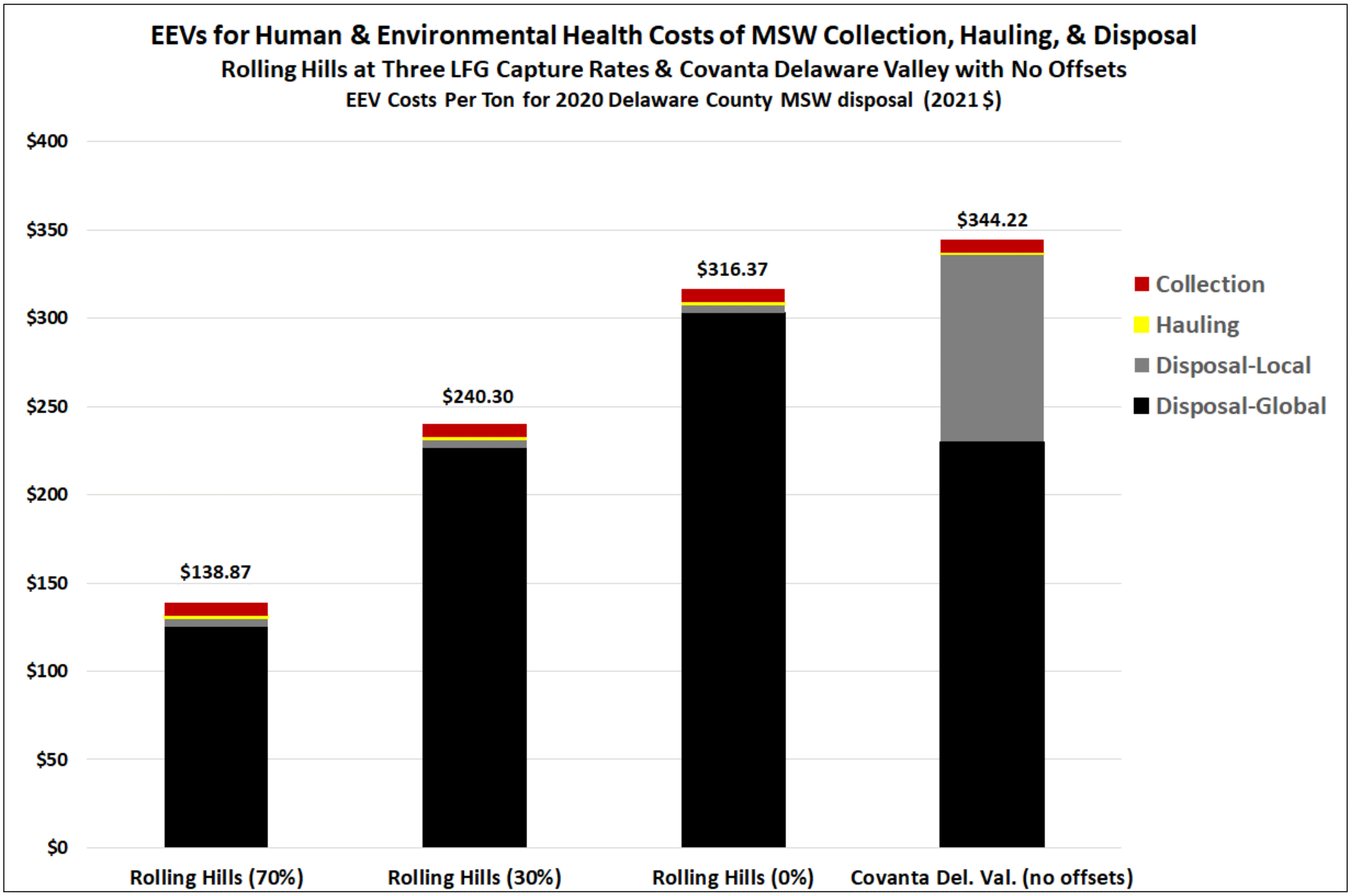
[39] De la Cruz, F. B., *et al*, 2010, *op. cit.*

[40] There has been recent peer-reviewed work measuring methane emissions from a new landfill without any LFG capture equipment in place for the first few years of MSW burial. For example, De la Cruz, F. B., *et al*, 2016, *op. cit.* suggests currently in-use models of LFG generation likely overestimate emissions during the first few years after initial burial.

[41] Note that the no offset per ton EEV cost for Covanta Delaware Valley shown in Figure 2 is $337. Figure 4 shows the higher cost of $344 because Figure 4 includes human and environmental health costs of $7.49 for MSW collection. These MSW collection costs are

Figure 4: Stacked EEVs for Human & Environmental Health Costs Per Ton for MSW Collection, Hauling and Disposal: Rolling Hills Landfill vs. Covanta Delaware Valley Incinerator



At 30% LFG capture, EEV landfilling costs for climate change, exceed climate costs for incineration. Rolling Hills LFG capture needs to be in the 50% neighborhood for its climate changing EEV costs to be lower than Covanta Delaware Valley's EEV climate costs that include offsets for electricity generation and metals recycling.

These differences between global and local human and environmental health impacts and between climate and human health impacts emphasize the importance of looking beyond climate change at other impacts from pollution emissions when evaluating incineration versus landfilling choices for disposal of MSW.

4. Comparison of Impact EEV Costs for Hauling MSW to Rolling Hills Landfill and Covanta Delaware Valley

There are concerns that shipping Delaware County MSW to an out-of-county landfill such as Rolling Hills Landfill for disposal would increase human and environmental health costs substantially versus continuing to use the Covanta Delaware Valley incinerator for disposal of most Delaware County MSW. However, studies on human and environmental health costs for managing MSW show that hauling/shipping amounts to a small fraction, typically less than 5%, of human and environmental health EEV costs for collecting, shipping and disposal of MSW.[42]

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excluded from Figure 2 which portrayed just hauling and disposal EEV costs. They are included on Figure 4 to support the brief discussion on hauling costs in Subsection 4.

