The Environmental Value of Metro Region Recycling for 2007

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Introduction and Summary

Metro Sustainability Center contracted with Sound Resource Management Group, Inc. (SRMG) to develop a version of SRMG's Measuring the Environmental Benefits Calculator (MEBCalc) specifically parameterized to reflect solid waste management practices in the Metro region. This report discusses the results of applying Metro MEBCalc to 2007 recycling in the Metro region. A companion report provides technical documentation for Metro MEBCalc and instructions for the calculator's users.

The Metro region recycled 1,339,718 tons of solid wastes in 2007. Metro MEBCalc estimates the environmental value of recycling for 1,292,509 of those tons – all grades of paper; PET, HDPE and film plastics; ferrous and non-ferrous metals including aluminum and steel cans; glass packaging; electronics; tires; wood; yard debris and food scraps. Future versions of Metro MEBCalc will estimate environmental value for recycling of used oil, gypsum wallboard, carpet and other materials as robust environmental data from life cycle assessment studies on these materials becomes available.

The average ton of material diverted to recycling and composting from Metro region solid wastes in 2007 has an estimated environmental value of $120. Total estimated economic value for the environmental benefits of diverting 1,292,509 tons from disposal is $154.6 million. Most of this environmental value comes from pollution reductions in the manufacture of new products made possible by the replacement of virgin raw materials with recycled materials and the replacement of synthetic petroleum-based fertilizers with compost.

In fact, if it were not for the upstream environmental benefits of recycling and composting, diversion of solid waste materials from disposal would only breakeven in terms of environmental benefits. In other words, the diversion of materials from disposal entails environmental costs for collection, processing, composting, and hauling materials to markets that are approximately equivalent to the environmental costs of garbage collection, hauling and disposal. These latter costs are avoided by diverting materials to recycling and composting. However, if diversion did not provide upstream environmental benefits, it would simply amount to replacing trash handling by recyclables and compostable handling to no particular avail as far as the environment is concerned. An important caveat to this conclusion is that it assumes that disposal facilities provide best available pollution control technologies so as to prevent releases of particulates, toxics and carcinogens as much as possible.

A second important finding from applying Metro MEBCalc to 2007 recycling quantities is that diversion of a portion of wood and yard debris to industrial fuel markets reduces emissions of substances that are damaging to the climate, but increases the emissions of substances that are toxic to human health and ecosystems. Combustion of wood and woody yard debris

causes minimal releases of greenhouse gases as long as the rate of tree harvest is slower than the rate of new forest growth.[1] Natural gas combustion, by contrast, results in release of fossil carbon sequestered in this fossil fuel. On the other hand, wood combustion is more like coal than natural gas in terms of toxic and carcinogenic releases. Given estimated costs for greenhouse gas emissions compared to toxics emissions, diversion of over 298,000 tons of wood, yard debris and tires to industrial fuels as substitutes for natural gas has an estimated environmental cost of $63.7 million. Excluding waste materials diverted to industrial fuels increases the economic value of Metro region recycling from $154.6 to $218.3 million, and raises the per ton average environmental benefit valuation for recycling to $220.

The following sections of this report provide details on environmental benefits by type of material diverted and end markets. The report also includes a discussion of life cycle analysis used to develop the estimates for the environmental benefits of recycling, the sources for the economic valuations of those environmental benefits, and the assumptions used on certain subjects on which life cycle analysts have yet to reach consensus.

Environmental Benefits by Material Type and Impact Category

Table 1, 2007 Environmental Benefit Results by Diverted Material Type and End Use Market, shows the economic valuation details for each type of material and end use market for each type of environmental impact assessed by Metro MEBCalc. As indicated in the table, overall environmental benefits vary widely by material and end use market, ranging from a negative overall environmental valuation of -$216 per ton for clean wood used as an industrial fuel substitute for natural gas up to $1,469 for recycling aluminum.

It is no surprise to find that aluminum recycling has the highest environmental benefit at $1,469 per ton. Aluminum is followed by desktop recycling at $734 and cardboard at $473 per ton. Composting yard debris and food scraps yields an environmental value per ton of $55 and $90, respectively. Food scraps composting has the higher value due to avoidance of its higher landfill methane releases and its lower landfill carbon storage potential compared to yard debris.

Desktop recycling has a high environmental benefit due to the materials and components that can be recovered for recycling when a discarded computer is disassembled and/or shredded. At the same time it should also be noted that, although electronics reuse is not included in the Metro recycling figures shown in Table 1, desktop reuse has a much higher environmental value than desktop recycling – nearly $60,000 per ton of desktop computers reused.

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[1] The rate of harvest may exceed the rate of growth over periods of time shorter than the 100 year time frame used in the United Nations Intergovernmental Panel on Climate Change's suggested methodologies for carbon accounting. When the time frame for a life cycle analysis of wood combustion is shorter than 100 years, then some portion of the carbon emissions from wood combustion may need to be counted as GHG emissions.

