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TECHNICAL MEMORANDUM

DATE:	February 20, 2023
TO:	Craig Kawaguchi, County of Hawai'i
FROM:	Katheryn Seckel, Environmental Planner, and Asa Reyes-Chavez, EIT, Parametrix
SUBJECT:	Life Cycle Assessment Technical Memorandum
CC:	Michael Rivera Michael Kaha Dwight Miller, PE, Parametrix Dr. Jeffery Morris, Sound Resource Management Group, Inc.
PROJECT NUMBER:	553-7041-001
PROJECT NAME:	County of Hawai'i Integrated Solid Waste Management System Life Cycle Assessment

EXECUTIVE SUMMARY

In the 2019 Integrated Solid Waste Management Plan (ISWMP) Hawai'i County established "goals that are expressed and measured in terms of environmental impacts (e.g., greenhouse gas emissions, toxicity, energy use) and consider full life cycle impacts in addition to tonnage-based landfill diversion or waste recovery goals." Accordingly, this life cycle assessment (LCA) is intended to help the County SWD measure environmental impacts associated with the end-of-life management of specific commodities that are currently disposed in the landfill or shipped out of the County to be recycled. The LCA considered three end-of-life scenarios for source-separated recyclables: 1) in-county landfilling, 2) out-of-county transport and recycling of diverted materials, and 3) out-of-county transport of burnable commodities and energy production at the H-Power waste-to-energy plant on O'ahu. It is important to emphasize that this is only considering readily recyclable materials with proven commodity markets. The West Hawai'i Landfill is a modern, well operated, and environmentally sound facility that provides effective and efficient disposal for those materials that cannot currently be cost-effectively diverted from disposal.

Based on the modeling for the three end of life scenarios compared in this LCA, recycling had the least amount of carbon emissions and incurred the least amount of environmental cost per ton per material Of the other two end-of-life scenarios, overall, landfilling produces less carbon emissions and incurs less environmental damage costs per ton of materials as compared to WTE.

While the results of the modeling used in this assessment demonstrates that recycling's impact on carbon emissions and environmental costs are most effective and desirable, this end-of-life scenario is not without its impacts to the environment. Transport and processing of recyclables are just some ways recycling can result in impacts to climate and human health.

Based on the data, to reduce overall emissions produced by the solid waste stream would be to continue investing in improving recycling operations and the promotion of waste reduction in the community. For this to occur, additional funding is necessary to provide facilities, equipment, and labor resources to increase separation of uncontaminated materials. Further, commodity markets must be strong enough to incentivize recycling and the public must participate in reducing contamination of recyclables.

INTRODUCTION

In accordance with County of Hawai’i (County) Resolution 322-19 regarding climate change and as a top recommendation in the County of Hawai’i’s 2019 Integrated Solid Waste Management Plan, the County of Hawai’i Solid Waste Division (SWD) requested a Life Cycle Assessment (LCA) of several of its residential recycling/landfill diversion programs.

The 2019 Integrated Solid Waste Management Plan recommends the County "establish goals that are expressed and measured in terms of environmental impacts (e.g., greenhouse gas emissions, toxicity, energy use) and consider full life cycle impacts in addition to tonnage-based landfill diversion or waste recovery goals." In response to that recommendation, this LCA is intended to help the County SWD measure environmental impacts associated with the end-of-life management of specific commodities that are either disposed in the landfill or shipped off the Big Island to be recycled. The goal is to determine the least impactful disposition of select commodities on human health and the environment considering the following three scenarios:

- Scenario 1 – End destination recycling facilities
- Scenario 2 – End destination H-Power plant on O’ahu
- Scenario 3 – End destination West Hawai’i Sanitary Landfill (WHSL)

This LCA is intended to be a decision-making tool to identify the action (scenario) that is least impactful to the environment. The commodities considered include the following:

- Old corrugated container (OCC) (corrugated cardboard)
- Scrap metal (metal cans, such as food cans; freon and non-freon appliances; and other scrap metal, such as sheet metal, copper, and brass, not including scrap automobiles)
- Plastic containers (bottle, jugs, and jars only), #2 and #5
- Mixed paper (phone books, magazines, junk mail, office paper, paperboard packaging, or any kind of paper that doesn't fall into the category of corrugated cardboard or newspaper is considered mixed paper)
- Office paper

The results of this LCA were modeled by Sound Resource Management Group through the application of their proprietary environmental benefits calculator (MEBCalc). Nine human and environmental health impacts were assessed by MEBCalc, including the following:

- Climate change (carbon dioxide or equivalent emissions, eCO2)
- Human respiratory disease and death from particulates
- Human disease and death from carcinogens
- Human disease and death from toxics
- Eutrophication
- Acidification
- Aquatic ecosystems toxicity
- Ozone depletion
- Ground-level smog formation

MODELING

The MEBCalc tool relies on a number of supporting tools and existing models, scientific research papers, and emissions profiles for activities and facilities in the waste management systems handling end-of-life for the six materials. The methodology and main sources for the tool are summarizes in the modeling report (Attachment A).

The following initial actions were begun prior to inputs to the model:

- Coordination with the County to establish existing recycling quantities.
- Coordination with County to estimate contamination for a more accurate accounting of what is recycled. Some of this information was supplied by Business Services of Hawai'i or the County, or it was estimated using reference data.
- Identification of likely vehicle types for transport of commodities.
- Consideration of existing landfill operations use of gas flaring in operations.
- Identification of physical boundaries (e.g., end-of-life disposition for recycling is within 20 miles of the receiving port).
- Consideration of virgin-content manufacturing versus recycling.
- Identification of the emissions profile and facility net efficiency from the H-Power 2021 Annual Air Emission Inventory Report received from Hawai'i State Department of Health.
- Consideration of the amount of energy generated and sold to the power grid by H-Power.
- Coordination with the County to identify the modes of transport and intermediary stopping points from transfer stations to point of disposition, as shown in Figure 1 below.

Figure 1. End-of-Life Transport and Disposition Scenarios

In addition, the County determined that quantification of environmental impacts beyond climate change emissions is desirable. Consequently, the MEBCalc tool was used to assess the benefits and harms for nine impacts that use the United Nations Intergovernmental Panel on Climate Change (IPCC) carbon dioxide equivalents (eCO2) and the U.S. Environmental Protection Agency's (EPA) Tool for Reduction and Assessment of Chemicals and Other Environmental Impacts (TRACI) RACI 2.1 characterization factors. An explanation of each of the nine categories of human and environmental health impacts, as stated in Attachment A, are listed below.

- Climate change: Considers the potential increase in greenhouse effects due to anthropogenic emissions. Carbon dioxide (CO2) from burning fossil fuels is the most common source of greenhouse gases (GHGs). Methane emissions from anaerobic decomposition of biogenic materials, such as food scraps or discarded paper, that are buried in a landfill are another large source of GHG effects. Pollutants that have climate impacts are characterized and converted into reference pollutant equivalents, eCO2.
- Human health – particulates: The potential human health impacts from anthropogenic releases of coarse particles known to aggravate respiratory conditions, such as asthma; fine particles that can lead to more serious respiratory symptoms and disease; and particulate precursors, such as nitrogen oxides and sulfur oxides. 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, ePM2.5, where PM2.5 is particulate matter no larger than 2.5 microns.
- Human health – carcinogens: Potential human health impacts from releases of chemicals that are carcinogenic to humans. There also are many chemical and heavy metal pollutants that are carcinogenic to humans, including 2,4-D, benzene, DDT, dioxins, formaldehyde, Kepone, permethrin, chromium, and lead. The reference substance for human carcinogenic potential is benzene. MEBCalc aggregates the pollutants that have human carcinogenic impacts into benzene equivalents eBenzene.
- Human health – toxics: The potential human health impacts (other than the respiratory and carcinogenic effects discussed above) 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- dichlorophenoxyacetic acid (2,4-D), benzene, dichloro-diphenyl-trichloroethane (DDT), formaldehyde, permethrin, toluene, chromium, copper, lead, mercury, silver, and zinc. Examples of the human toxicity effects from these toxins include heart disease, kidney failure, reproductive disorders, cognitive effects, and disruption of the endocrine system. Emissions of pollutants that have non-carcinogenic toxicity impacts on human health are characterized and converted into reference pollutant equivalents, eToluene.
- Eutrophication: The potential environmental impacts resulting from the emissions of pollutants to air, soil, or water that add macro nutrients to soil or water. The addition of mineral nutrients, such as nitrogen and phosphorous, to soil or water 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 the death of fish and other species, otherwise known as eutrophication. Pollutants that are indicative of eutrophic impacts are characterized by nitrogen equivalents, eNitrogen.
- Acidification: The 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 by sulfur dioxide equivalents, eSO2.

- Aquatic ecosystem 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, ethyl benzene, formaldehyde, Kepone, permethrin, toluene, chromium, copper, lead, silver, and zinc. Pollutants that have toxicity impacts to aquatic ecosystems are characterized 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 trichlorofluoromethane, CFC-11, where CFC is the acronym for chlorofluorocarbon. CFC-11 is sometimes called R-11. Pollutants that have the potential to deplete ozone are characterized 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 (O3). For example, nitrogen oxides (NOx) 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 as ozone equivalents, eO_3.

For the LCA analysis portion of modeling, the MEBCalc tool used the following resources:

- EPA/Research Triangle Institute's Decision Support Tool (RTI International)
- EPA's Waste Reduction Model (WARM)
- EPA's Landfill Gas Emissions Model (LandGEM)
- EPA's AP-42 compilations, air emission factors
- H-Power's 2021 Annual Air Emission Inventory Report
- National Renewable Energy Laboratory 2021 Life Cycle Greenhouse Gas Emissions from Electricity Generation data
- A wide variety of peer reviewed scientific journal articles and sources

These resources and uses are explained in more detail in Attachment A.

In simple terms, the MEBCalc tool is set-up to do the following:

1. Input data (e.g., commodities, mode of transport, distances) into the Microsoft Excel calculator spreadsheet.
2. Produce reference pollutant equivalents for the nine human and environmental health impacts discussed above.
3. Convert monetization factors in 2021 dollar costs.

The results for reference pollutant equivalents and 2021 dollar costs are discussed in the Results section below.

RESULTS

The results for this LCA include reference pollutant equivalents, total emissions, and monetization factors. The monetization factor is the summation of the costs associated with damages that pollution causes as reflected by the following:

- 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 disamenities in the fallout zones of pollutant releases imposed on all entities within Earth's planetary ecosystems

Table 1 summarizes the theoretical total tons of eCO2 emissions produced from each end-of-life scenario for the various materials collected in 2021 (scrap metal and cardboard) and 2017/2018 (office paper, mixed paper, and plastics),[1] where positive values indicate increases in emissions and negative numbers indicate reductions in emissions. The emissions are derived from the processes unique to each scenario, including hauling/shipping, processing, and manufacturing. Table 2 summarizes the total economic value of benefit or (harm) in 2021 dollars for each scenario. These damage costs are based on the per ton of reference substance emitted (e.g., CFC-1, SO2) for each of MEBCalc's nine human and environmental health impacts.

Table 1. Summary of Total eCO2 Emissions Produced in 2021

Scenarios:	Scenario 1: Recycling	Scenario 2: WTE, H-Power	Scenario 3: Landfilling, WHSL
Materials:	(Tons of eCO2 emissions for 2021 tonnage of collected material)		
Office Paper	-301	137	265
Mixed Paper	-1,559	506	1,306
Carboard/OCC	-4,213	2,293	3,112
#2 Plastics (HDPE)	-38	55	1
#5 Plastics (PP)	-26	37	1
Mixed Scrap Metals	-2,789	N/A	31
Total Emissions:	-8,926	3,028	4,716

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[1] Starting in 2018, the County eliminated mixed recycling, which had included plastics and office/mixed paper. Recycling quantities for Fiscal Year 2018 reflect the latest full year these materials were recovered.

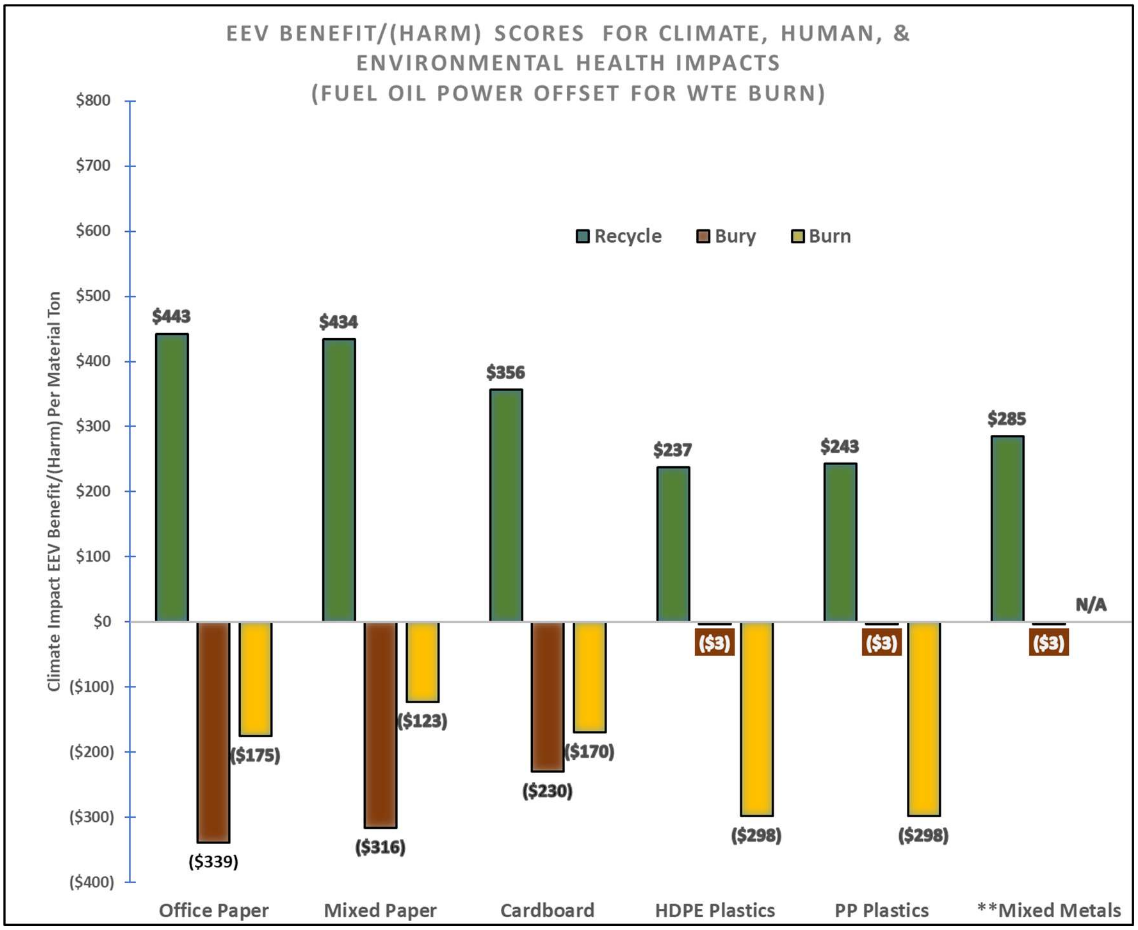
Table 2. Summary of Economic Benefit/(Harm) for Each Scenario

Scenarios:	Scenario 1: Recycling	Scenario 2: WTE, H-Power	Scenario 3: Landfilling, WHSL
Materials:	(per ton of material)		
Office Paper	$649	($172)	($344)
Mixed Paper	$656	($119)	($322)
Carboard/OCC	$581	($160)	($235)
#2 Plastics (HDPE)	$434	($112)	($6)
#5 Plastics (PP)	$449	($112)	($6)
Mixed Scrap Metals	$1,836	N/A	($6)