[42] See, for example: Morris, J., 2020, A triple win: Decreased trash generation, reduced costs & lower environmental impacts for Seattle, *Resource Recycling*, pp. 24-29; and Morris, J., 2005, Comparative LCAs for curbside recycling versus either landfilling or incineration with energy recovery. *International Journal of Life Cycle Assessment*, 10(4) 273-284.

Figure 4 confirms this general result specifically for disposal of Delaware County MSW at the Rolling Hills Landfill compared with disposal at the Covanta Delaware Valley incinerator plus transportation of ash to Rolling Hills Landfill. In fact, the EEV costs of human and environmental health impacts for hauling MSW by truck to Rolling Hills Landfill or Covanta Delaware Valley for disposal are 1% or less of total EEV costs for MSW collection, hauling and disposal, regardless of which facility is used for disposal. Hauling EEV costs for MSW disposal at Rolling Hills are $1.56 per ton compared with $0.76 per ton for hauling MSW to Covanta Delaware Valley. These estimates account for round-trip mileage by truck to Rolling Hills compared with the round trip to Covanta Delaware Valley plus the round trip for hauling ash from Covanta Delaware Valley to disposal at Rolling Hills Landfill.

The conclusion here is that, although hauling MSW by truck to a disposal facility has higher human and environmental health costs the further one transports MSW for disposal, the by far more important aspect of EEV costs is the emissions from disposal of MSW at a particular disposal facility. Figures 2 and 4 illustrate that Rolling Hills Landfill is the better human and environmental health choice for disposal of MSW despite the landfill being more than five times farther away for hauling MSW from Delaware County's transfer stations than the Covanta Delaware Valley incinerator.

X. LCA & Monetization Results for Delaware County's Recommended Zero Waste Management Programs

Tables B1 and B2 in Appendix B show LCA results for the recommended Zero Waste Plan for Delaware County disposal and diversion to recycling & composting, respectively. Following successful implementation of Zero Waste diversion and disposal programs for MSW generated in Delaware County, diversion from disposal to recycling and composting would total 522,126 tons. Source reduction from potential waste generation would total 51,613 tons. Disposal would be reduced from 467,700 tons in 2020, to 112,697 tons.

Potential municipal waste generation (including materials source reduced under the Zero Waste Plan as well as materials recycled and composted under that recommended plan) would remain about the same as in the 2020 baseline at 686,400 tons. However, actual discards requiring management by Delaware County Solid Waste Authority or private haulers would decrease to 634,800 tons. The County's diversion rate would increase to 82.2% for MSW actually generated in Delaware County.

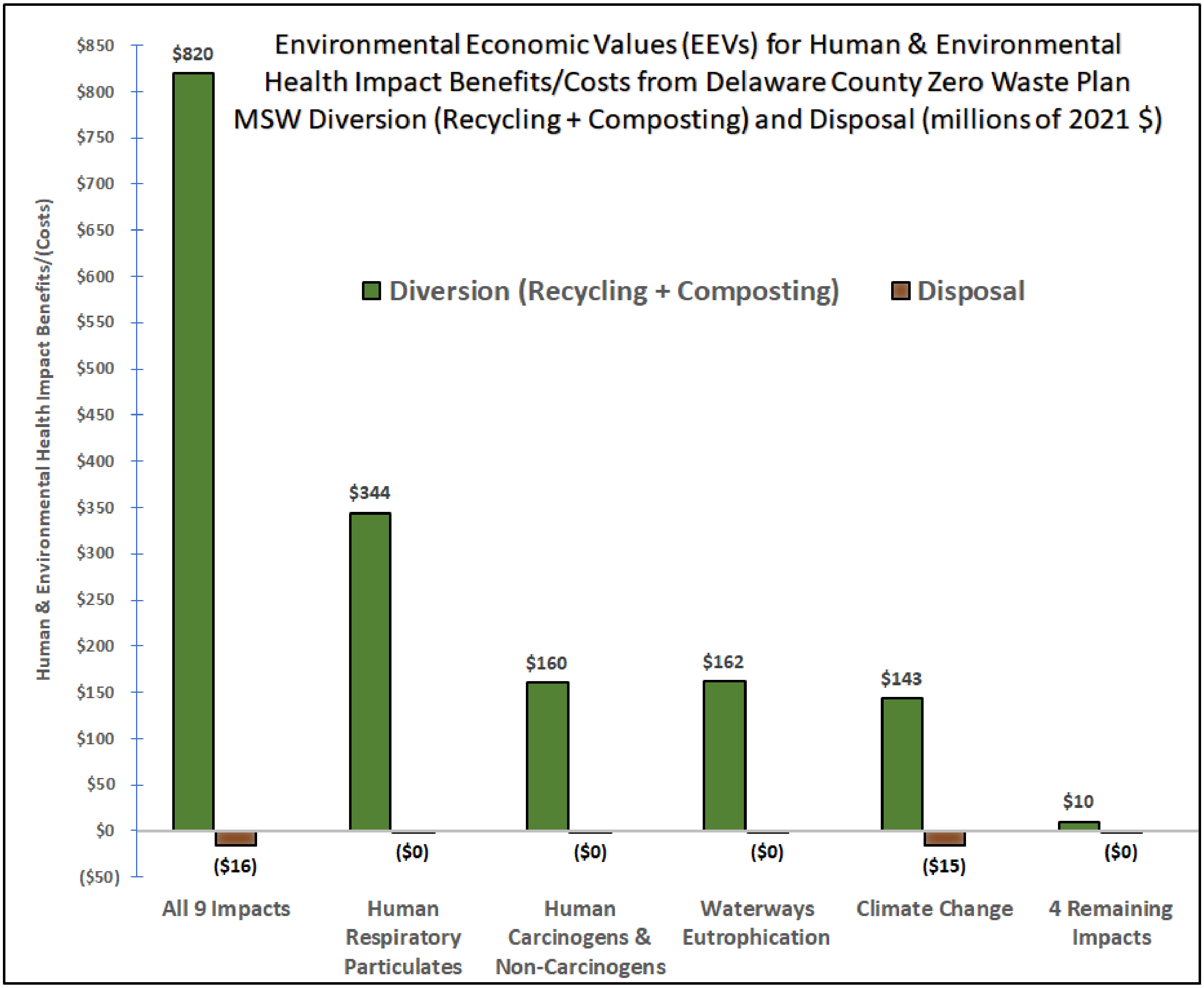
In addition, Tables B1 and B2 in Appendix B provide monetized total and per ton LCA damage benefits or costs. Benefits in Tables B1 and B2 are displayed as positive values. Damage costs are displayed as negative values. These values are presented in 2021 dollars

One of the advantages of monetizing physical impacts is that results for each of the nine impacts can be added together to produce an overall environmental economic value (EEV) benefit/(cost) score for diversion and disposal. Figure 5 graphically displays overall projected EEVs in millions of dollars for diversion and disposal from the nine human and environmental health impacts for Delaware County after full implementation of Phases 1 and 2 of Delaware County's Zero Waste Plan.

Figure 5 indicates that diversion avoids substantial human and environmental health emissions by substituting upstream production using diverted materials for upstream production based on extracting virgin resources form ecosystems. The margin between EEV costs from using diverted materials versus EEV costs from using virgin resources outweighs damage costs for collection, transfer and hauling/shipping activities, and composting or material recovery facility (MRF) processing of diverted MSW materials.

Figure 5 also exhibits the Zero Waste Plan's beneficial results for human health respiratory, human health non-carcinogenic plus carcinogenic toxicity, waterways eutrophication, and climate change. Tables B1 and B2 in Appendix B indicate that the same beneficial relationship for diversion over disposal also holds for acidification, aquatic ecosystems toxicity, ozone depletion, and ground level smog formation as summarized by the Figure 5 relationship for total EEVs for those four impacts.

Figure 5: EEVs for Zero Waste Plan Projected Benefits/(Costs) of All Nine Impacts and Separate EEVs for Climate Change, Human Respiratory Particulates, Human Carcinogens + Non-Carcinogens, Waterways Eutrophication, & the Remaining Four Impacts



Diversion of 522,126 tons of MSW from disposal to recycling and composting as projected under the Delaware County Zero Waste Plan would avoid emissions of almost 703,000 tons of carbon dioxide equivalents (eCO_2). This metric accounts for the climate impacts of collecting recyclables and compostables, MRF processing, composting, and hauling and shipping diverted materials. It also accounts for upstream manufacturing of recycled-content products, as well as displacement of virgin-content manufacturing of the same quantities and types of products. In addition, for biogenic materials diverted to composting, the metric accounts for the upstream displacement of petroleum-based fertilizers and pesticides by soil amendments composted from diverted biogenic materials such as food scraps and yard maintenance debris. The total for avoided carbon dioxide equivalent emissions also includes incremental carbon sequestration due to healthier soils from organic soil supplements enhancing plant growth.

According to EPA, avoidance of 703,000 tons of carbon dioxide equivalent carbon emissions provides the same climate benefit as taking 142,000 gasoline-powered passenger vehicles off the road each year following completion of the

Delaware County Zero Waste Plan, or reducing annual miles driven by gasoline-powered passenger cars by 1.6 billion miles.[43]

Under the Delaware County Zero Waste Plan, disposal of 112,697 tons of MSW at the Rolling Hills Landfill has a carbon footprint of 73,000 tons eCO_2 emitted into the atmosphere and contributing to climate change. Based on the same EPA GHG equivalence calculator, Delaware County's MSW ZW Plan projected disposal climate footprint is equivalent to annual carbon dioxide emissions from 15,000 gas-powered passenger vehicles driving 170 million miles.

[43] U.S. EPA, Greenhouse Gas Equivalencies Calculator, *op. cit.*

XI. APPENDIX A

Table A1: LCA RESULTS FOR 2020 BASELINE DELAWARE COUNTY DISPOSAL OF 467,770 TONS MSW (TOP) AND PER MSW TON (BOTTOM)

Life Cycle Assessment for 467,770 Tons MSW Disposal	Ten Indicators of 2020 Human & Environmental Health Benefits(+) / Costs(-) from Delco Disposal : Impact Tons and Environmental Economic Values (EEVs)									
	Climate Change	Human Health - Particulates	Human Health - Toxics	Human Health- Carcinogens	Eutrophication	Acidification	Ecosystems Toxicity	Ozone Depletion	Smog Formation	EEVs
MSW System Component	eCO_2	$ePM_{2.5}$	eToluene	eBenzene	eN	eSO_2	e2,4-D	eCFC-11	eO_3	2021 $
Collect	-15,243	-0.38	-293.50	-0.19	-0.30	-10.51	-0.03	-0.0004	-262.43	($3,503,915)
Haul	-1,716	-0.07	-1.54	0.00	-0.10	-1.96	0.00	0.0000	-76.36	($412,348)
Disposal	-389,024	-25.12	-48,458.07	-101.97	-17.16	-172.77	0.56	-0.2069	-5,300.47	($112,034,683)
LMWCs Metals Recycling	15,038	13.79	1,586.05	3.03	1.63	89.85	0.05	0.0000	828.57	$11,912,831
LCA Impact Total	-390,945	-11.78	-47,167.06	-99.13	-15.93	-95.39	0.58	-0.2072	-4,810.70	($104,038,115)
EEV for Impact Total (2021 $)	($79,815,787)	($6,875,589)	($15,555,636)	($233,941)	($382,280)	($37,650)	$2,317	($11,328)	($1,128,221)	
EEVs (millions of 2021 $)	($79.8)	($6.9)	($15.6)	($0.2)	($0.4)	($0.0)	$0.0	($0.0)	($1.1)	($104.0)