WTE = waste to energy

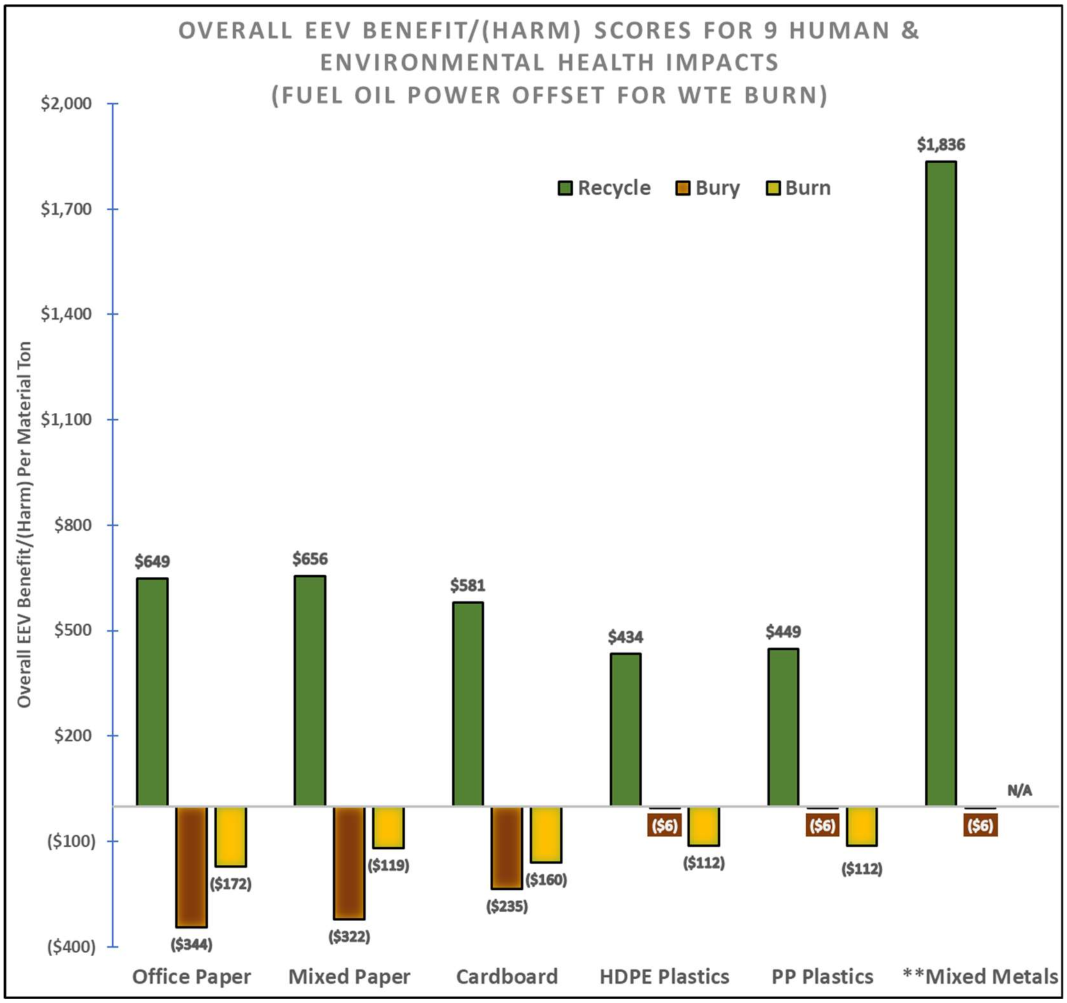
As shown in Table 1, recycling is the end-of-life scenario that results in the lowest eCO2 emissions for all materials. For example, recycling office paper reduces emissions by 301 tons of eCO2, while waste-to-energy (WTE) incineration and landfilling office paper would increase emissions by 137 and 265 tons eCO2, respectively. Overall, recycling of all these materials would have resulted in a net reduction of 8,926 tons eCO2. WTE incineration of these materials, except for mixed scrap metal, would have increased emissions by 3,028 tons eCO2. Landfilling would have also increased emissions by 4,716 tons eCO2. From these results, landfilling has the greatest negative environmental impact due to the largest increase in emissions. This is largely due to organic-based materials, like office paper and mixed paper, that breakdown in landfills and contribute more to emissions of GHGs. The same is true for burning these materials in the WTE stream, but to a lesser degree.

Below, Figure 2 illustrates the environmental economic value (EEV) score for each of the materials as it relates to climate change on a per ton basis, which is also summarized in Table 2. Figure 3 summarizes the EEV for overall impacts for all materials for the nine impacts on a per ton basis. The green bars show that recycling produces a positive economic value for each material. Recycling processed materials by shipping them to recycled-content manufacturing facilities in either North America or Asia reduces total human and environmental health damage costs in terms of climate change, human, and environmental health on a per ton basis by $443 for office paper, $434 for mixed paper, $356 for cardboard, $237 for HDPE plastic containers, $243 for PP plastic containers, and $285 for mixed metals.



**Note: Mixed Metals does not include outputs from the WTE end-of-life scenario as the other materials do.

Figure 2. Environmental Economic Value (EEV) of Benefit/(Harm) for Climate Environmental Impact from Recycling, Burying, or Burning 1 Ton Each of Six Materials Generated in Hawaii County (2021 dollars)



**Note: Mixed Metals does not include outputs from the WTE end-of-life scenario as the other materials do.

Figure 3. Overall Environmental Economic Value (EEV) of Benefit/(Harm) for Nine Environmental Impacts from Recycling, Burying, or Burning 1 Ton Each of Five Materials Generated in Hawaii County (2021 dollars).

Conversely, landfilling and WTE have negative EEVs for each end-of-life scenario from a climate, human, and environmental perspective as well as overall for the nine modeled impacts. Landfilling processed materials by hauling them to WHSL increases total human and environmental health damage costs in terms of climate change, human, and environmental health on a per ton basis by $344 for office paper, $322 for mixed paper, $235 for cardboard, and $6 for HDPE plastic containers, PP plastic containers, and mixed metals. For landfilling, while substantial hauling causes emissions, HDPE and PP plastic containers do not biodegrade in a landfill, so there are less emissions and thus a smaller EEV factor overall. For WTE, hauling and shipping the material contributes largely to the generation of emissions and ultimately outweighs the benefits of avoiding pollution from the use of power generated from fuel oil combustion power plants on Oahu. While there is a larger positive impact across the nine modeled impacts for HDPE and PP plastic materials sent to WTE, this is largely due to the greater energy content of plastics compared with paper. In summary, fuel oil power offsets for plastics are larger than for paper materials. Attachment A goes into more depth comparing the scenarios relative to negative or positive impacts for the different materials and assesses the environmental benefits and costs assuming that HPower electricity displaces solar power rather than fuel oil power generation on Oahu.

CONCLUSION

Based on the results of this study, recycling has the least impact in terms of emissions and environmental cost benefit out of the three end-of-life scenarios modeled for this LCA. Overall, the WTE end-of-life scenario does produce less emissions than landfilling, although it does incur more environmental damage costs per ton of materials as compared to landfilling.

While recycling demonstrates the least impact on carbon emissions and environmental costs are most effective and desirable, this end-of-life scenario is not without its damages on the environment. A majority of the impact from recycling these materials result from impacts to climate change and human health, as seen in Figure 4.

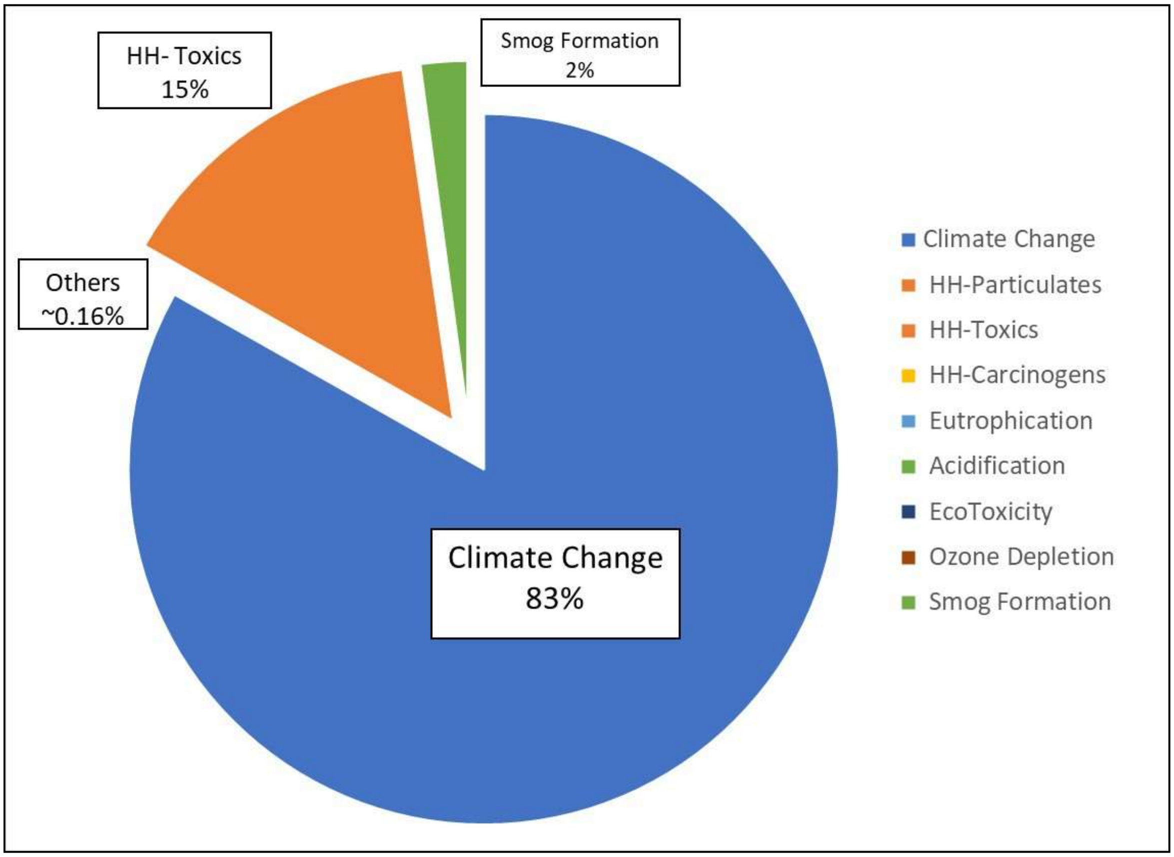


Figure 4. Recycling One Ton of All Six Materials for a Net $4,600 Human/Environmental Damage Decrease

A prime option to reduce overall emissions produced by the solid waste stream would be to continue investing in efforts towards improving existing recycling operations and the promotion of waste reduction in the community.

Examples of initiatives include the following:

- Providing compaction units for recyclables at select transfer stations.
- Improving payloads for hauling of recyclables.
- Applying zero waste measures to reduce waste.
- Implementing and retaining a recycling program that emphasizes clean, source-separated recycling instead of single-stream recycling. According to the Institute for Self-Reliance, source separated or "dual stream can offer lower processing fees, reduced contamination, better quality materials, better market access and higher prices and closer ties between processor and end markets." Furthermore, dual stream can offer greater flexibility in deciding compaction levels, co-collection, timing and frequency of collection, properly scaled processing equipment, proper configuration of equipment, and establishing stable, long-term relationships with end markets."[2]
- Taking advantage of unused backhaul capacity. According to Hawai'i County Zero Waste Plan,[3] most of the shipping containers that return to the continental U.S. are empty, and unused capacity ranges from 65 to 85 percent. Reducing unused backhaul capacity would allow for fewer trips, thus decreasing emissions.
- Supporting legislation for extended producer responsibility (EPR) in the form of take-back programs and/or responsibility of life-cycle costs of producers' products and associated packaging.
- Supporting on-island recycling. For example, Circlepack, a local company founded in 2020, shreds cardboard generated on-island and upcycles the material for mulching, packaging material, and other products.[4]

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[2] Institute for Self-Reliance. 2019. Dual Stream vs. Single Stream Recycling. Jacq Streur and Deborah Kapiloff, authors. August 22, 2019. Available at: https://ilsr.org/dual-stream-vs-single-stream-recycling/. Accessed December 6, 2022.

[3] Recycling Hawai'i. 2021. Hawai'i County Zero Waste Plan. Prepared by Recycle Hawai'i in conjunction with the institute for Local Self-Reliance, Zero Waste Associates and Hidden Resources.

[4] Circlepack. 2022. Upcycling Cardboard in Hawai'i. Available at: https://www.circlepack.co/. Accessed December 6, 2022.

Attachment A

MEBCalc LCA Methodology and Results for Hawai’i Waste Management Options Analysis

MEBCalc LCA Methodology and Results for Hawai'i Waste Management Options Analysis

Prepared for Parametrix, Inc. by Dr. Jeffrey Morris, Sound Resource Management Group, Inc.

This report and the results herein detail a life cycle analysis (LCA) and assessment for 9 human and environmental health impacts from 3 end-of-life (EOL) management methods – recycling, landfilling and waste-to-energy (WTE) incineration – for handling 6 material wastes – office paper, mixed paper, cardboard, high density polyethylene (HDPE) food and product containers, polypropylene (PP) food and product containers, and mixed ferrous and non-ferrous metals. One exception is that LCAs for mixed metals only cover recycling and landfilling options. The 6 discarded materials are generated on Hawai'i Island (aka the Big Island) in the State of Hawai'i.

Sound Resource Management Group's measuring environmental benefits calculator (MEBCalc) provides the results. MEBCalc's assessment of benefits and harms for the 9 impacts relies on a number of supporting tools, scientific research papers, and emissions profiles for activities and facilities in the waste management systems handling EOLs for the 6 materials. The following three sections summarize methodology and main sources for the MEBCalc tool. The succeeding four sections detail and discuss results.

I. Methodology for Indexing Pollutants That Cause One or More of the Nine Human and Environmental Health Impacts

There are thousands of 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, also known as discards, via activities such as collection, recycling, composting or 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. The method that is used for assessing greenhouse gas (GHG) pollutants is an example of how scientists have synthesized a large number of harmful emissions into an index for characterizing human and environmental health impacts, in this example, GHG pollutants causing climate change.

The United Nations Intergovernmental Panel on Climate Change (IPCC) has an index – carbon dioxide equivalents (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 of incoming solar radiation. Examples from the IPCC *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). GWPs for these examples represent each GHG's average climate forcing effect over the 100 years following their release. GWPs also are characterization factors that express the climate forcing potential of any greenhouse gas relative to that of carbon dioxide. Users calculate the climate change index eCO_2 by multiplying each GHG's GWP, its climate change characterization factor, by the amount of it released to the atmosphere.

In a similar vein, The US 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 8 human and environmental health impacts in addition to climate change. For climate change the TRACI characterization factors are IPCC GWPs which can be summed to carbon dioxide equivalents.

Many chemicals and substances have TRACI characterization factors of 0 for some impacts, meaning that they do not contribute to damages for those particular environmental 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 8 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 (CO_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 so that their releases can be added up to obtain an index of total impact.