Life Cycle Assessment Per Ton for MSW Disposal	Ten Indicators of 2020 Human & Environmental Health Benefits(+) / Costs(-) Per Ton Delaware County MSW Collected for Disposal Human & Environmental Health Impact Pounds and Environmental Economic Values (EEVs)									
	Climate Change	Human Health - Particulates	Human Health - Toxics	Human Health- Carcinogens	Eutrophication	Acidification	Ecosystems Toxicity	Ozone Depletion	Smog Formation	EEVs
MSW System Component	eCO_2	$ePM_{2.5}$	eToluene	eBenzene	eN	eSO_2	e2,4-D	eCFC-11	eO_3	2021 $
Collect	-65.17	0.00	-1.25	0.00	0.00	-0.04	0.00	0.00	-1.12	($7.49)
Haul	-7.34	0.00	-0.01	0.00	0.00	-0.01	0.00	0.00	-0.33	($0.88)
Disposal	-1,663.31	-0.11	-207.19	-0.44	-0.07	-0.74	0.00	0.00	-22.66	($239.51)
LMWCs Metals Recycling	64.30	0.06	6.78	0.01	0.01	0.38	0.00	0.00	3.54	$25.47
LCA Impact Per Ton Disposed	-1,671.53	-0.05	-201.67	-0.42	-0.07	-0.41	0.00	0.00	-20.57	($222.41)
EEVs Per Ton (2021 $)	($170.63)	($14.70)	($33.25)	($0.50)	($0.82)	($0.08)	$0.00	($0.02)	($2.41)	

Table A2: LCA RESULTS FOR 2020 BASELINE DELAWARE COUNTY DIVERSION OF 218,599 TONS MSW (TOP) AND PER MSW TON (BOTTOM)

Life Cycle Assessment for 218,599 Tons MSW Diversion	Ten Indicators of Human & Environmental Health Benefits(+) / Costs(-) from 2020 Delco Diversion : Impact Tons and Environmental Economic Values (EEVs)									
	Climate Change	Human Health - Particulates	Human Health - Toxics	Human Health- Carcinogens	Eutrophication	Acidification	Ecosystems Toxicity	Ozone Depletion	Smog Formation	EEVs
MSW System Component	eCO_2	$ePM_{2.5}$	eToluene	eBenzene	eN	eSO_2	e2,4-D	eCFC-11	eO_3	2021 $
Collect	-9,073	-0.23	-174.70	-0.11	-0.18	-6.26	-0.02	-0.0002	-156.20	($2,085,607)
Process	-58,119	-2.78	-69.89	-0.02	86.52	-100.15	-0.15	0.0000	-1,169.09	($11,746,283)
Ship	-582	-0.02	-0.52	0.00	-0.04	-0.66	0.00	0.0000	-25.91	($139,905)
Manufacture	313,957	296.83	305,404.20	465.20	2,918.88	1,711.72	16.63	-0.0002	15,011.56	$413,404,154
LCA Impact Total	246,183	293.81	305,159.10	465.06	3,005.19	1,604.65	16.47	-0.0005	13,660.36	$399,432,359
EEV for Impact Total (2021 $)	$50,261,082	$171,420,933	$100,641,074	$1,097,502	$72,108,528	$633,375	$66,214	-$25	$3,203,676	
EEVs (millions of 2021 $)	$50.3	$171.4	$100.6	$1.1	$72.1	$0.6	$0.1	$0.0	$3.2	$399.4

Life Cycle Assessment Per Ton for MSW Diversion	Ten Indicators of Human & Environmental Health Benefits(+) / Costs(-) Per Ton Delaware County MSW Diverted in 2020 Human & Environmental Health Impact Pounds and Environmental Economic Values (EEVs)									
	Climate Change	Human Health - Particulates	Human Health - Toxics	Human Health- Carcinogens	Eutrophication	Acidification	Ecosystems Toxicity	Ozone Depletion	Smog Formation	EEVs
MSW System Component	eCO_2	$ePM_{2.5}$	eToluene	eBenzene	eN	eSO_2	e2,4-D	eCFC-11	eO_3	2021 $
Collect	-83.01	0.00	-1.60	0.00	0.00	-0.06	0.00	0.00	-1.43	($9.54)
Process	-531.74	-0.03	-0.64	0.00	0.79	-0.92	0.00	0.00	-10.70	($53.73)
Ship	-5.33	0.00	0.00	0.00	0.00	-0.01	0.00	0.00	-0.24	($0.64)
Manufacture	2,872.45	2.72	2,794.20	4.26	26.71	15.66	0.15	0.00	137.34	$1,891.15
LCA Impact Per Ton Diverted	2,252.38	2.69	2,791.95	4.25	27.49	14.68	0.15	0.00	124.98	$1,827.24
EEVs Per Ton (2021 $)	$229.92	$784.18	$460.39	$5.02	$329.87	$2.90	$0.30	($0.00)	$14.66	

Table A3: LCA RESULTS PER MSW TON FOR 2020 MSW DISPOSAL AT COVANTA DELAWARE VALLEY INCINERATOR AND ROLLING HILLS LANDFILL

LCA Results Per MSW Ton for LMWC and LF Used for Delaware County MSW Disposal	Ten Indicators of Human & Environmental Health Benefits(+) / Costs(-) Per Ton of 2020 MSW Disposal at Delaware Valley LMWC and Rolling Hills LF Human & Environmental Health Impact Pounds and Environmental Economic Values (EEVs)									
	Climate Change	Human Health - Particulates	Human Health - Toxics	Human Health- Carcinogens	Eutrophication	Acidification	Ecosystems Toxicity	Ozone Depletion	Smog Formation	EEVs
MSW System Component	eCO_2	$ePM_{2.5}$	eToluene	eBenzene	eN	eSO_2	e2,4-D	eCFC-11	eO_3	2021 $
Covanta Delaware Valley LMWC										
MSW & Ash Hauling	-6.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.3	($0.76)
MSW & Ash Disposal	-1757.8	-0.1	-252.9	-0.5	-0.1	-0.8	0.0	0.0	-26.2	($263.68)
Metals Recycling	78.1	0.1	8.2	0.0	0.0	0.5	0.0	0.0	4.3	$30.93
LCA Impact Per Ton Disposed	-1686.1	-0.1	-244.7	-0.5	0.0	-0.4	0.0	0.0	-22.1	($233.51)
EEVs Per Ton (2021 $)	($172.12)	($17.24)	($40.35)	($0.59)	($0.54)	($0.08)	$0.01	$0.00	($2.60)	
Rolling Hills Landfill										
MSW Hauling	-12.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.6	($1.52)
MSW Disposal	-1222.3	0.0	-5.3	-0.1	-0.2	-0.2	0.0	0.0	-4.7	($129.86)
LCA Impact Per Ton Disposed	-1,235.0	0.0	-5.3	-0.1	-0.2	-0.2	0.0	0.0	-5.3	($131.38)
EEVs Per Ton (2021 $)	($126.07)	($1.60)	($0.88)	($0.06)	($1.98)	($0.04)	($0.00)	($0.14)	($0.62)	

XII. APPENDIX B

TABLE B1 - LCA RESULTS FOR ZERO WASTE PLAN DISPOSAL OF 112,697 TONS MSW (TOP) AND PER MSW TON (BOTTOM)

Life Cycle Assesment for 112,697 Tons MSW Disposal	Ten Indicators of ZW Plan Human & Environmental Health Benefits(+) / Costs(-) from Delco Disposal : Impact Tons and Environmental Economic Values (EEVs)									
	Climate Change	Human Health - Particulates	Human Health - Toxics	Human Health- Carcinogens	Eutrophication	Acidification	Ecosystems Toxicity	Ozone Depletion	Smog Formation	EEVs
MSW System Component	eCO_2	$ePM_{2.5}$	eToluene	eBenzene	eN	eSO_2	e2,4-D	eCFC-11	eO_3	2021 $
Collect	-3,672	-0.09	-70.71	-0.04	-0.07	-2.53	-0.01	0.00	-63.22	($844,174)
Haul	-714	-0.03	-0.64	0.00	-0.04	-0.81	0.00	0.00	-31.79	($171,683)
Disposal	-68,876	-0.28	-300.18	-2.94	-9.26	-9.97	0.00	-0.28	-264.31	($14,634,871)
LCA Impact Total	-73,263	-0.40	-371.54	-2.99	-9.38	-13.31	-0.01	-0.28	-359.33	($15,650,728)
EEV for Impact Total (2021 $)	($14,957,365)	($233,638)	($122,533)	($7,056)	($225,077)	($5,255)	($43)	($15,491)	($84,271)	
EEVs (millions of 2021 $)	($15.0)	($0.2)	($0.1)	($0.0)	($0.2)	($0.0)	($0.0)	($0.0)	($0.1)	($15.7)

Life Cycle Assessment Per Ton for MSW Disposal	Ten Indicators of Human & Environmental Health Benefits(+) / Costs(-) Per Ton Delaware County MSW Collected Under Zero Waste Plan for Disposal Human & Environmental Health Impact Pounds and Environmental Economic Values (EEVs)									
	Climate Change	Human Health - Particulates	Human Health - Toxics	Human Health- Carcinogens	Eutrophication	Acidification	Ecosystems Toxicity	Ozone Depletion	Smog Formation	EEVs
MSW System Component	eCO_2	$ePM_{2.5}$	eToluene	eBenzene	eN	eSO_2	e2,4-D	eCFC-11	eO_3	2021 $
Collect	-65.17	0.00	-1.25	0.00	0.00	-0.04	0.00	0.00	-1.12	($7.49)
Haul	-12.68	0.00	-0.01	0.00	0.00	-0.01	0.00	0.00	-0.56	($1.52)
Disposal	-1,222.32	0.00	-5.33	-0.05	-0.16	-0.18	0.00	-0.01	-4.69	($129.86)
Totals Per Ton Disposed	-1,300.17	-0.01	-6.59	-0.05	-0.17	-0.24	0.00	-0.01	-6.38	($138.88)
EEVs Per Ton (2021 $)	($132.72)	($2.07)	($1.09)	($0.06)	($2.00)	($0.05)	($0.00)	($0.14)	($0.75)	

TABLE B2 - LCA RESULTS FOR ZERO WASTE PLAN DIVERSION OF 522,126 TONS (TOP) AND PER MSW TON (BOTTOM)