TRACI's characterization factors may indicate that any given pollutant has more than one human or environmental health impact. For example, sulfur dioxide, causes both acidification and human health damages. To prevent what might appear to be double counting in such instances, TRACI's nine categories assess mutually exclusive environmental impacts. What might seem like a possibility for double counting is, thus, avoided using TRACI methodology for keeping impacts mutually exclusive.[1]

The 9 human and environmental health impacts assessed by MEBCalc use the IPCC and TRACI 2.1 characterization factors. A brief comment 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 for each impact, follows:[2]

- **Climate change** – the potential increase in greenhouse effects due to anthropogenic 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 and converted into their reference substance impacts carbon dioxide equivalents, eCO_2.
- **Human respiratory disease and death from particulates** – potential human health impacts from anthropogenic releases of coarse particles known to aggravate respiratory conditions such as asthma, fine particles that can lead to more serious respiratory symptoms and disease, and particulate precursors such as nitrogen oxides (NO_x) and sulfur oxides (SO_x). 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 equivalences, $ePM_{2.5}$, where $PM_{2.5}$ is particulate matter no larger than 2.5 microns.
- **Human disease and death from non-carcinogenic toxics** – potential human health impacts (other than particulates' respiratory and toxics' carcinogenic effects) 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. Emissions of pollutants that have human health non-

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[1] More information on TRACI is provided in the following: Jane C. Bare, *Developing a Consistent Decision-Making Framework by Using the U.S. EPA's TRACI,* U.S. Environmental Protection Agency, Cincinnati, OH, 2002; Jane C. Bare, Gregory A. Norris, David W. Pennington and Thomas McKone, 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 Jane C. Bare, 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, provide expositions on the original and more recent versions of the TRACI model.

[2] These human and environmental health impact categories that match the impact categories used in TRACI are also widely used in life cycle assessments and the scientific literature that assess damage costs from environmental impacts.

carcinogenic toxicity impacts are characterized and converted into reference pollutant equivalents, eT, where T is toluene.

- **Human disease and death from carcinogens** – potential human health impacts from releases of chemicals that are carcinogenic to humans. There also are many chemical and heavy metal pollutants that are carcinogenic to humans, including 2,4-D, benzene, DDT, dioxins, formaldehyde, kepone, permethrin, chromium, and lead. The 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 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, ethyl benzene, formaldehyde, kepone, permethrin, toluene, chromium, copper, lead, silver, and zinc. Pollutants that have toxicity impacts to aquatic ecosystems are characterized 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 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 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 as ozone equivalents, eO_3.

II. 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 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 systems activities and facilities.

In addition, MEBCalc tracks the timing of carbon releases from current year handling of wastes. Materials buried today in a landfill, for example, release carbon dioxide, methane and other GHGs from their anaerobic biodegradation slowly over many years. In contrast, combustion of materials in a waste-to-energy (WTE) incineration facility releases all the carbon in those materials all at once, and virtually all as CO_2. 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 throughout the 100- year LCA timeframe.[3]

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

1. 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.
2. Companies that own or manage WTE incineration disposal facilities 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 WTE incineration facilities use future plant and tree growth CO_2 sequestration as offsets when calculating their climate footprint, then so should recycling, composting and landfilling 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 WTE 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 the unnecessary and complicated tracking and 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 CO_2.
3. Concentrations of CO_2 in the atmosphere continue to increase. Oceans absorb about 30% of CO_2 released to the atmosphere, and increased 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 the 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 imbalance between demand need for offsets and actual regrowth means that carbon dioxide polluters cannot legitimately claim that planetary regrowth automatically offsets their carbon emissions. 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.

III. MEBCalc Sources for Pollutant Emissions Over the Life Cycle of Each of the 6 Material Discards

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, MEBCalc originally relied significantly on two waste management LCA models -- EPA/Research Triangle Institute's Decision Support Tool (RTI International) and EPA's WARM model (Waste Reduction Model (WARM) | US EPA).[4]

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[3] MEBCalc uses DYNCO$_2$ for dynamic carbon accounting, Dynamic Carbon Footprint - Life Cycle Assessment Tool - CIRAIG.

[4] Note that MEBCalc does not assess the use phase for materials and products handled by waste management systems. This is not 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 a product or service are assumed to be the same regardless of what EOL management method is used to manage discards. Use phase impacts are also assumed to be the same for virgin- or recycled-content materials and products. MEBCalc does take into account the upstream impacts for products and materials produced from virgin raw materials and fuels versus recycled

Since developing the first version of MEBCalc, Sound Resource Management Group has continually revised emissions data using updates from these two models, as well as substantial new data from a wide variety of peer-reviewed scientific journal articles and other well-regarded sources. These sources include publications by organizations such as Environmental Paper Network, Oregon Department of Environmental Quality (DEQ), National Renewable Energy Laboratory (NREL), U.S. Department of Energy's Energy Information Administration (EIA), and The Association of Plastic Recyclers (APR). Relevant peer-reviewed scientific articles 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.[5]

For landfill emissions MEBCalc relies on EPA's Landfill Gas Emissions Model (LandGEM see Emissions Estimation Tools | US EPA).

For the HPower Waste-to-Energy (WTE) incineration facility in Honolulu, which is used to model the WTE disposal option for managing materials generated on Hawai'i Island, Sound Resource Management Group relied on HPower's annual emissions report for 2021 to the Hawai'i Department of Health (HDOH), and Hawaiian Electric Company's 2021 report to the Hawai'i Public Utilities Commission which details electrical energy generated using renewable energy sources.[6,7] Appendix B, Table B1 provides emissions inventory and power production efficiency calculations.

MEBCalc evaluation of HPower human and environmental health impacts includes offsets (i.e., emissions deductions) for emissions from fuel- and distillate-oil-fired power production. The emissions profiles for fuel and distillate oil power production are from EPA AP-42 compilations.[8] (See AP-42: Compilation of Air Emissions Factors | US EPA at https://www.epa.gov/air-emissions-factors-and-quantification/ap-42-compilation-air-emissions-factors.)

Emissions data for HPower offsets from solar power come from National Renewable Energy Laboratory 2021 fact sheet Life Cycle Greenhouse Gas Emissions from Electricity Generation: Update (available at Life Cycle Greenhouse Gas Emissions from Electricity Generation: Update (nrel.gov)).

For hauling and shipping impacts, MEBCalc relies on Parametrix and Sound Resource Management Group calculations for tons-weighted average mileage distances from Hawai'i transfer stations (12 on the east side of Hawai'i and 10 on the west side) to four processing and waste consolidation facilities and one landfill. Three of the processing/consolidation facilities are located on the east side of Hawai'I near to or in Hilo. One is located on the west side in Kona. One of the three east side facilities is EHRSS (East Hawaii Regional Sort Station) in Hilo. For

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materials. In fact, as LCA results from recycling the 6 materials show, the differences between virgin- and recycled-content human and environmental health impacts provide most, if not always all, of the benefits from recycling.

[5] 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., 2010, Bury or burn North American MSW? LCAs provide answers for climate impacts & carbon neutral power potential, *Environmental Science & Technology* 44 (20): 7944-7949; 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.

[6] HPower 2021 Annual Air Emissions Inventory and GHG submittal for Covered Source Permit (CSP) Nos. 0255-01-C & 0255-02-C, including submittal of 2021 Annual Air Emissions Inventory through the State Local Emissions Inventory System (SLEIS) for HPower's two CSPs covering three boilers, as well as 2022 annual fee summaries for covered sources for criteria air pollutants and for GHGs

[7] Hawaiian Electric Company (HECO), 2021 Renewable Portfolio Standard Status Report, prepared for Hawai'i Public Utilities Commissions, February 8, 2022, page 2.

[8] EPA, AP-42 Fifth Edition, Volume I Chapter 3: Stationary Internal Combustion Sources, specifically sections 3.1 Stationary Gas Turbines and 3.4 Large Stationary Diesel and All Stationary Dual-Fuel Engines. Section 3.1 includes updates in Final Section - Supplement F, dated April 2000, while Section 3.4 includes Final Section – Supplement B dated October 1996.

hauling by truck from the four processing facilities to various destinations, as indicated in the following paragraphs, MEBCalc relies on road mileage data gathered by Parametrix.

For recycling paper, cardboard and plastics, materials from transfer stations go the processing/consolidation facility located in Keeau near to Hilo. Metals recyclables go to either another of the east side processing/consolidation facilities or to the west side processing/consolidation facility in Kona. The non-metal recyclables go from processing/consolidation by truck to EHRSS and then to Hilo Harbor on Hawai'i's east side. Metals for recycling from the east side metals processing/ consolidation facility go to Hilo Harbor. From the west side metals processing/consolidation facility location, metal recyclables go to Kawaihae barge port on the west side of Hawai'i. Both harbors send materials by sea to Honolulu Harbor. From Honolulu, recyclables go to either U.S. mainland or Taiwan recycling markets for manufacturing into recycled-content products and materials. For sea shipment distances MEBCalc relies on the port-to-port sea miles calculator from SEA-DISTANCES.ORG (available at https://sea-distances.org/advanced).

All materials, including metals, to be landfilled from the east side transfer stations go to EHRSS and then on to Puuanahulu Landfill on the west side of Hawai'i. Materials destined for landfill disposal from west side transfer stations go directly to Puuanahulu.

For HPower WTE incineration disposal of paper, cardboard and plastics, these materials are trucked from their processing/consolidation facility in Keaau to EHRSS which in turn trucks them to Hilo Harbor for shipment to Honolulu Harbor. Trucks carry materials from Honolulu Harbor to HPower. Ash from burning at HPower is trucked 5.5 miles to Waimanalo Gulch Sanitary Landfill..

All trucking mileage is assumed to be round trip – i.e., empty backhauls, as is mileage for shipments by barge to HPower. Shipments of recyclables from Hawai'i to Oahu and to recycling markets on the U.S. mainland and Taiwan are all assumed to be one way. Containers of processed recyclable materials are presumed to be clean enough for backhaul uses.

IV. LCA Results for the 9 Human & Environmental Health Impacts

For each material – office paper, mixed paper, cardboard, HDPE, PP, and mixed metals -- tables A1 through A6 in Appendix A show LCA results for each of the 9 human and environmental health impacts. Results are both on an aggregate basis for a hypothetical 5,000 tons for each material and on a per ton basis, except that the 5,000 tons is a combined aggregate for the two plastic materials HDPE and PP. They are split 60/40 and Tables A4 and A5, respectively, list aggregates of 3000 tons for HDPE and 2000 tons for PP.

Some specific human and environmental health impact results are worth mentioning separately due to their estimated economic environmental costs, as discussed in the following sections of this report. These include climate change from eCO_2 emissions, human health respiratory harm from $ePM_{2.5}$ emissions, and human health non-carcinogenic toxicity impacts from eT (toluene) emissions.

1. *Climate Change*

(a). Recycling Paper and cardboard

For the paper materials, recycling 5000 tons has the climate benefit of reducing carbon dioxide equivalent (eCO_2) emissions by 10,800 and 10,600 tons annually for office paper and mixed paper materials, respectively. Recycling 5,000 tons of cardboard reduces eCO_2 emissions by 8,600 tons.

These estimates account for hauling and shipping, MRF processing, and manufacturing of recycled-content paper products that displace virgin-content manufacturing of the same quantities and types of paper and paperboard products. This upstream displacement provides the climate benefits for recycling, while the hauling, shipping and MRF processing impacts increase climate changing carbon emissions. These negative impacts amount to nearly 335 tons eCO_2 for each of the two discarded paper materials, as well as for cardboard. The manufacturing benefits from displacing virgin-content paper by recycled-content paper amount to 11,200 and 11,000 tons eCO_2, respectively, for office and mixed paper, and 9,100 tons eCO_2 for cardboard.

In other words, upstream benefits from substituting recycled-content paper for paper manufactured by harvesting trees and refining tree wood outweigh by over 30 times the hauling and processing climate impacts of the recycling system. For cardboard the multiple is 27. These results are typical for recycling. Upstream benefits from recycling substantially outweigh the negative impacts from recycling collection, hauling and processing.

According to EPA (https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator), reductions between 10,800 and 10,600 tons of carbon dioxide equivalent carbon emissions provides the same climate benefit annually as taking 2,100 gasoline-powered vehicles off the road, or reducing annual miles driven by gasoline-powered passenger cars by over 24 million miles.

(b). Recycling HDPE and PP Plastic Containers

For the combined HDPE and PP plastic containers, recycling 5000 tons has net climate benefits by reducing carbon emissions totaling nearly 5,900 tons eCO_2. This provides an environmental health benefit equivalent to taking 1,150 gas-powered passenger vehicles off the road, or reducing annual miles driven each year by over 13 million. In addition, for plastic containers the climate harms from hauling and processing 5000 tons of plastic containers are outweighed nearly 18 times by the upstream benefits from recycling. Plastics recycling has lower upstream climate benefits per ton than paper and cardboard recycling.

(c). Recycling Mixed Metals

Recycling 5,000 mixed metals tons reduces climate changing carbon emissions by 7,000 tons eCO_2, an environmental benefit equivalent to taking nearly 1,400 gas-powered passenger vehicles off the road, or reducing annual miles driven each year by over 15 million. In addition, for mixed metals the climate harms from hauling and processing 5000 tons of plastic containers are outweighed 22 times by the upstream benefits from recycling. At the same time, one should note that refining/remelting recycled metals and manufacturing recycled-content products and materials are still energy intensive processes despite the substantial energy savings from not having to extract and refine metallic ores to make virgin-content materials.

(d). Landfilling/WTE: Paper, Cardboard, Plastic and Metals

Results for landfilling 5000 tons of paper materials on Hawai'i island (aka Big Island) or barging them to Oahu island for WTE incineration at HPOWER in Honolulu entail increased eCO_2 emissions of 8,300 and 7,800, respectively, for on island office paper and mixed paper landfilling. This compares to increased eCO_2 emissions amounting to 4,300 and 3,000 tons, respectively, for WTE burning of paper discards on Oahu island at HPOWER. For cardboard the comparable results are 5,600 tons increased eCO_2 emissions for burying versus 4,100 tons increased eCO_2 emissions for burning. For combined plastics the on-Hawai'i-island landfilling versus Honolulu burning comparisons are less than 100 tons of increased eCO_2 emissions for burying versus more than 7,000 tons increase for WTE incineration.

Mixed metals are not sent to HPower for burning. When landfilled on Hawai'i 5,000 tons of mixed metals increase eCO_2 emissions by just over 75 tons.

2. *Human Health Respiratory & Non-Carcinogenic Toxicity Emissions*

Small particulates no greater than 2.5 microns in size, including the many but very light nanoparticles, cause increases in morbidity and reduced life spans that entail costs per ton of $ePM_{2.5}$ emissions estimated at $583,400 in 2021 dollars.[9] Monetized cost estimates for each of the 9 reference substances' physical human and environmental health impacts are discussed in the following section. In this section we report on results for the physical emissions decreases or increases, and comment on two of those impacts – human health respiratory and non-carcinogenic toxicity. The monetized economic cost estimates for physical pollution releases provided guidance for selecting these two human health impacts to review in addition to climate impacts discussed in the preceding subsection.

(a). Recycling Paper and Cardboard

Recycling 5000 tons each for the two categories of paper results in nearly 2 tons $ePM_{2.5}$ decrease each for office paper and mixed paper as benefits for human health respiratory impacts. Paper recycling benefits for human non-carcinogenic toxicity amount to approximately 8 tons and 9 tons of eT decreases for office paper and mixed paper, respectively.

For cardboard, recycling 5,000 tons has human health respiratory benefits as a result of reducing $ePM_{2.5}$ emissions by 1.5 tons. However, recycling this amount of cardboard causes an increase in human non-carcinogenic toxicity amounting to nearly 90 tons eT.

(b). Landfilling/WTE Paper and Cardboard

Results for landfilling 5000 tons of either type of paper discards on Hawai'i island (aka Big Island) or barging them to Oahu island for WTE incineration at HPOWER in Honolulu entail increases in particulate emissions of 0.02 tons and 0.2 tons $ePM_{2.5}$, respectively. For toxicity emissions the estimates for paper amount to increased emissions of approximately 20 tons eT versus decreases of more than 400 tons eT, respectively, for landfilling on Hawai'i island versus WTE incineration in Honolulu.