Life Cycle Assessment for 522,126 Tons MSW Diversion	Ten Indicators of Human & Environmental Health Benefits(+) / Costs(-) for Delco ZW Plan Recycling + Composting : Impact Tons and EEVs									
	Climate Change	Human Health - Particulates	Human Health - Toxics	Human Health- Carcinogens	Eutrophication	Acidification	Ecosystems Toxicity	Ozone Depletion	Smog Formation	EEVs
MSW System Component	eCO_2	$ePM_{2.5}$	eToluene	eBenzene	eN	eSO_2	e2,4-D	eCFC-11	eO_3	2021 $
Collect	-20,505	-0.51	-394.83	-0.25	-0.41	-14.14	-0.04	-0.0005	-353.04	($4,713,727)
Process	-158,131	-6.13	-193.98	-0.04	332.18	-216.71	-0.51	0.0000	-2,810.93	($28,704,002)
Ship	-1,850	-0.07	-1.66	0.00	-0.11	-2.11	0.00	0.0000	-82.34	($444,623)
Manufacture	883,335	596.63	476,969.84	1,268.74	6,416.50	4,233.31	38.26	0.0453	38,417.94	$853,542,150
LCA Impact Total	702,848	589.91	476,379.36	1,268.44	6,748.17	4,000.35	37.71	0.0448	35,171.63	$819,679,798
EEV for Impact Total (2021 $)	$143,494,252	$344,181,048	$157,109,293	$2,993,385	$161,920,164	$1,578,984	$151,647	$2,450	$8,248,575	
EEVs (millions of 2021 $)	$143.5	$344.2	$157.1	$3.0	$161.9	$1.6	$0.2	$0.0	$8.2	$819.7

Life Cycle Assessment Per Ton for MSW Diversion	Ten Indicators of Human & Environmental Health Benefits(+) / Costs(-) Per Ton for ZW Plan Recycling + Composting in Delaware County, PA Human & Environmental Health Impact Pounds and Environmental Economic Values (EEVs)									
	Climate Change	Human Health - Particulates	Human Health - Toxics	Human Health- Carcinogens	Eutrophication	Acidification	Ecosystems Toxicity	Ozone Depletion	Smog Formation	EEVs
MSW System Component	eCO_2	$ePM_{2.5}$	eToluene	eBenzene	eN	eSO_2	e2,4-D	eCFC-11	eO_3	2021 $
Collect	-78.55	0.00	-1.51	0.00	0.00	-0.05	0.00	0.00	-1.35	($9.03)
Process	-605.72	-0.02	-0.74	0.00	1.27	-0.83	0.00	0.00	-10.77	($54.98)
Ship	-7.09	0.00	-0.01	0.00	0.00	-0.01	0.00	0.00	-0.32	($0.85)
Manufacture	3,383.61	2.29	1,827.03	4.86	24.58	16.22	0.15	0.00	147.16	$1,634.74
LCA Impact Per Ton Diverted	2,692.25	2.26	1,824.77	4.86	25.85	15.32	0.14	0.00	134.72	$1,569.89
EEVs Per Ton (2021 $)	$274.83	$659.19	$300.90	$5.73	$310.12	$3.02	$0.29	$0.00	$15.80	

XIII. APPENDIX C

Table C1: Air Emission Factors for Covanta Delaware Valley and Covanta Plymouth Incinerators Used for Disposal of Delaware County MSW in 2020

Air Emissions (kilograms per metric ton MSW burned)		Covanta MSW Incinerator	
TRACI CAS#	***Pollutant Name***	***Delaware Valley***	***Plymouth***
7664417	ammonia	***	4.27E-03
7440382	arsenic	2.01E-06	9.47E-07
50328	benzo(a)pyrene*	9.22E-09	9.32E-07
7440417	beryllium	1.81E-07	***
7440439	cadmium	1.46E-06	2.39E-06
124389	carbon dioxide	1.22E+03	1.22E+03
630080	carbon monoxide	2.93E-01	1.53E-01
97440473	chromium (hexavalent)	1.81E-06	1.17E-05
1746016	dioxins/furans indexed as 2,3,7,8-TCDD TEQs**	1.28E-10	3.91E-10
VOC	hydrocarbons (NMOC when methane reported separately)	7.18E-03	7.62E-03
7647010	hydrochloric acid (aka hydrogen chloride)	8.34E-03	1.71E-01
7439921	lead	1.13E-05	1.69E-05
7439976	mercury	1.67E-05	5.68E-06
74828	methane	2.74E-01	3.21E-01
7440020	nickel	1.77E-05	1.27E-05
NOX	nitrogen oxides (NO_x)	9.23E-01	1.48E+00
10024972	nitrous oxide (N_2O)	3.60E-02	4.22E-02
PM2.5	$PM_{2.5}$ (includes condensable PM)	6.38E-02	2.63E-02
PM10	PM_{10} (excludes condensable and $PM_{2.5}$ filterable particulates)	4.09E-02	8.08E-03
7446095	sulfur dioxide	1.20E-01	1.24E-01
	*Polycyclic aromatic hydrocarbons (PAHs) indexed as benzo(a)pyrene emissions		
	**2,3,7,8-TCDD TEQs = 2,3,7,8-tetrachlorodibenzo-p-dioxin toxicity equivalents		
	***No emissions data reported in PA DEP database		

XIV. APPENDIX D

Table D1: Diversion Materials Composition for 2020 Baseline and Post Zero Waste Programs Implementation