For disposal of 5,000 tons of cardboard via landfilling on Hawai'i or WTE burning in Honolulu, Oahu at HPower, landfilling causes increased particulate emissions amounting to 0.02 tons $ePM_{2.5}$ and increased non-carcinogenic eT emissions of 21 tons. Disposal via WTE increases $ePM_{2.5}$ emissions by 0.2 tons, but decreases eT emissions by nearly 450 tons.

(c). Landfilling/WTE Plastics and Mixed Metals

For managing 5000 tons of combined HDPE and PP plastics, results for on-Hawai'i Island landfilling versus barging to Oahu for WTE incineration in Honolulu amount to an increase of 0.004 tons of $PM_{2.5}$ emissions for landfilling versus a decrease of 0.07 tons for WTE incineration. For human toxicity results are an increase of 11 tons compared with a decrease of 1,300 tons eT for landfill and WTE incineration, respectively.

Landfilling 5,000 tons of mixed metals increases $ePM_{2.5}$ emissions by 0.004 tons and eT emissions by over 10 tons. Mixed metals that are separated from other solid wastes are not burned at HPower.

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[9] Based on Jeffrey Morris, *Economic Damage Costs for Nine Human Health and Environmental Impacts*, prepared for Oregon Department of Environmental Quality and Oregon Metro, July 2020, and EPA*, Technical Support Document: Estimating the Benefit Per Ton of Reducing PM2.5 and PM2.5 Precursors from 17 Sectors*, January 2013. Economic costs used in MEBCalc updated to 2021 dollars.

V. *Monetizing Physical Emissions Data to Estimate Damage Costs for 9 Human and Environmental Health Impacts*

This section's discussion and the following section's graphs illustrate how environmental economic values (EEVs), made possible by monetizing the 9 physical human and environmental health categories reference substances for pollutant emissions, simplify comparisons among the methods for managing each of the 6 material discards. Otherwise, the physical quantity estimates for the 9 pollution impacts are so disparate in absolute quantities and impact severities that they defy readily understandable comparisons of relative importance for pollution from the 9 impacts.

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-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 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 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 9 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 9 human and environmental health impacts. These damage costs are based on more than 30 scientific studies sourced and reviewed by Sound Resource Management Group in a 2019-20 study and report for Oregon Department of Environmental Quality (DEQ) and Oregon Metro that summarizes these damage cost estimations.[10]

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[10] 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
Toxicity Non-Carcinogenic Effects (T)	$330
Carcinogenicity Effects (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 very brief 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 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 presented as present value dollar costs per metric ton of carbon dioxide emissions in the current year. These estimates are often called the social cost of carbon (SCC).

  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 allowed 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.[11] 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.[12] 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.

  The human health cost per ton for 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 by a person, 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 human receptors 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 8 impacts could still underestimate the human health damages from current year particulate emissions.

- ***Human Health Non-Carcinogenic Effects from Toxic Pollutants*** – Most references for human health - non-cancer impacts base their cost estimates on mercury emissions to air, some of which deposit in water. Once in water, mercury works its way up the food chain to contaminate fish species that are consumed by humans. 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 down to low and very low doses. 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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[11] 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.

[12] Indirect particulate emissions are caused by gaseous emissions of pollutants such as nitrogen oxides (NO_x) and sulfur oxides (SOx) that react with other compounds in the atmosphere to form particulate matter. Such gaseous emissions are often termed particle matter 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 population receptors, 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, and fisheries decline due to eutrophication of surface waters. An example of the latter 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, facilitated annual auctions for those permits, and published the spot clearing price reached during those auctions.

  Average prices in the spot auctions have recently dropped below $1/metric ton 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.[13]

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[13] 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 average 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 confidence interval.

VI. Monetization of LCA Results for the 9 Human and Environmental Health Impacts for Each of the 6 Materials

In addition to physical impacts in reference substance terms, Tables 1 through 6 in Appendix A provide monetized total and per ton LCA damage cost reductions. These benefits are displayed as positive 2021-dollar values. Damage cost increases are displayed as negative 2021-dollar values.

One of the advantages of monetizing physical impacts is that results for each of the 9 impacts can be added together to produce an overall environmental economic value (EEV) benefit/(cost) score in 2021-dollar terms for each material. Figure 1 graphically displays the EEV for overall per ton impacts for all materials except mixed metals. Mixed metals have a much higher recycling EEV, such that including mixed metals on the graph would tend to distort comparison of results among the other 5 materials. Hence, the results for mixed metals are discussed in report text following discussion for each of Graphs 1 through 4.

Figure 1 indicates that recycling processed materials by shipping them to recycled-content manufacturing facilities in either North America or Asia reduces total human and environmental health damage costs for the 9 impacts on a per ton basis by $649 for office paper, $656 for mixed paper, $581 for cardboard, $434 for HDPE plastic containers, and $449 for PP plastic containers. Recycling does incur damage costs for collection, transfer and hauling/shipping activities, as well as for manufacturing recycled-content products from the five materials. However, the damage cost reductions from reduced virgin-content product manufacturing outweighs these damage costs by a substantial amount.

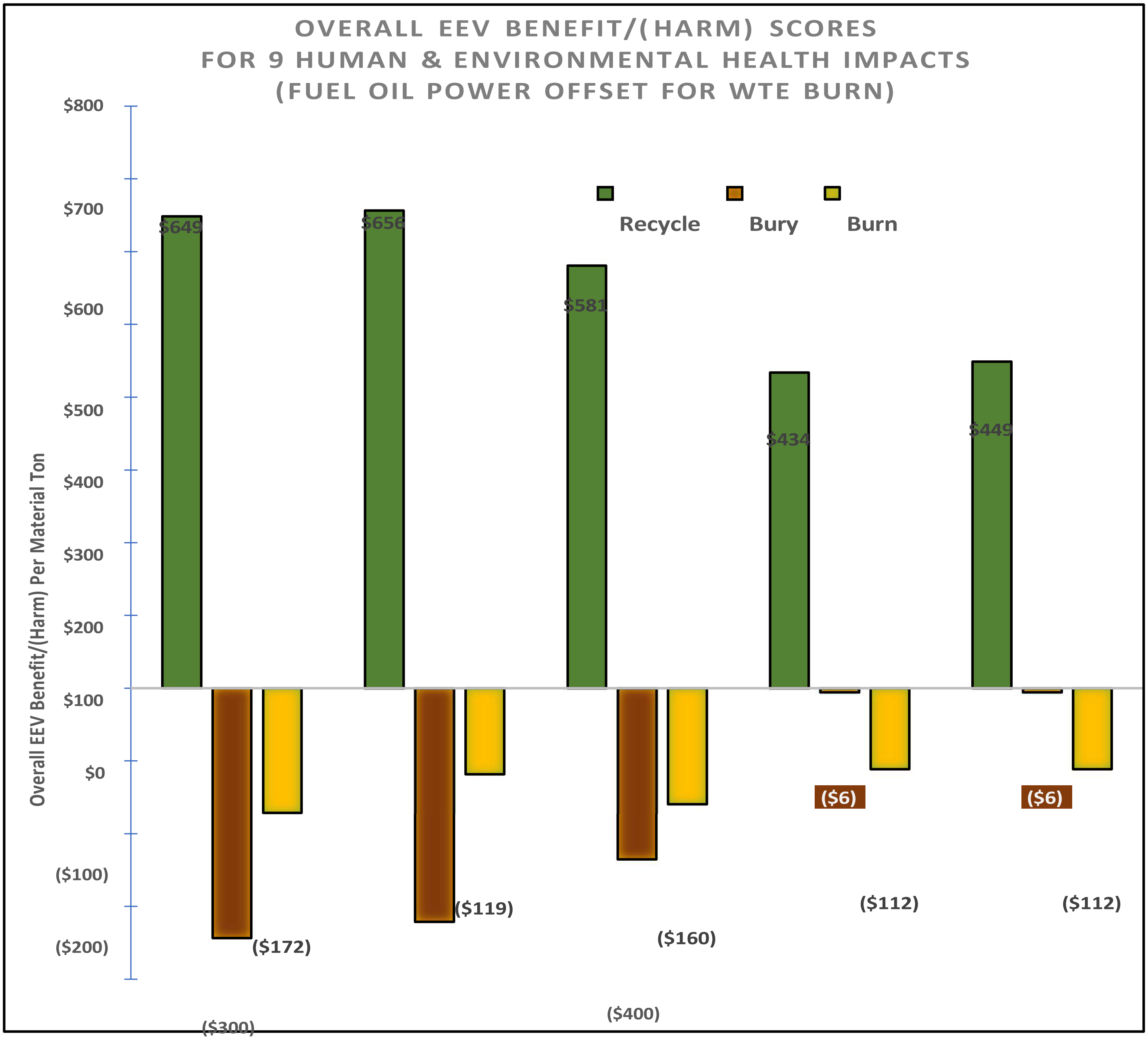
In contrast both on-Hawai'i Island landfilling (LF) and in-Honolulu WTE incineration increases damage costs in aggregate for all five materials. LF mitigates pollution damages to some extent by collecting and flaring methane generated from the buried biogenic paper and cardboard materials. However, their remain significant climate and smog formation impacts for generated methane that escapes to the atmosphere because landfill gas (LFG) collection efficiency is, as is true for virtually all modern landfills, well below 100%. Also, even for the methane that is captured and converted to carbon dioxide through flaring of LFG, carbon dioxide itself has a negative climate impact.

Thus, as indicated on Figure 1 waste management activities required for the landfilling of office paper, mixed paper, and cardboard on Hawai'i Island incur human and environmental health damage costs per ton that in aggregate for the 9 impacts total $344, $322, and $235, respectively. HDPE and PP plastic containers do not biodegrade in a LF. Thus, their waste management environmental damages only amount to $6 per ton

The negative impacts of hauling and barging collected materials from Hawai'i to Oahu and their disposal at the HPower WTE incineration facility to generate power for distribution to Oahu Island residential and commercial entities outweigh the benefits of avoiding pollution from the use of power generated from fuel oil combustion power plants on Oahu. For paper and cardboard materials, the carbon dioxide and other emissions from combustion result in net damage costs per ton of $172, $119, and $160 per ton for office paper, mixed paper, and cardboard, respectively. These net impact damage costs take into account the reduction in pollutant emissions from fuel oil combustion that would be needed to provide the electricity generated at HPower. For HDPE and PP plastic containers, the net damage costs per ton are $112. Lower damage costs for WTE disposal of plastic containers versus paper are mostly due to the greater energy content of plastics compared with paper. I.e., WTE fuel oil power offsets for plastics are larger than for paper.

Aggregate EEVs for net benefit/harm results per ton of mixed metals amount to $1,836 in benefits for recycling and $6 in harms for landfilling.

Figure 1: Total Economic Value of LCA Benefits/(Harms) Per Ton for 3 Waste Management Methods for Five Materials



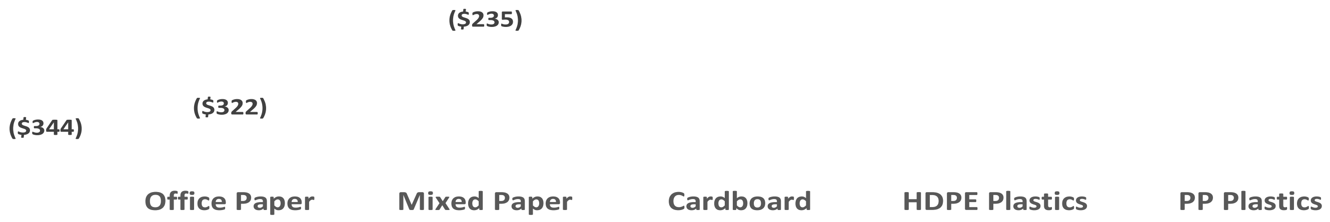
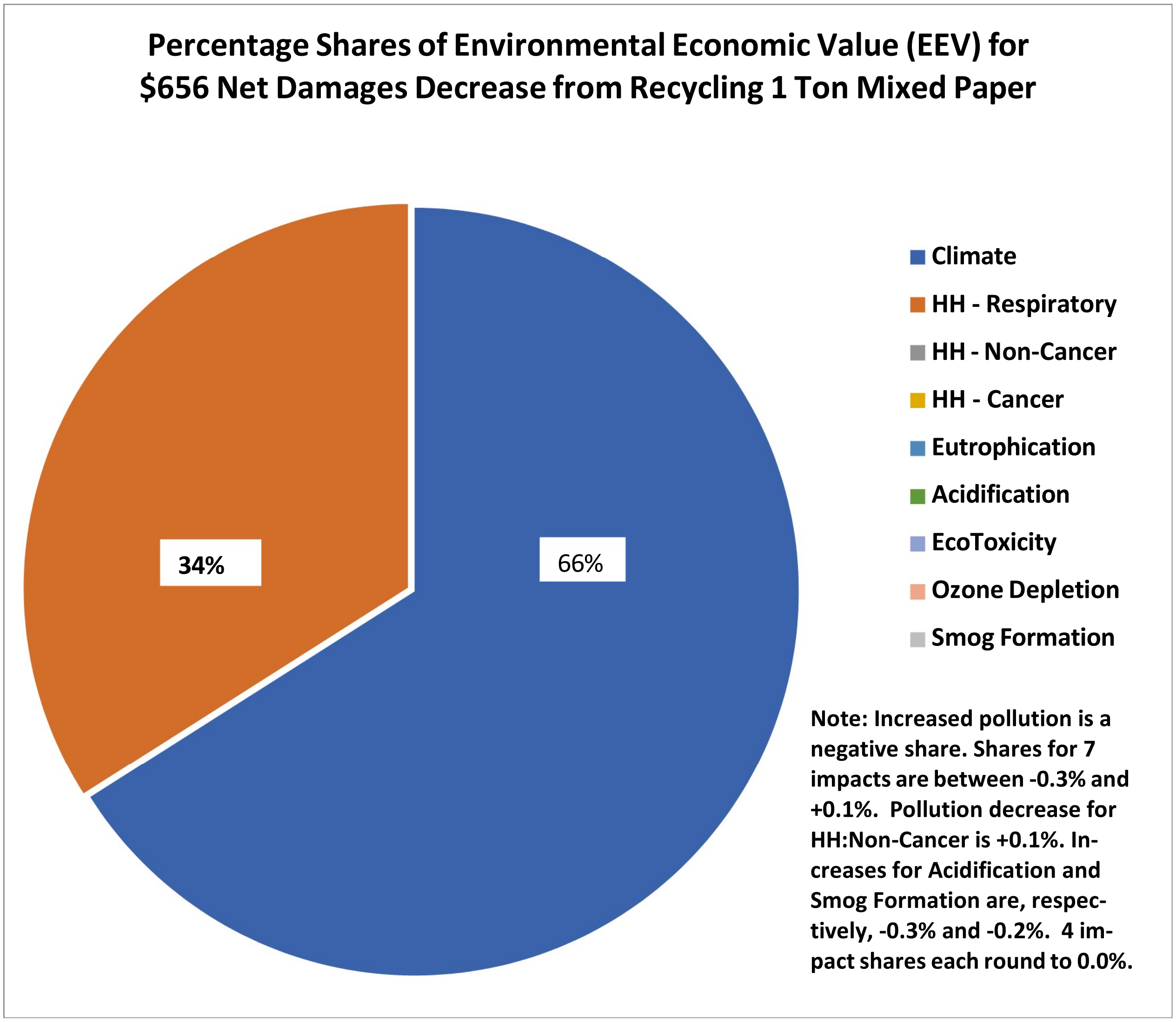

($235)
($322)
($344)
Office Paper
Mixed Paper
Cardboard
HDPE Plastics
PP Plastics

Figure 2 breaks down the distribution for mixed paper's $656 total net recycling value among the 9 human and environmental health impacts. Note that climate benefits from mixed paper recycling account for 66%, rounded to nearest whole percentage point of net environmental economic value (EEV). A 50% or greater share of net recycling EEV for climate impacts is typical for the 5 materials – office paper, mixed paper, cardboard, HDPE plastic containers, and PP plastic containers. For mixed metals, however, climate impact benefits account for just 16% of aggregate EEV benefit from recycling. Human health respiratory and non-carcinogenic toxicity provide 53% and 30%, respectively, of aggregated EEV mixed metals recycling benefit.

Human health respiratory benefits account for 34% of mixed paper recycling EEV. The other 7 impacts account for some benefits and more harms, but don't net to a rounded percentage point of benefit or harm.

Figure 2: Recycling One Ton of Mixed Paper Shares for Net $650 Human/Environmental Damages Decrease



Note: Increased pollution is a negative share. Shares for 7 impacts are between -0.3% and +0.1%. Pollution decrease for HH:Non-Cancer is +0.1%. Increases for Acidification and Smog Formation are, respectively, -0.3% and -0.2%. 4 impact shares each round to 0.0%.

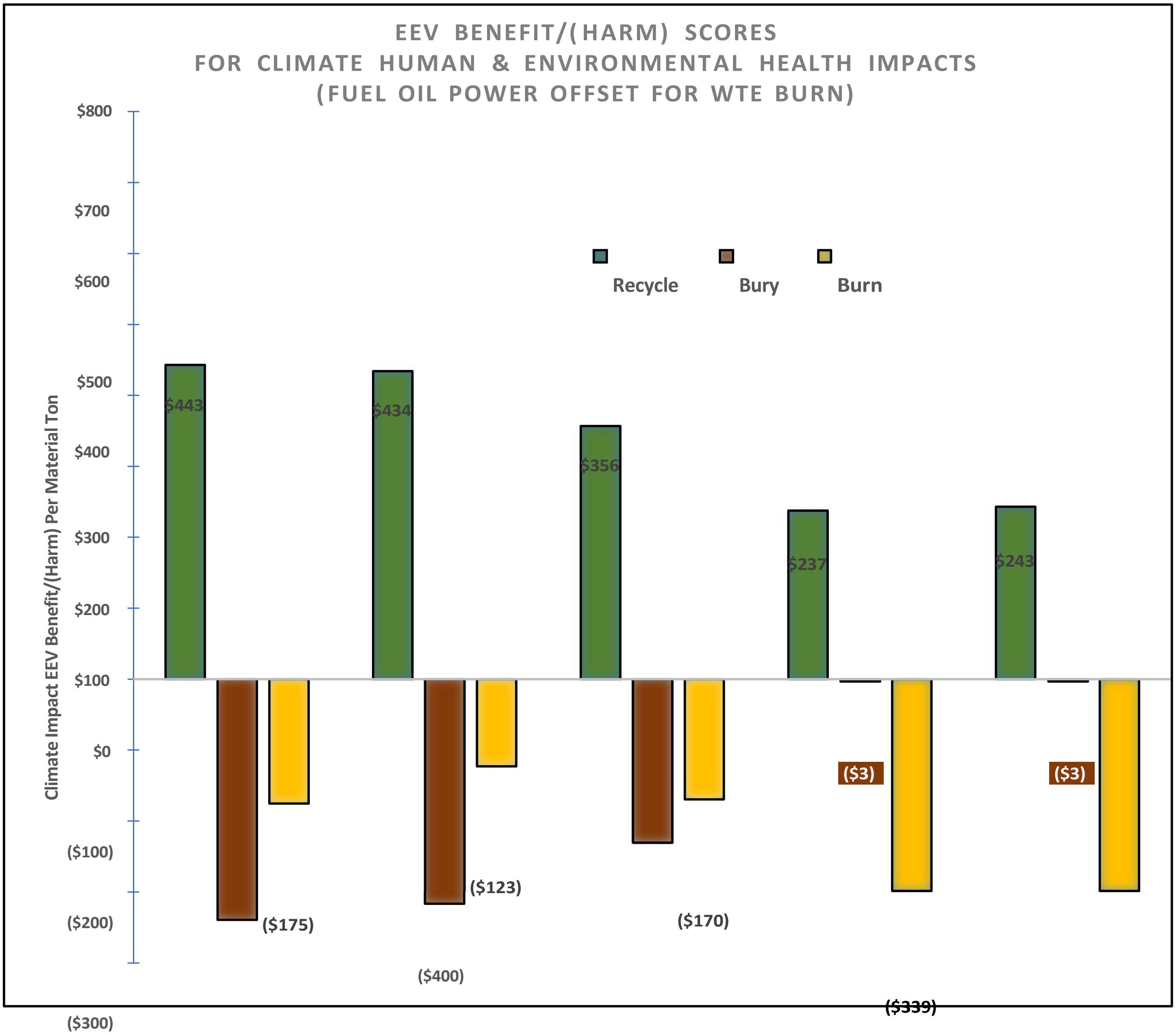
Figure 3 shows the EEVs for just climate change and Figure 4 shows combined EEVs for the other 8 human and environmental health impacts. A comparison of EEVs in these two charts validates the conclusion that climate change accounts for 50% or more of total EEV for the 3 management methods for handling discards of those 5 materials.

This may seem strange when referring back to Table 1 which shows that the eCO_2 climate damage cost ranks last among reference substance damage costs for the 9 impacts. However, the EEVs for Figures 1, 3 and 4 are the result of a reference substance's damage cost per ton multiplied by total tons of pollution releases. Physical-quantity-released estimates for reference substance tons shown in Tables 1 through 6 in Appendix A indicate the disparity in physical releases of reference substance equivalents. Tons of carbon dioxide equivalents emitted are more than 10 times larger.

Climate change and human health respiratory impacts are illustrative, with each providing 66% and 34% respectively, for mixed paper recycling EEV benefits, as illustrated by the Figure 2 pie chart. Table 2 for mixed paper lists eCO_2 emission reductions at 10,600 tons and $ePM_{2.5}$ emission reductions at 1.9 tons from recycling 5,000 tons of mixed paper. Multiplying these tons by the Table 1 respective damage costs per ton of $204 and $583,449, yields $2.2 million and $1.1 million, respectively, for climate versus human health respiratory benefits. This is a ratio of 1.9 more EEV for climate benefits vs. human respiratory benefits.

Figure 3 indicates that EEVs for climate change alone parallel aggregate EEVs shown in Figure 1 for all 9 impacts. That is, rankings based on environmental economic value for each of the management methods are the same for climate change as they are for all 9 impacts together. Recycling is best for all 5 materials. LF is worst for paper and second best for plastics, while WTE is second best for paper and worst for plastics.

Figure 3: Per Ton Value of Climate Impact Benefits/(Harms) for Material Wastes Management Methods



($230)

($316)

($298)

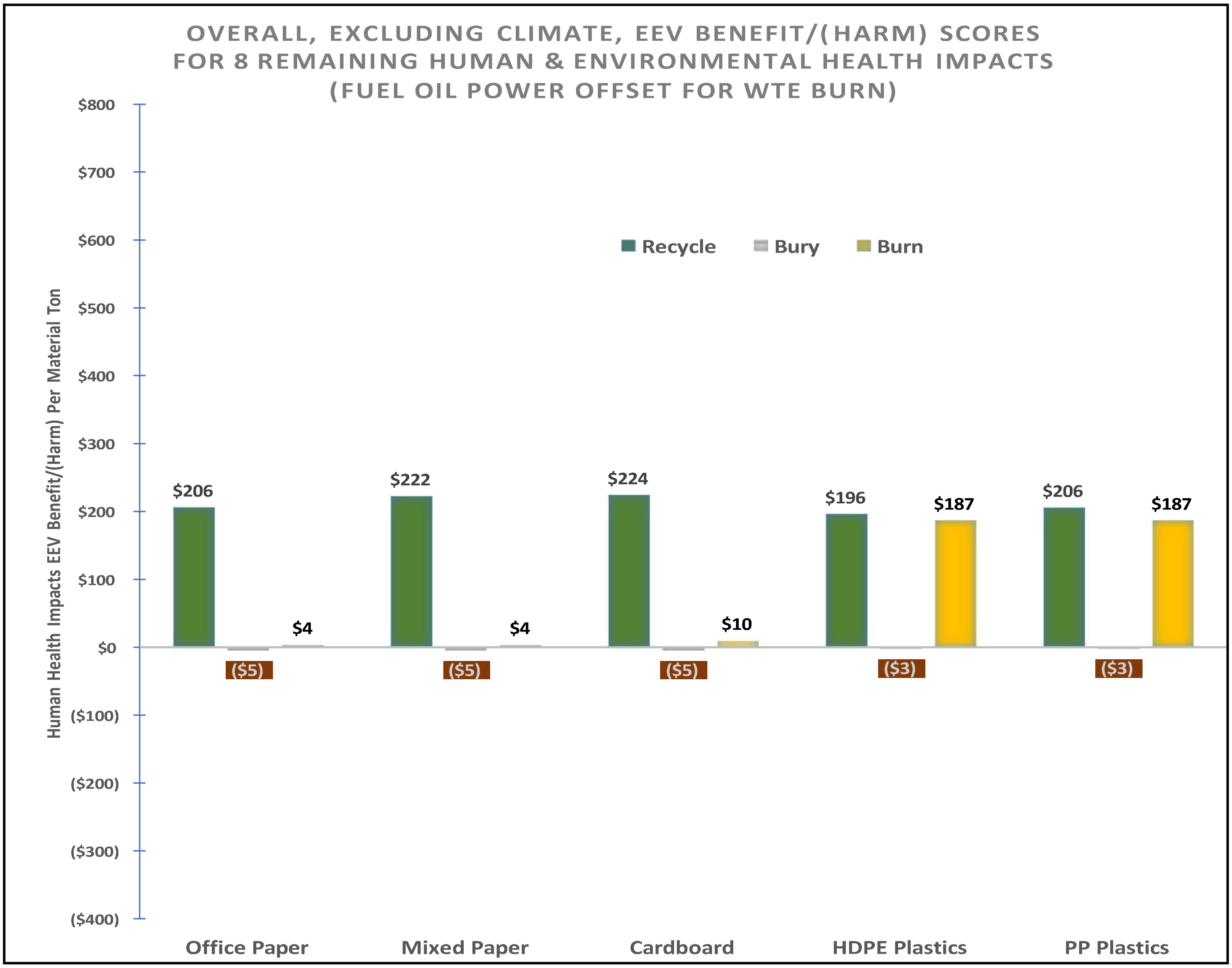
($298)

Office Paper **Mixed Paper** **Cardboard** **HDPE Plastics** **PP Plastics**

Climate EEVs for net benefit/harm results per ton of mixed metals amount to $285 in benefits for recycling and $3 in harms for landfilling. See Appendix Table 6 for mixed metals EEV results for each of the 9 human and environmental health impacts.

Figure 4 tells a different story for the 5 materials displayed, with recycling still first, but WTE second and landfill worst for all 5 materials. The change in rankings for plastics, elevating WTE above LF and coming in close to recycling in Figure 4, is mainly due to the WTE offsets for fuel oil power plants for human health respiratory and non-carcinogenic impacts, and smog formation effects. According to EPA AP-42 emissions data for fuel oil generated power, fuel oil has atmospheric releases worse than natural gas power and closing in on coal-fired power plants.

Figure 4: Per Ton Aggregated Value of Remaining 8 Human & Environmental Health Impacts Benefits/(Harms) for Material Wastes Management Methods



Given their compilation dates (1996 for diesel and distillate oil large scale internal combustion engines), EPA AP-42 emission factors may be outdated for estimating actual emissions from fuel-oil powered utility scale electricity generation on Oahu. In comparison to the current 2021 HPower emissions data, AP-42 emissions estimates for fuel oil power may not accurately profile emissions avoided through Hawaiian Electric Company (HECO) purchases of power from HPOWER. Whether the AP-42 emissions profiles are approximately correct surrogates, substantially underestimate, or substantially overestimate actual emissions from oil-fired power generation on Oahu is unknown. Hence, MEBCalc calculations for HPower human and environmental health impacts and damage costs may be unreliable for emissions from oil-fired power generation on Oahu in 2021 avoided by HPower sales of electricity to HECO.

VII. Sensitivity of Monetized LCA Results to Fuel Type Offsets for WTE Incineration's Human & Environmental Health Impacts

Hawai'i recently closed its remaining coal-fired power generation facility. HECO is aggressively promoting and developing solar power sources for Oahu, as well the other Hawaiian islands. This raises questions regarding what changes to human and environmental health impacts for HPower would occur if power generation using fuel oil as a power source is greatly reduced or eliminated. To answer these questions, MEBCalc assessed environmental benefits and costs assuming that HPower electricity displaces solar power rather fuel oil power generation on Oahu.

Figures 5, 6 and 7 in comparison to Figures 1, 3 and 4 illustrate WTE's substantial sensitivity to the type of energy displaced for paper and plastic materials. These 4 materials adequately illustrate the sensitivity of rankings based on EEV scores to the power displaced by HPower electricity.

Figure 5: Total Economic Value of LCA Benefits/(Harms) Per Ton for 3 Waste Management Methods for Four Materials with Solar Power as Offset for WTE Power

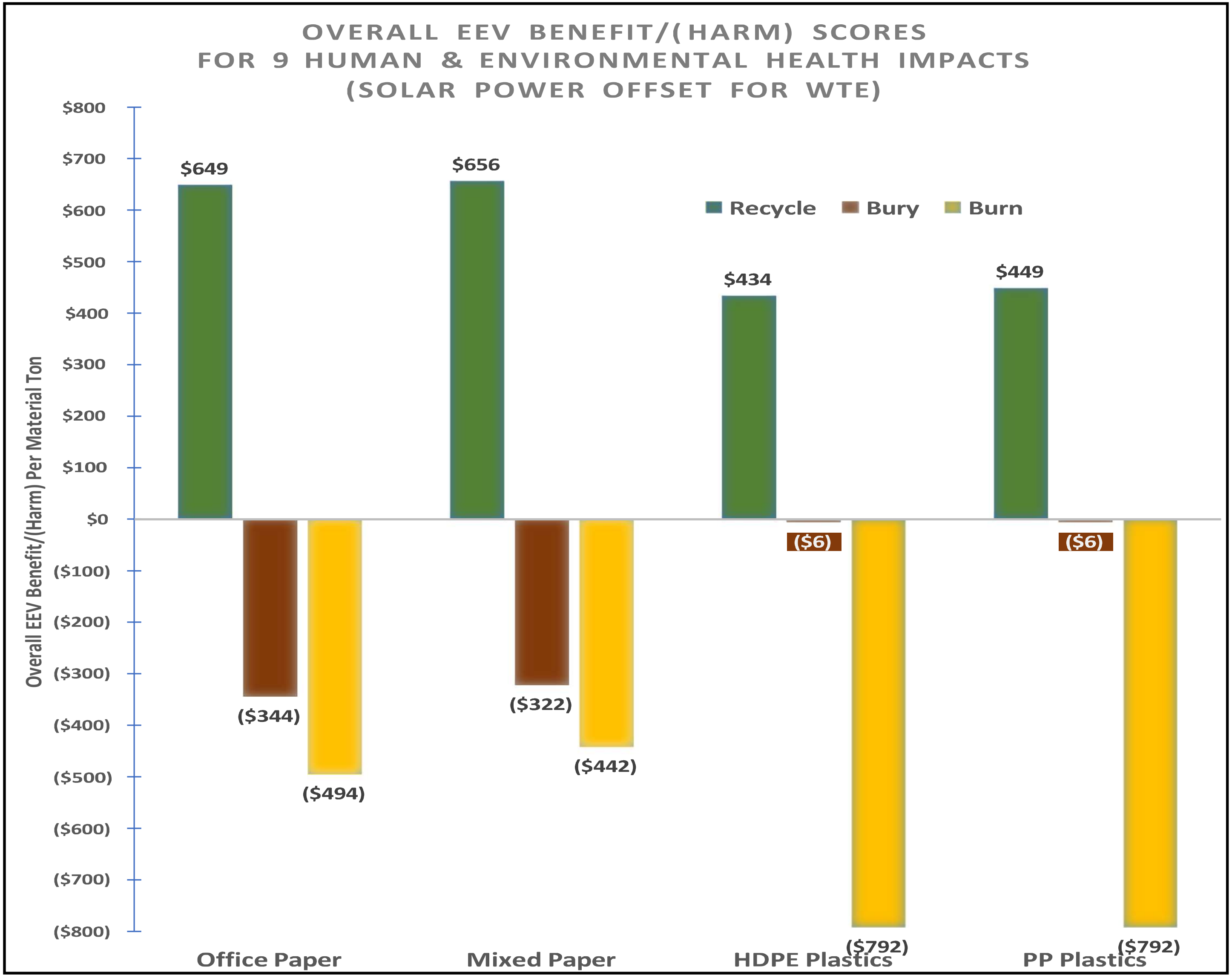


Figure 5 shows aggregate human and environmental health benefits and costs when HPower electricity displaces solar power rather than displacing fuel-oil-fired power generation. Figure 5 in comparison with Figure 1 indicates substantial negative sensitivity for WTE incineration when it displaces a sustainable and renewable energy source rather than a fossil-fuel power source. In the case of solar power versus fuel oil power the increase in WTE's damage costs per ton burned is between 3 and 7 times due to the substantially lower aggregate footprint for solar power versus fuel oil power for the 9 human and environmental impacts indexed on the basis of environmental economic values (EEVs). In fact, with solar as HPower's displaced power source WTE ranks lowest for discards management for all 4 waste materials.