	Baseline Diversion Composition (Tons)			Zero Waste Diversion Composition (Tons)		
	Residential	Commercial	Combined	Residential	Commercial	Combined
Material						
Corrugated Cardboard (OCC)	8,179	24,876	**33,055**	16,264	45,893	**62,157**
Newspaper (ONP)	177	29	**206**	1,839	744	**2,583**
Office Paper	188	2,425	**2,613**	811	3,318	**4,130**
Mixed Paper	12,988	8,517	**21,505**	45,525	37,623	**83,148**
Textiles	123	9	**132**	9,154	2,498	**11,652**
Plastics #1 (PET)	1,069	589	**1,658**	4,131	2,293	**6,424**
Plastics #2 (HDPE)	878	474	**1,352**	2,153	1,758	**3,910**
Plastics #5 (PP)	38	31	**69**	38	31	**69**
Plastics #4 (LDPE) Film	0	160	**160**	6,281	14,585	**20,866**
Glass Containers	4,660	2,382	**7,042**	9,263	4,380	**13,643**
Aluminum	250	433	**684**	2,376	1,560	**3,936**
Copper/Other Non-ferrous	4	13,476	**13,480**	1,279	14,291	**15,569**
Tinned Cans	808	430	**1,238**	1,894	1,571	**3,465**
Other Ferrous	241	80,181	**80,422**	3,641	83,439	**87,081**
Electronics	0	0	**0**	826	407	**1,233**
Carpet	0		**0**	3,188	2,962	**6,150**
Household Batteries – Alkaline	0	0	**0**	72	0	**72**
Gypsum Wallboard	0		**0**	1,014	871	**1,886**
Masonry/Asphalt/Concrete	0	84	**84**	906	675	**1,581**
Asphalt Roofing Shingles	0	0	**0**	338	1,303	**1,642**
Wood Waste	122	24,084	**24,205**	4,121	37,117	**41,238**
Yard Debris	22,763	4,351	**27,114**	39,088	9,696	**48,784**
Food Scraps	0	3,580	**3,580**	33,597	53,624	**87,220**
Disposable Diapers	0	0	**0**	2,355	1,140	**3,495**
Animal By-products	0	0	**0**	2,801	326	**3,127**
Durable Plastic Products	0	0	**0**	2,000	1,991	**3,991**
Single-Use Food Service	0	0	**0**	6,004	10,316	**16,320**
Flat/Other Non-container Glass	0	0	**0**	1,739	591	**2,329**
Painted Wood	0	0	**0**	8,887	3,258	**12,145**
Mixed Construction & Demolition Debris	0	0	**0**	3,973	2,614	**6,586**
Sand/Soil/Dirt	0	0	**0**	1,328	1,629	**2,957**
Miscellaneous Organics	0	0	**0**	1,681	1,303	**2,984**
Miscellaneous Inorganics	0	0	**0**	555	724	**1,280**
Bulky Materials	0	0	**0**	9,177	1,086	**10,263**
Totals	**52,487**	**166,112**	**218,599**	**228,296**	**345,618**	**573,914**

Table D2: New Post Zero Waste Programs Implementation Diversion Materials Composition

	Residential Diversion Composition (Tons)			Commercial Diversion Composition (Tons)		
	Source Reduction	Recycling	Compost	Source Reduction	Recycling	Compost
Material						
Corrugated Cardboard (OCC)	174	7,905	0	489	20,528	0
Newspaper (ONP)	0	1,657	0	0	715	0
Office Paper	0	619	0	0	894	0
Mixed Paper	717	31,794	0	631	28,475	0
Textiles	4,104	0	4,925	283	0	2,206
Plastics #1 (PET)	145	2,488	0	91	1,430	0
Plastics #2 (HDPE)	29	1,238	0	32	1,251	0
Plastics #5 (PP)	0	0	0	5	115	0
Plastics #4 (LDPE) Film	60	6,218	0	57	14,369	0
Glass Containers	34	4,557	0	32	1,966	0
Aluminum	14	2,102	0	14	1,113	0
Copper/Other Non-ferrous	0	1,271	0	0	815	0
Tinned Cans	12	1,070	0	27	1,113	0
Other Ferrous	0	3,396	0	0	3,258	0
Electronics	65	757	0	27	380	0
Carpet	796	2,389	0	769	2,193	0
Household Batteries – Alkaline	0	72	0	0	0	0
Gypsum Wallboard	253	759	0	226	645	0
Masonry/Asphalt/Concrete	421	650	0	204	387	0
Asphalt Roofing Shingles	120	215	0	272	1,032	0
Wood Waste	2,388	0	1,607	6,109	0	6,924
Yard Debris	0	0	16,314	0	0	5,345
Food Scraps	0	0	33,590	5,159	0	44,884
Disposable Diapers	2,353	0	0	1,140	0	0
Animal By-products	0	0	2,800	0	0	326
Durable Plastic Products	820	3,679	0	1,946	6,856	0
Single-Use Food Service	1,343	2,571	0	1,134	2,435	0
Flat/Other Non-container Glass	43	1,692	0	14	577	0
Painted Wood	8,882	0	0	3,258	0	0
Mixed Construction & Demolition Debris	1,520	2,280	0	679	1,935	0
Sand/Soil/Dirt	0	1,326	0	0	1,629	0
Miscellaneous Organics	0	0	1,679	0	0	1,303
Miscellaneous Inorganics	0	361	0	0	145	0
Bulky Materials	4,343	4,826	0	380	706	0
Medical Wastes, Personal Protective Equipment, & Household Hazardous Wastes	0	193	0	0	579	0
Totals	**28,637**	**86,084**	**60,914**	**22,976**	**95,541**	**60,988**

Table D3: New Post Zero Waste Programs Implementation Diversion Plus Baseline Diversion Materials Composition

	Residential Diversion Composition (Tons)				Commercial Diversion Composition (Tons			
	Source Reduction	Recycling	Compost	Combined	Source Reduction	Recycling	Compost	Combined
Material								
Corrugated Cardboard (OCC)	174	16,084	0	**16,257**	489	45,404	0	**45,893**
Newspaper (ONP)	0	1,834	0	**1,834**	0	744	0	**744**
Office Paper	0	807	0	**807**	0	3,319	0	**3,319**
Mixed Paper	717	44,782	0	**45,499**	631	36,992	0	**37,623**
Textiles	4,104	123	4,925	**9,152**	283	9	2,206	**2,498**
Plastics #1 (PET)	145	3,557	0	**3,702**	91	2,019	0	**2,110**
Plastics #2 (HDPE)	29	2,116	0	**2,145**	32	1,725	0	**1,757**
Plastics #5 (PP)	0	38	0	**38**	5	146	0	**151**
Plastics #4 (LDPE) Film	60	6,218	0	**6,278**	57	14,529	0	**14,585**
Glass Containers	34	9,217	0	**9,250**	32	4,348	0	**4,380**
Aluminum	14	2,352	0	**2,367**	14	1,546	0	**1,560**
Copper/Other Non-ferrous	0	1,275	0	**1,275**	0	14,291	0	**14,291**
Tinned Cans	12	1,878	0	**1,890**	27	1,543	0	**1,570**
Other Ferrous	0	3,637	0	**3,637**	0	83,439	0	**83,439**
Electronics	65	757	0	**822**	27	380	0	**407**
Carpet	796	2,389	0	**3,185**	769	2,193	0	**2,962**
Household Batteries – Alkaline	0	72	0	**72**	0	0	0	**0**
Gypsum Wallboard	253	759	0	**1,011**	226	645	0	**871**
Masonry/Asphalt/Concrete	421	650	0	**1,071**	204	471	0	**675**
Asphalt Roofing Shingles	120	215	0	**335**	272	1,032	0	**1,303**
Wood Waste	2,388	0	1,729	**4,117**	6,109	0	31,008	**37,118**
Yard Debris	0	0	39,077	**39,077**	0	0	9,696	**9,696**
Food Scraps	0	0	33,590	**33,590**	5,159	0	48,464	**53,623**
Disposable Diapers	2,353	0	0	**2,353**	1,140	0	0	**1,140**
Animal By-products	0	0	2,800	**2,800**	0	0	326	**326**
Durable Plastic Products	820	3,679	0	**4,499**	1,946	6,856	0	**8,802**
Single-Use Food Service	1,343	2,571	0	**3,913**	1,134	2,435	0	**3,568**
Flat/Other Non-container Glass	43	1,692	0	**1,735**	14	577	0	**591**
Painted Wood	8,882	0	0	**8,882**	3,258	0	0	**3,258**
Mixed Construction & Demolition Debris	1,520	2,280	0	**3,800**	679	1,935	0	**2,613**
Sand/Soil/Dirt	0	1,326	0	**1,326**	0	1,629	0	**1,629**
Miscellaneous Organics	0	0	1,679	**1,679**	0	0	1,303	**1,303**
Miscellaneous Inorganics	0	361	0	**361**	0	145	0	**145**
Bulky Materials	4,343	4,826	0	**9,169**	380	706	0	**1,086**
Medical Wastes, Personal Protective Equipment, and Household Hazardous Wastes	0	193	0	**193**	0	579	0	**579**
Totals	**28,637**	**115,687**	**83,799**	**228,123**	**22,976**	**229,637**	**93,003**	**345,617**

XV. APPENDIX E

Table E1: Disposal Materials Composition for 2020 Baseline and Post Zero Waste Programs Implementation

	Baseline Disposal Composition (Tons)			Zero Waste Disposal Composition (Tons)		
	Residential	Commercial	**Combined**	Residential	Commercial	**Combined**
Material						
Corrugated Cardboard (OCC)	8,687	24,438	**33,125**	2,093	5,888	**7,981**
Newspaper (ONP)	1,927	905	**2,832**	464	218	**682**
Office Paper	720	1,131	**1,851**	173	273	**446**
Mixed Paper	37,641	36,204	**73,845**	9,069	8,722	**17,791**
Textiles	16,417	5,657	**22,074**	3,955	1,363	**5,318**
Plastics #1 (PET)	3,371	2,037	**5,408**	812	491	**1,303**
Plastics #2 (HDPE)	1,439	1,584	**3,023**	347	382	**728**
Plastics #4 (LDPE) Film	13,515	23,985	**37,500**	3,256	5,779	**9,035**
Glass Containers	7,467	3,168	**10,635**	1,799	763	**2,562**
Aluminum	2,405	1,358	**3,763**	579	327	**907**
Copper/Other Non-ferrous	1,444	905	**2,349**	348	218	**566**
Tinned Cans	1,203	1,358	**2,561**	290	327	**617**
Other Ferrous	3,859	3,620	**7,479**	930	872	**1,802**
Electronics	2,164	905	**3,069**	521	218	**739**
Carpet	5,308	3,847	**9,155**	1,279	927	**2,206**
Household Batteries – Alkaline	241	0	**241**	58	0	**58**
Gypsum Wallboard	1,686	1,131	**2,817**	406	273	**679**
Masonry/Asphalt/Concrete	1,203	679	**1,882**	290	164	**453**
Asphalt Roofing Shingles	478	1,810	**2,288**	115	436	**551**
Wood Waste	13,997	16,971	**30,968**	3,372	4,089	**7,461**
Yard Debris	17,375	5,883	**23,259**	4,186	1,417	**5,604**
Food Scraps	35,734	51,591	**87,325**	8,609	12,430	**21,039**
Disposable Diapers	9,413	3,168	**12,581**	2,268	763	**3,031**
Sand/Soil/Dirt	5,306	4,526	**9,832**	1,278	1,090	**2,369**
Miscellaneous Organics	15,446	4,526	**19,972**	3,721	1,090	**4,812**
Miscellaneous Inorganics	20,981	23,533	**44,514**	5,055	5,670	**10,724**
Bulky Materials	12,065	1,358	**13,423**	2,907	327	**3,234**
Totals	**241,493**	**226,277**	**467,770**	**58,181**	**54,515**	**112,697**

Source: PA_DEP_Report_FINAL_10-04-2022.pdf (state.pa.us)

Table E2: Diversion and Disposal Tons for 2020 Baseline and Post Zero Waste Programs Implementation

Delaware County Diversion and Disposal Tons		
	2020 Baseline	Zero Waste
Diversion	218,599	573,739
Memo: Diversion Detail		
Source Reduction	0	51,613
Recycling	163,699	345,324
Composting	54,900*	176,802
Disposal	467,770	112,697
Total Generation	686,369	686,436

*Includes 4,841 wood waste beneficial use as fuel.