Figure 6 shows EEV changes for just net climate environmental impacts incurred in the life cycle of HPower electricity. In fact, as indicated by comparing Figures 3 and 6, climate change EEV rankings remain unchanged for the 3 discards management methods – recycling, landfilling and WTE incineration. WTE continues to rank ahead of landfilling for managing paper discards. However, the increase in damage costs for paper burning at HPower on Oahu decreases that management method's superiority over landfilling on Hawai'i down to a 3% smaller EEV damage cost for office paper and 13% smaller EEV damages for mixed paper.

Figure 6: Per Ton Value of Climate Impact Benefits/(Harms) for Material Wastes Management Methods with Solar Power as Offset for WTE Power

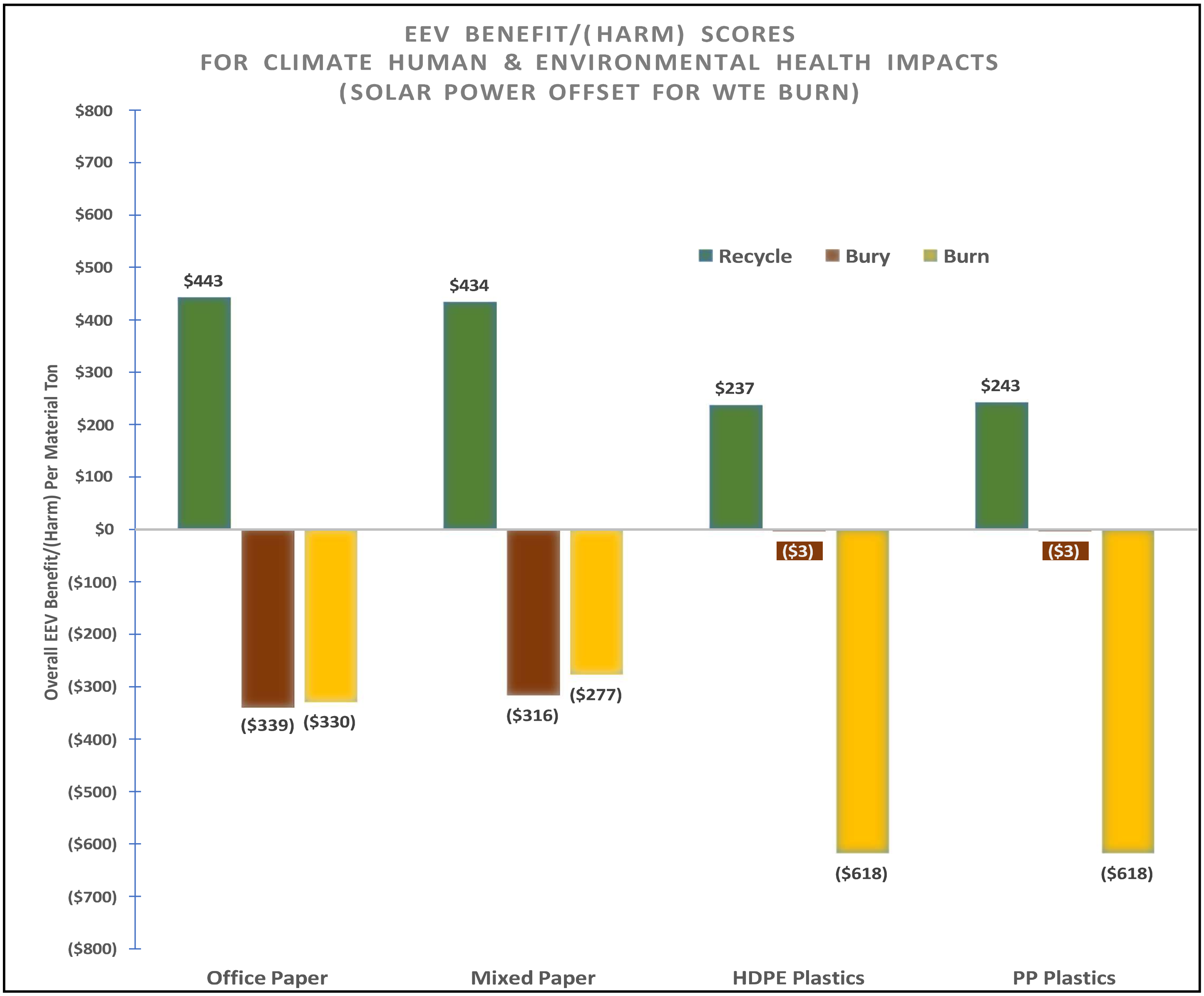
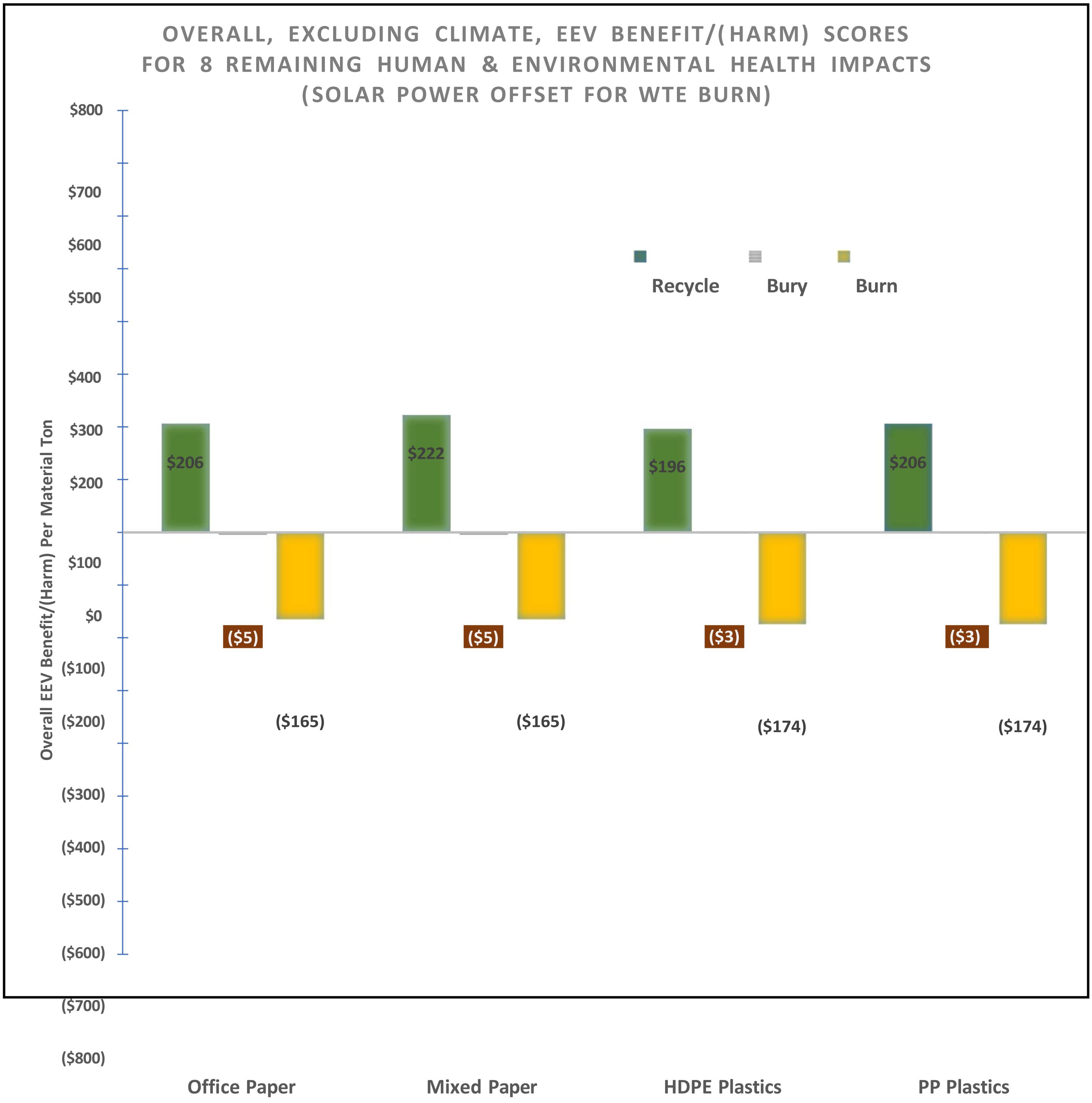


Figure 7 for the 8 impacts besides climate change shows their aggregated EEVs for the 4 materials and 3 waste management methods. Results when assuming WTE power displaces solar power put WTE in a distant last place for the 8 impacts indexed by totaling EEVs for each of those 8 human and environmental health impacts.

Figure 7: Per Ton Aggregated Value of 8 Human & Environmental Health Impacts Benefits/(Harms) for Material Wastes Management Methods with Solar Power Offset for WTE Power



Conclusions from this sensitivity analysis include:

1. Recycling is best for all four materials regardless of the power source displaced by WTE power. This is because recycling actually has positive aggregated EEV benefits for 9 impacts in either case, has positive EEV benefits for

climate impacts separately for either WTE power displacement, and has positive aggregated EEV benefits for the 8 non-climate impacts for all four discarded materials for either power source displaced by WTE, but the race between landfill and WTE is very close when solar is the displaced power source.

2. Landfilling is second best most of the time in terms of having lower damage costs than WTE when solar is the power source displaced by WTE. That is, for paper and plastic materials LF is second best for overall aggregated EEVs. It is second best for plastic container climate EEVs, and second best for aggregated EEVs for all 4 materials for the 8 non-climate impacts. Landfilling remains worst for either case of WTE displaced power source for both paper materials.
3. WTE is worst in the solar power displacement case in terms of impacts indexed by EEVs for all three EEV index situations portrayed in Figure 5, 6, and 7 for all four paper and plastic materials, except for separate climate impacts where WTE is narrowly second best as portrayed on Figure 6 for both paper types.

APPENDIX A

Table A1: LCA and Monetization Results for Office Paper

	Ten Indicators of Environmental Benefit/Harm(-) for Recycling, Burying or Burning Office Paper Generated in Hawaii County (impacts in tons)									
	Climate Change	Human Health - Particulates	Human Health - Toxics	Human Health- Carcinogens	Eutrophication	Acidification	Ecosystems Toxicity	Ozone Depletion	Smog Formation	EEV Benefit / (Harm)
	eCO2	ePM2.5	eToluene	eBenzene	eN	eSO2	e2,4-D	eCFC-11	eO3	2021 $
Office Paper										
Recycle 5000 Tons										
Haul/Ship	-2.18E+02	-8.76E-03	-1.96E-01	-9.31E-05	-1.31E-02	-2.48E-01	-2.05E-04	0.00E+00	-9.69E+00	($52,300)
Process	-1.16E+02	-1.51E-02	-2.46E-01	-1.31E-04	-1.07E-02	-5.61E-01	-2.11E-04	0.00E+00	-5.59E+00	($34,307)
Manufacture*	1.12E+04	1.85E+00	8.22E+00	1.23E-02	-1.63E-01	-3.01E+01	-6.69E-03	-2.33E-06	-6.88E+01	$3,329,923
Total	1.08E+04	1.82E+00	7.78E+00	1.20E-02	-1.87E-01	-3.09E+01	-7.11E-03	-2.33E-06	-8.41E+01	$3,243,316
Landfill 5000 Tons										
Haul/Ship	-3.76E+01	-1.51E-03	-3.38E-02	-1.61E-05	-2.27E-03	-4.29E-02	-3.53E-05	0.00E+00	-1.67E+00	($9,031)
Process/Bury	-8.26E+03	-1.57E-02	-2.00E+01	-1.94E-01	-1.03E-01	-4.81E-01	-9.23E-05	-2.16E-02	-1.31E+01	($1,710,353)
Total	-8.30E+03	-1.72E-02	-2.01E+01	-1.94E-01	-1.05E-01	-5.24E-01	-1.28E-04	-2.16E-02	-1.48E+01	($1,719,384)
WTE Burn 5000 Tons										
Haul/Ship	-6.91E+01	-2.78E-03	-6.22E-02	-2.96E-05	-4.17E-03	-7.88E-02	-6.50E-05	0.00E+00	-3.07E+00	($16,604)
Process/Burn*	-4.23E+03	-2.27E-01	4.16E+02	-4.23E+00	9.11E-02	1.23E+01	1.69E-01	9.49E-05	7.92E+01	($841,477)
Total	-4.30E+03	-2.29E-01	4.16E+02	-4.23E+00	8.69E-02	1.22E+01	1.69E-01	9.49E-05	7.62E+01	($858,080)
Recycle One Ton										
Haul/Ship	-4.35E-02	-1.75E-06	-3.92E-05	-1.86E-08	-2.63E-06	-4.96E-05	-4.09E-08	0.00E+00	-1.94E-03	($10.46)
Process	-2.31E-02	-3.02E-06	-4.91E-05	-2.62E-08	-2.14E-06	-1.12E-04	-4.22E-08	0.00E+00	-1.12E-03	($6.86)
Manufacture*	2.23E+00	3.70E-04	1.64E-03	2.45E-06	-3.25E-05	-6.01E-03	-1.34E-06	-4.65E-10	-1.38E-02	$665.98
Total	2.17E+00	3.65E-04	1.56E-03	2.41E-06	-3.73E-05	-6.17E-03	-1.42E-06	-4.65E-10	-1.68E-02	$648.66
Monetized Score/Ton	$442.61	$212.82	$0.51	$0.01	($0.90)	($2.44)	($0.01)	($0.00)	($3.95)	$648.66
Landfill One Ton										
Haul/Ship	-7.52E-03	-3.03E-07	-6.76E-06	-3.22E-09	-4.53E-07	-8.57E-06	-7.07E-09	0.00E+00	-3.34E-04	($1.81)
Process/Bury	-1.65E+00	-3.14E-06	-4.01E-03	-3.88E-05	-2.06E-05	-9.62E-05	-1.85E-08	-4.32E-06	-2.62E-03	($342.07)
Total	-1.66E+00	-3.44E-06	-4.01E-03	-3.88E-05	-2.10E-05	-1.05E-04	-2.55E-08	-4.32E-06	-2.96E-03	($343.88)
Monetized Score/Ton	($338.98)	($2.01)	($1.32)	($0.09)	($0.50)	($0.04)	($0.00)	($0.24)	($0.69)	($343.88)
WTE Burn One Ton										
Haul/Ship	-1.38E-02	-5.57E-07	-1.24E-05	-5.91E-09	-8.33E-07	-1.58E-05	-1.30E-08	0.00E+00	-6.15E-04	($3.32)
Process/Burn*	-8.45E-01	-4.53E-05	8.32E-02	-8.47E-04	1.82E-05	2.45E-03	3.39E-05	1.90E-08	1.58E-02	($168.30)
Total	-8.59E-01	-4.59E-05	8.32E-02	-8.47E-04	1.74E-05	2.44E-03	3.39E-05	1.90E-08	1.52E-02	($171.62)
Monetized Score/Ton	($175.39)	($26.77)	$27.45	($2.00)	$0.42	$0.96	$0.14	$0.00	$3.57	($171.62)

Note: Asterisk symbol * indicates That the following offsets are included in LCA results: recycling for avoided office paper virgin-content manufacturing, and WTE for avoided generation of electricity from fuel oil due to combustion of office paper.

Table A2: LCA and Monetization Results for Mixed Paper

	Ten Indicators of Environmental Benefit/Harm(-) for Recycling, Burying or Burning Mixed Paper Generated in Hawaii County (impacts in tons)									
	Climate Change	Human Health - Particulates	Human Health - Toxics	Human Health- Carcinogens	Eutrophication	Acidification	Ecosystems Toxicity	Ozone Depletion	Smog Formation	EEV Benefit / (Harm)
	eCO2	ePM2.5	eToluene	eBenzene	eN	eSO2	e2,4-D	eCFC-11	eO3	2021 $
Mixed Paper										
Recycle 5000 Tons										
Haul/Ship	-2.17E+02	-8.73E-03	-1.95E-01	-9.27E-05	-1.31E-02	-2.47E-01	-2.04E-04	0.00E+00	-9.65E+00	($52,089)
Process	-1.16E+02	-1.51E-02	-2.46E-01	-1.31E-04	-1.07E-02	-5.61E-01	-2.11E-04	0.00E+00	-5.59E+00	($34,307)
Manufacture*	1.10E+04	1.95E+00	9.48E+00	1.46E-02	2.75E-02	-2.13E+01	-4.67E-03	-1.94E-06	-1.57E+01	$3,367,984
Total	1.06E+04	1.93E+00	9.03E+00	1.44E-02	3.71E-03	-2.21E+01	-5.09E-03	-1.94E-06	-3.09E+01	$3,281,588
Landfill 5000 Tons										
Haul/Ship	-3.76E+01	-1.51E-03	-3.38E-02	-1.61E-05	-2.27E-03	-4.29E-02	-3.53E-05	0.00E+00	-1.67E+00	($9,031)
Process/Bury	-7.71E+03	-1.64E-02	-2.11E+01	-2.04E-01	-1.03E-01	-4.89E-01	-9.64E-05	-2.28E-02	-1.34E+01	($1,598,589)
Total	-7.75E+03	-1.79E-02	-2.12E+01	-2.04E-01	-1.05E-01	-5.31E-01	-1.32E-04	-2.28E-02	-1.50E+01	($1,607,620)
WTE Burn 5000 Tons										
Haul/Ship	-6.91E+01	-2.78E-03	-6.22E-02	-2.96E-05	-4.17E-03	-7.88E-02	-6.50E-05	0.00E+00	-3.08E+00	($16,606)
Process/Burn*	-2.93E+03	-2.27E-01	4.16E+02	-4.23E+00	9.11E-02	1.23E+01	1.69E-01	9.49E-05	7.92E+01	($577,599)
Total	-3.00E+03	-2.29E-01	4.16E+02	-4.23E+00	8.69E-02	1.22E+01	1.69E-01	9.49E-05	7.62E+01	($594,204)
Recycle One Ton										
Haul/Ship	-4.34E-02	-1.75E-06	-3.90E-05	-1.85E-08	-2.61E-06	-4.94E-05	-4.08E-08	0.00E+00	-1.93E-03	($10.42)
Process	-2.31E-02	-3.02E-06	-4.91E-05	-2.62E-08	-2.14E-06	-1.12E-04	-4.22E-08	0.00E+00	-1.12E-03	($6.86)
Manufacture*	2.19E+00	3.90E-04	1.90E-03	2.93E-06	5.49E-06	-4.26E-03	-9.35E-07	-3.87E-10	-3.13E-03	$673.60
Total	2.13E+00	3.86E-04	1.81E-03	2.88E-06	7.43E-07	-4.42E-03	-1.02E-06	-3.87E-10	-6.18E-03	$656.32
Monetized Score/Ton	$433.93	$224.97	$0.60	$0.01	$0.02	($1.75)	($0.00)	($0.00)	($1.45)	$656.32
Landfill One Ton										
Haul/Ship	-7.52E-03	-3.03E-07	-6.76E-06	-3.22E-09	-4.53E-07	-8.57E-06	-7.07E-09	0.00E+00	-3.34E-04	($1.81)
Process/Bury	-1.54E+00	-3.28E-06	-4.22E-03	-4.09E-05	-2.06E-05	-9.77E-05	-1.93E-08	-4.55E-06	-2.67E-03	($319.72)
Total	-1.55E+00	-3.58E-06	-4.23E-03	-4.09E-05	-2.11E-05	-1.06E-04	-2.63E-08	-4.55E-06	-3.01E-03	($321.52)
Monetized Score/Ton	($316.44)	($2.09)	($1.40)	($0.10)	($0.51)	($0.04)	($0.00)	($0.25)	($0.71)	($321.52)
WTE Burn One Ton										
Haul/Ship	-1.38E-02	-5.57E-07	-1.24E-05	-5.91E-09	-8.34E-07	-1.58E-05	-1.30E-08	0.00E+00	-6.15E-04	($3.32)
Process/Burn*	-5.87E-01	-4.53E-05	8.32E-02	-8.47E-04	1.82E-05	2.45E-03	3.39E-05	1.90E-08	1.58E-02	($115.52)
Total	-6.01E-01	-4.59E-05	8.32E-02	-8.47E-04	1.74E-05	2.44E-03	3.39E-05	1.90E-08	1.52E-02	($118.84)
Monetized Score/Ton	($122.62)	($26.77)	$27.45	($2.00)	$0.42	$0.96	$0.14	$0.00	$3.57	($118.84)

Note: Asterisk symbol * indicates that the following offsets are included in LCA results: recycling for avoided paper and paperboard virgin-content manufacturing, and WTE for avoided generation of electricity from fuel oil due to combustion of mixed paper.

Table A3: LCA and Monetization Results for Cardboard

	Ten Indicators of Environmental Benefit/Harm(-) for Recycling, Burying or Burning Cardboard Generated in Hawaii County (impacts in tons)									
	Climate Change	Human Health - Particulates	Human Health - Toxics	Human Health- Carcinogens	Eutrophication	Acidification	Ecosystems Toxicity	Ozone Depletion	Smog Formation	EEV Benefit / (Harm)
	eCO2	ePM2.5	eToluene	eBenzene	eN	eSO2	e2,4-D	eCFC-11	eO3	2021 $
Cardboard										
Recycle 5000 Tons										
Haul/Ship	-2.17E+02	-8.73E-03	-1.95E-01	-9.27E-05	-1.31E-02	-2.47E-01	-2.04E-04	0.00E+00	-9.65E+00	($52,103)
Process	-1.16E+02	-1.51E-02	-2.46E-01	-1.31E-04	-1.07E-02	-5.61E-01	-2.11E-04	0.00E+00	-5.59E+00	($34,307)
Manufacture*	9.06E+03	1.56E+00	-8.80E+01	4.30E-01	3.12E+00	5.13E+01	2.03E-02	-1.80E-05	7.06E+02	$2,989,881
Total	8.60E+03	1.53E+00	-8.86E+01	4.30E-01	3.08E+00	5.04E+01	1.98E-02	-1.80E-05	6.84E+02	$2,903,471
Landfill 5000 Tons										
Haul/Ship	-3.76E+01	-1.51E-03	-3.38E-02	-1.61E-05	-2.27E-03	-4.29E-02	-3.53E-05	0.00E+00	-1.67E+00	($9,031)
Process/Bury	-5.60E+03	-1.64E-02	-2.11E+01	-2.04E-01	-1.03E-01	-4.89E-01	-9.64E-05	-2.28E-02	-1.34E+01	($1,167,390)
Total	-5.63E+03	-1.77E-02	-2.11E+01	-2.04E-01	-1.05E-01	-5.27E-01	-1.28E-04	-2.28E-02	-1.49E+01	($1,176,421)
WTE Burn 5000 Tons										
Haul/Ship	-6.91E+01	-2.78E-03	-6.21E-02	-2.95E-05	-4.17E-03	-7.88E-02	-6.49E-05	0.00E+00	-3.07E+00	($16,598)
Process/Burn*	-4.08E+03	-1.96E-01	4.46E+02	-4.20E+00	1.05E-01	1.29E+01	1.75E-01	9.83E-05	8.77E+01	($781,936)
Total	-4.11E+03	-1.97E-01	4.46E+02	-4.20E+00	1.03E-01	1.28E+01	1.75E-01	9.83E-05	8.66E+01	($798,534)
Recycle One Ton										
Haul/Ship	-4.34E-02	-1.75E-06	-3.90E-05	-1.85E-08	-2.62E-06	-4.95E-05	-4.08E-08	0.00E+00	-1.93E-03	($10.42)
Process	-2.31E-02	-3.02E-06	-4.91E-05	-2.62E-08	-2.14E-06	-1.12E-04	-4.22E-08	0.00E+00	-1.12E-03	($6.86)
Manufacture*	1.81E+00	3.11E-04	-1.76E-02	8.61E-05	6.23E-04	1.03E-02	4.06E-06	-3.59E-09	1.41E-01	$597.98
Total	1.75E+00	3.06E-04	-1.77E-02	8.60E-05	6.19E-04	1.01E-02	3.98E-06	-3.59E-09	1.38E-01	$580.69
Monetized Score/Ton	$356.39	$178.71	($5.84)	$0.20	$14.84	$3.99	$0.02	($0.00)	$32.38	$580.69
Landfill One Ton										
Haul/Ship	-7.52E-03	-3.03E-07	-6.76E-06	-3.22E-09	-4.53E-07	-8.57E-06	-7.07E-09	0.00E+00	-3.34E-04	($1.81)
Process/Bury	-1.12E+00	-3.28E-06	-4.22E-03	-4.09E-05	-2.06E-05	-9.77E-05	-1.93E-08	-4.55E-06	-2.67E-03	($233.48)
Total	-1.13E+00	-3.58E-06	-4.23E-03	-4.09E-05	-2.11E-05	-1.06E-04	-2.63E-08	-4.55E-06	-3.01E-03	($235.28)
Monetized Score/Ton	($230.20)	($2.09)	($1.40)	($0.10)	($0.51)	($0.04)	($0.00)	($0.25)	($0.71)	($235.28)
WTE Burn One Ton										
Haul/Ship	-1.38E-02	-5.56E-07	-1.24E-05	-5.91E-09	-8.33E-07	-1.58E-05	-1.30E-08	0.00E+00	-6.15E-04	($3.32)
Process/Burn*	-8.17E-01	-3.91E-05	8.92E-02	-8.40E-04	2.10E-05	2.57E-03	3.51E-05	1.97E-08	1.75E-02	($156.39)
Total	-8.31E-01	-3.97E-05	8.91E-02	-8.40E-04	2.01E-05	2.56E-03	3.51E-05	1.97E-08	1.69E-02	($159.71)
Monetized Score/Ton	($169.59)	($23.14)	$29.40	($1.98)	$0.48	$1.01	$0.14	$0.00	$3.97	($159.71)

Note: Asterisk symbol * indicates that the following offsets are included in LCA results: recycling for avoided cardboard virgin-content manufacturing, and WTE for avoided generation of electricity from fuel oil due to combustion of cardboard.

Table A4: LCA and Monetization Results for High Density Polyethylene (HDPE) Plastic Containers

	Ten Indicators of Environmental Benefit/Harm(-) for Recycling, Burying or Burning HDPE Containers Generated in Hawaii County (impacts in tons)									
	Climate Change	Human Health - Particulates	Human Health - Toxics	Human Health- Carcinogens	Eutrophication	Acidification	Ecosystems Toxicity	Ozone Depletion	Smog Formation	EEV Benefit / (Harm)
	eCO2	ePM2.5	eToluene	eBenzene	eN	eSO2	e2,4-D	eCFC-11	eO3	2021 $
HDPE Plastics										
Recycle 3000 Tons										
Haul/Ship	-1.30E+02	-5.24E-03	-1.17E-01	-5.56E-05	-7.84E-03	-1.48E-01	-1.22E-04	0.00E+00	-5.79E+00	($31,254)
Process	-6.94E+01	-9.07E-03	-1.47E-01	-7.87E-05	-6.41E-03	-3.37E-01	-1.27E-04	0.00E+00	-3.36E+00	($20,584)
Manufacture*	3.69E+03	9.76E-01	7.41E-01	1.16E+00	5.28E-02	7.56E+00	-2.19E-03	9.96E-08	9.79E+01	$1,352,522
Total	3.49E+03	9.62E-01	4.77E-01	1.16E+00	3.85E-02	7.07E+00	-2.44E-03	9.96E-08	8.87E+01	$1,300,684
Landfill 3000 Tons										
Haul/Ship	-2.26E+01	-9.08E-04	-2.03E-02	-9.65E-06	-1.36E-03	-2.57E-02	-2.12E-05	0.00E+00	-1.00E+00	($5,419)
Process/Bury	-2.40E+01	-1.69E-03	-6.46E+00	-5.18E-02	-5.85E-02	-2.20E-01	-4.53E-05	-1.25E-02	-6.01E+00	($11,724)
Total	-4.66E+01	-2.60E-03	-6.48E+00	-5.18E-02	-5.99E-02	-2.45E-01	-6.65E-05	-1.25E-02	-7.01E+00	($17,143)
WTE Burn 3000 Tons										
Haul/Ship	-4.14E+01	-1.67E-03	-3.72E-02	-1.77E-05	-2.49E-03	-4.72E-02	-3.89E-05	0.00E+00	-1.84E+00	($9,940)
Process/Burn*	-4.34E+03	4.23E-01	7.80E+02	-1.90E+00	3.01E-01	1.83E+01	2.11E-01	1.18E-04	2.00E+02	($324,850)
Total	-4.38E+03	4.21E-01	7.80E+02	-1.90E+00	2.98E-01	1.83E+01	2.11E-01	1.18E-04	1.98E+02	($334,791)
Recycle One Ton										
Haul/Ship	-4.34E-02	-1.75E-06	-3.90E-05	-1.85E-08	-2.61E-06	-4.94E-05	-4.08E-08	0.00E+00	-1.93E-03	($10.42)
Process	-2.31E-02	-3.02E-06	-4.91E-05	-2.62E-08	-2.14E-06	-1.12E-04	-4.22E-08	0.00E+00	-1.12E-03	($6.86)
Manufacture*	1.23E+00	3.25E-04	2.47E-04	3.87E-04	1.76E-05	2.52E-03	-7.30E-07	3.32E-11	3.26E-02	$450.84
Total	1.16E+00	3.21E-04	1.59E-04	3.87E-04	1.28E-05	2.36E-03	-8.13E-07	3.32E-11	2.96E-02	$433.56
Monetized Score/Ton	$237.42	$187.00	$0.05	$0.91	$0.31	$0.93	($0.00)	$0.00	$6.94	$433.56
Landfill One Ton										
Haul/Ship	-7.52E-03	-3.03E-07	-6.76E-06	-3.22E-09	-4.53E-07	-8.57E-06	-7.07E-09	0.00E+00	-3.34E-04	($1.81)
Process/Bury	-8.00E-03	-5.63E-07	-2.15E-03	-1.73E-05	-1.95E-05	-7.32E-05	-1.51E-08	-4.17E-06	-2.00E-03	($3.91)
Total	-1.55E-02	-8.66E-07	-2.16E-03	-1.73E-05	-2.00E-05	-8.18E-05	-2.22E-08	-4.17E-06	-2.34E-03	($5.71)
Monetized Score/Ton	($3.17)	($0.51)	($0.71)	($0.04)	($0.48)	($0.03)	($0.00)	($0.23)	($0.55)	($5.71)
WTE Burn One Ton										
Haul/Ship	-1.38E-02	-5.55E-07	-1.24E-05	-5.90E-09	-8.32E-07	-1.57E-05	-1.30E-08	0.00E+00	-6.14E-04	($3.31)
Process/Burn*	-1.45E+00	1.41E-04	2.60E-01	-6.33E-04	1.00E-04	6.11E-03	7.05E-05	3.94E-08	6.65E-02	($108.28)
Total	-1.46E+00	1.40E-04	2.60E-01	-6.33E-04	9.94E-05	6.09E-03	7.05E-05	3.94E-08	6.59E-02	($111.60)
Monetized Score/Ton	($298.33)	$81.92	$85.78	($1.49)	$2.39	$2.41	$0.28	$0.00	$15.45	($111.60)

Note: Asterisk symbol * indicates that the following offsets are included in LCA results: recycling for avoided HDPE virgin-content manufacturing, and WTE for avoided generation of electricity from fuel oil due to combustion of HDPE plastics.

Table A5: LCA and Monetization Results for Polypropylene (PP) Plastic Containers

	Ten Indicators of Environmental Benefit/Harm(-) for Recycling, Burying or Burning PP Containers Generated in Hawaii County (impacts in tons)									
	Climate Change	Human Health - Particulates	Human Health - Toxics	Human Health-Carcinogens	Eutrophication	Acidification	Ecosystems Toxicity	Ozone Depletion	Smog Formation	EEV Benefit / (Harm)
	eCO2	ePM2.5	eToluene	eBenzene	eN	eSO2	e2,4-D	eCFC-11	eO3	2021 $
PP Plastics										
Recycle 2000 Tons										
Haul/Ship	-8.67E+01	-3.49E-03	-7.80E-02	-3.71E-05	-5.23E-03	-9.89E-02	-8.15E-05	0.00E+00	-3.86E+00	($20,836)
Process	-4.63E+01	-6.05E-03	-9.82E-02	-5.25E-05	-4.27E-03	-2.25E-01	-8.44E-05	0.00E+00	-2.24E+00	($13,723)
Manufacture*	2.51E+03	6.62E-01	1.21E+00	1.56E+00	1.58E-01	6.78E+00	-1.44E-03	1.18E-07	9.36E+01	$931,684
Total	2.38E+03	6.53E-01	1.04E+00	1.56E+00	1.48E-01	6.46E+00	-1.60E-03	1.18E-07	8.75E+01	$897,125
Landfill 2000 Tons										
Haul/Ship	-1.50E+01	-6.05E-04	-1.35E-02	-6.43E-06	-9.06E-04	-1.71E-02	-1.41E-05	0.00E+00	-6.69E-01	($3,611)
Process/Bury	-1.60E+01	-1.13E-03	-4.31E+00	-3.46E-02	-3.90E-02	-1.46E-01	-3.02E-05	-8.34E-03	-4.01E+00	($7,816)
Total	-3.10E+01	-1.73E-03	-4.32E+00	-3.46E-02	-3.99E-02	-1.64E-01	-4.44E-05	-8.34E-03	-4.68E+00	($11,427)
WTE Burn 2000 Tons										
Haul/Ship	-2.76E+01	-1.11E-03	-2.48E-02	-1.18E-05	-1.66E-03	-3.14E-02	-2.59E-05	0.00E+00	-1.23E+00	($6,624)
Process/Burn*	-2.89E+03	2.82E-01	5.20E+02	-1.27E+00	2.00E-01	1.22E+01	1.41E-01	7.87E-05	1.33E+02	($216,567)
Total	-2.92E+03	2.81E-01	5.20E+02	-1.27E+00	1.99E-01	1.22E+01	1.41E-01	7.87E-05	1.32E+02	($223,191)
Recycle One Ton										
Haul/Ship	-4.34E-02	-1.75E-06	-3.90E-05	-1.85E-08	-2.61E-06	-4.94E-05	-4.08E-08	0.00E+00	-1.93E-03	($10.42)
Process	-2.31E-02	-3.02E-06	-4.91E-05	-2.62E-08	-2.14E-06	-1.12E-04	-4.22E-08	0.00E+00	-1.12E-03	($6.86)
Manufacture*	1.26E+00	3.31E-04	6.07E-04	7.81E-04	7.90E-05	3.39E-03	-7.18E-07	5.89E-11	4.68E-02	$465.84
Total	1.19E+00	3.26E-04	5.19E-04	7.81E-04	7.42E-05	3.23E-03	-8.01E-07	5.89E-11	4.37E-02	$448.56
Monetized Score/Ton	$242.81	$190.43	$0.17	$1.84	$1.78	$1.27	($0.00)	$0.00	$10.26	$448.56
Landfill One Ton										
Haul/Ship	-7.51E-03	-3.03E-07	-6.76E-06	-3.21E-09	-4.53E-07	-8.57E-06	-7.06E-09	0.00E+00	-3.34E-04	($1.81)
Process/Bury	-8.00E-03	-5.63E-07	-2.15E-03	-1.73E-05	-1.95E-05	-7.32E-05	-1.51E-08	-4.17E-06	-2.00E-03	($3.91)
Total	-1.55E-02	-8.66E-07	-2.16E-03	-1.73E-05	-2.00E-05	-8.18E-05	-2.22E-08	-4.17E-06	-2.34E-03	($5.71)
Monetized Score/Ton	($3.17)	($0.51)	($0.71)	($0.04)	($0.48)	($0.03)	($0.00)	($0.23)	($0.55)	($5.71)
WTE Burn One Ton										
Haul/Ship	-1.38E-02	-5.55E-07	-1.24E-05	-5.89E-09	-8.31E-07	-1.57E-05	-1.30E-08	0.00E+00	-6.13E-04	($3.31)
Process/Burn*	-1.45E+00	1.41E-04	2.60E-01	-6.33E-04	1.00E-04	6.11E-03	7.05E-05	3.94E-08	6.65E-02	($108.28)
Total	-1.46E+00	1.40E-04	2.60E-01	-6.33E-04	9.94E-05	6.09E-03	7.05E-05	3.94E-08	6.59E-02	($111.60)
Monetized Score/Ton	($298.33)	$81.92	$85.78	($1.49)	$2.39	$2.41	$0.28	$0.00	$15.45	($111.60)

Note: Asterisk symbol * indicates that the following offsets are included in LCA results: recycling for avoided PP virgin-content manufacturing, and WTE for avoided generation of electricity from fuel oil due to combustion of PP plastics.

Table A6: LCA and Monetization Results for Mixed Metals

	Ten Indicators of Environmental Benefit/Harm(-) for Recycling or Burying Mixed Ferrous and Non-Ferrous Metals Generated in Hawaii County (impacts in tons)									
	Climate Change	Human Health - Particulates	Human Health - Toxics	Human Health- Carcinogens	Eutrophication	Acidification	Ecosystems Toxicity	Ozone Depletion	Smog Formation	EEV Benefit / (Harm)
	eCO2	ePM2.5	eToluene	eBenzene	eN	eSO2	e2,4-D	eCFC-11	eO3	2021 $
Mixed Metals										
Recycle 5000 Tons										
Haul/Ship	-2.10E+02	-8.44E-03	-1.88E-01	-8.96E-05	-1.26E-02	-2.39E-01	-1.97E-04	0.00E+00	-9.32E+00	($50,342)
Process	-1.16E+02	-1.51E-02	-2.46E-01	-1.31E-04	-1.07E-02	-5.61E-01	-2.11E-04	0.00E+00	-5.59E+00	($34,307)
Manufacture*	7.31E+03	8.32E+00	8.42E+03	1.19E+01	4.36E-01	4.39E+01	4.80E-01	-4.80E-07	3.47E+02	$9,263,124
Total	6.99E+03	8.30E+00	8.42E+03	1.19E+01	4.13E-01	4.31E+01	4.80E-01	-4.80E-07	3.32E+02	$9,178,476
Landfill 5000 Tons										
Haul/Ship	-3.76E+01	-1.51E-03	-3.38E-02	-1.61E-05	-2.27E-03	-4.29E-02	-3.53E-05	0.00E+00	-1.67E+00	($9,031)
Process/Bury	-4.00E+01	-2.82E-03	-1.03E+01	-8.29E-02	-9.75E-02	-3.65E-01	-7.31E-05	-2.00E-02	-9.96E+00	($19,326)
Total	-7.76E+01	-4.33E-03	-1.04E+01	-8.29E-02	-9.98E-02	-4.08E-01	-1.08E-04	-2.00E-02	-1.16E+01	($28,358)
Recycle One Ton										
Haul/Ship	-4.19E-02	-1.69E-06	-3.77E-05	-1.79E-08	-2.53E-06	-4.78E-05	-3.94E-08	0.00E+00	-1.86E-03	($10.07)
Process	-2.31E-02	-3.02E-06	-4.91E-05	-2.62E-08	-2.14E-06	-1.12E-04	-4.22E-08	0.00E+00	-1.12E-03	($6.86)
Manufacture*	1.46E+00	1.66E-03	1.68E+00	2.38E-03	8.73E-05	8.79E-03	9.60E-05	-9.59E-11	6.93E-02	$1,852.62
Total	1.40E+00	1.66E-03	1.68E+00	2.38E-03	8.26E-05	8.63E-03	9.59E-05	-9.59E-11	6.63E-02	$1,835.70
Monetized Score/Ton	$285.30	$968.06	$555.39	$5.62	$1.98	$3.41	$0.39	($0.00)	$15.55	$1,835.70
Landfill One Ton										
Haul/Ship	-7.52E-03	-3.03E-07	-6.76E-06	-3.22E-09	-4.53E-07	-8.57E-06	-7.07E-09	0.00E+00	-3.34E-04	($1.81)
Process/Bury	-8.00E-03	-5.63E-07	-2.07E-03	-1.66E-05	-1.95E-05	-7.30E-05	-1.46E-08	-4.00E-06	-1.99E-03	($3.87)
Total	-1.55E-02	-8.66E-07	-2.07E-03	-1.66E-05	-2.00E-05	-8.16E-05	-2.17E-08	-4.00E-06	-2.33E-03	($5.67)
Monetized Score/Ton	($3.17)	($0.51)	($0.68)	($0.04)	($0.48)	($0.03)	($0.00)	($0.22)	($0.55)	($5.67)

Note: Asterisk symbol * indicates that the following offsets are included in LCA results: recycling for avoided mixed metals virgin-content manufacturing.

APPENDIX B

Table B1: HPower WTE Incineration Facility 2021 Emissions Inventory and Power Output Efficiency

Pollutant	2021 Emissions					HPOWER 2021 Throughput		
	(Tons)	(pounds)	(kilograms)	lbs/ton combusted	(kg/metric ton combusted)	(tons)		(tonnes)
PM2.5	110.342	220,684.00	100,100.58	3.2975E-01	1.6487E-01	669,255		607,138
PM10	124.063	248,126.00	112,548.06	3.7075E-01	1.8537E-01	**(6)**		**(7)**
SO2	18.0531	36,106.20	16,377.50	5.3950E-02	2.6975E-02			
NOx	838.006	1,676,012.00	760,226.26	2.5043E+00	1.2521E+00			
VOC	5.94313	11,886.26	5,391.52	1.7760E-02	8.8802E-03			
CO	144.9	289,800.00	131,451.07	4.3302E-01	2.1651E-01			
NH3	7.00252	14,005.04	6,352.58	2.0926E-02	1.0463E-02			
Lead	0.00457	9.14	4.15	1.3657E-05	6.8285E-06			
Beryllium	0.0004	0.80	0.36	1.1954E-06	5.9768E-07			
Cadmium	0.01466	29.32	13.30	4.3810E-05	2.1905E-05			
Dioxins	0.00001	0.02	0.01	2.9884E-08	1.4942E-08			
HCL	16.4	32,800.00	14,877.83	4.9010E-02	2.4505E-02			
HF	0.2025	405.00	183.70	6.0515E-04	3.0258E-04			
Mercury	0.00541	10.82	4.91	1.6167E-05	8.0836E-06			
Sources:	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**			

Municipal Waste Combustor	Design Capacity (million BTUs/hr)	Actual 2021 Operating Hours	Fuel Type	2021 Throughput		2021 Annual Heat Inputs **(8)**			2021 Annual Heat Inputs/Pound MSW		
						Solid Waste	Diesel	Total	Solid Waste	Diesel	Total
				(tons solid waste)	(gallons diesel)	(million Btus)			(Btus)		
MWC 1	370	6,525	RDF	177,715	143,340	1,682,387	19,781	1,702,169	4,733	56	4,789
MWC 2	370	6,732	RDF	181,932	133,470	1,722,314	18,419	1,740,733	4,733	51	4,784
MWC 3	405	7,775	Solid Waste	309,608	154,490	2,556,253	21,319	2,577,572	4,128	34	4,163
Totals/Ave	1,145	7,011		669,255	431,300	5,960,954	59,520	6,020,474	**4,453**	44	4,498
total hours in a year		8,760		**(6)**	**(6)**	**99.0%**	**1.0%**	**100.0%**			
operating hours availability		80.0%							Btus/gallon diesel	**138,000**	

6,020,473,900,000	heat inputs in 2021
1,764,500	2021 MWh at 3,412 btus per kWh and 100% efficiency
366,365	2021 MWh provided to Hawai'ian Electric Company (HECO) **(9)**
20.76%	**net efficiency**
19.77%	**net-net efficiency**

Notes:

(1) Table: 2021 Emissions Inventory Report, Emissions Summary for HPOWER (15003-00082), page 1 of HPOWER 2021 Annual Air Emissions Inventory and GHG Submittal for Covered Source Permit (CSP) Nos. 0255-01-C & 0255-02-C, 2021 Annual Air Emissions Inventory through the State Local Emissions System (SLEIS) for HPOWER's two Covered Source Permits covering three boilers.

(2) =tons*2000

(3) =pounds/2.20462262 pounds per kilogram

(4) =col C/cell J7

(5) =col E/2 or col F/cell L7

(6) *op. cit*., see (1), pages 52, 59 and 65.

(7) = cell J7*2000/2204.62262

(8) Heat Inputs for MSW and diesel from HPOWER 2021 Annual Air Emissions Inventory and GHG submittal for Covered Source Permit (CSP) Nos. 0255-01-C & 0255-02-C, 2021 Annual Air Emissions Inventory through the State Local Emissions System (SLEIS) for HPOWER's two Covered Source Permits covering three boilers, Subpart C: General Stationary Fuel Combustion, pp. 1 through 5.

(9) Hawai'ian Electric Company, 2021 Renewable Portfolio Standard Status Report, prepared for Hawai'I Public Utilities Commissions, February 8, 2022