Table 1: 2007 Environmental Benefit Results by Diverted Material Type and End Use Market

Material & Market	Metro 2007 Quantities Recovered (tons)	Environmental Benefits Total (million $)	Environmental Benefits Per Ton Recycled	Climate Change	Human Health - Respiratory	Human Health - Toxics	Human Health - Carcinogens	Eutrophication	Acidification	Ecosystems Toxicity
Cardboard	237,962	$112.6	$473	$104	$75	$274	$1	$0	$6	$13
Newsprint	96,105	29.5	307	82	25	180	1	0	7	12
Office Paper	99,608	17.2	173	155	17	-1	0	0	1	0
Metro Mixed Paper	23,205	4.6	199	101	19	71	0	0	6	2
PET	6,273	0.6	98	69	22	-10	0	0	15	1
HDPE	12,033	0.7	60	56	10	-11	0	0	4	0
LDPE Plastic Film	5,254	0.5	90	74	16	-7	0	0	6	1
Glass Packaging										
Glass containers	44,087	1.4	33	9	11	11	0	0	1	1
Fiberglass insulation	1,473	0.1	66	16	27	19	0	0	1	3
Aggregate	8,107	0.0	2	1	0	-1	0	0	0	2
Aluminum	11,743	17.3	1,469	402	189	687	8	0	54	129
Other Non-ferrous	9,390	5.5	588	148	80	279	4	0	22	55
Tinned Cans	4,019	0.3	73	42	30	-1	0	0	1	0
Other Ferrous	150,953	10.9	72	42	30	-1	0	0	1	0
Electronics										
Desktop reuse	0	0.0	0	0	0	0	0	0	0	0
Desktop recycling	678	0.5	734	208	101	331	4	0	27	63
Laptop reuse	0	0.0	0	0	0	0	0	0	0	0
Laptop recycling	0	0.0	0	0	0	0	0	0	0	0
Monitor reuse	0	0.0	0	0	0	0	0	0	0	0
Monitor recycling	2,052	0.3	142	49	20	54	1	0	6	12
TV reuse	0	0.0	0	0	0	0	0	0	0	0
TV recycling	3,432	1.2	361	106	50	158	2	0	13	32
Tires										
Crumb rubber	6,617	1.6	242	197	45	0	0	0	0	0
Engineering applications	2,209	0.0	4	3	0	0	0	0	0	2
Fuel sub for natural gas	1,644	-0.2	-116	-60	-46	0	0	0	-9	0
Fuel sub for coal	0	0.0	0	0	0	0	0	0	0	0
Masonry/Asphalt/Concrete	0	0.0	0	0	0	0	0	0	0	0
Clean Wood										
Reuse	0	0.0	0	0	0	0	0	0	0	0
Compost	16,195	0.6	38	-6	4	31	1	0	1	7
Papermaking pulp	18,220	1.8	98	77	3	17	0	0	1	1
Fuel sub for natural gas	254,788	-55.1	-216	3	-1	-123	-4	0	0	-91
Fuel sub for coal	0	0.0	0	0	0	0	0	0	0	0
Yard Debris										
Mulch	43,240	0.3	7	-19	3	20	0	0	1	2
Compost	181,769	9.9	55	8	5	33	1	0	1	7
Fuel sub for natural gas	41,906	-8.5	-203	16	-1	-122	-4	0	0	-91
Food Scraps	9,546	0.9	90	43	5	33	1	0	1	7
Totals and Overall Averages	1,292,509	$154.6	$120	$55	$25	$52	$0	$0	$3	-$15

The high environmental value for desktop reuse is brought into better perspective by noting that on a per desktop computer basis the environmental value of avoiding manufacture of a new desktop computer through reusing an existing discarded computer is between $550 and $650. This compares with an environmental value from recycling between $7 and $8 per desktop unit recycled. Shredding a used computer to recycle it has much lower environmental benefit than refurbishing the computer for reuse.

Table 1 also indicates the estimated environmental costs of toxic releases when waste materials such as used tires, clean wood and yard debris are used to replace natural gas for industrial fuels. Excluding these uses of recycled materials increases the per ton value of human health and ecosystem toxics reductions from $52 to $105 and from -$15 to $8, respectively, per average ton of material recycled in the Metro region. It also increases the value of climate change changing pollution reductions from $55 to $70 per ton, because using these materials as fuel substitutes does not provide as much climate change benefit as the average benefit from recycling all the other materials.

Uses of Metro MEBCalc to Conduct What-If Analyses

The User Inputs spreadsheet in Metro's environmental benefits calculator includes the following input data provided by the calculator's user:
- Quantities recycled, categorized by material and collection method.
- The distribution of disposal quantities among (1) landfills that collect landfill gas and generate electricity, (2) landfills that collect landfill gas (LFG) and flare it, (3) landfills handling relatively inert materials, and (4) the waste-to-energy incineration facility in Brooks, Oregon.
- Processing residue rates.
- Allocation of materials to end markets for those materials that are recycled into two or more very different types of new products or energy uses.
- Estimated distances to end markets and transport mode.
- Scrap values for recycled materials.

These inputs can be based on actual data for some historical period such as the most recent year. They can also be used to conduct "what if" and scenario analyses.

The Benefit Results spreadsheet in Metro's calculator computes an economic value for environmental effects of recycling according to the estimated value for reductions in each environmental impact that is listed in that spreadsheet. The calculator's user can conduct "what if" analyses by changing these valuations. For example, the user could increase the valuation for reductions in climate changing greenhouse gas (GHG) emissions from the $40 per ton of CO_2 equivalents (eCO2) shown on the spreadsheet. This might produce a different ranking for efforts under consideration to divert additional amounts of various types of waste material from disposal than does the $40 per ton valuation for GHGs.

The user can also evaluate differences in environmental impacts for recycling, composting, and energy recovery, or differences between closed loop and open loop recycling for materials such as glass containers that are used to manufacture new glass containers and are also used to make non-glass-container products such as fiberglass insulation.

On the other hand, Metro MEBCalc cannot be used on a stand alone basis to evaluate different collection and processing scenarios such as weekly versus biweekly curbside recycling collections. The calculator also does not directly measure whether a particular waste management method involves a sustainable level of resource use. At the same time, the calculator does indicate whether recycling and composting provide environmental improvements relative to disposal by landfill or waste-to-energy combustion.

## Brief Discussion of MEBCalc's Life Cycle Analysis

Figure 1, Product Life Cycle Phases, portrays environmental flows across a product's life cycle in terms of energy and material inputs and energy and pollution outputs (to air, water and land). The typical product's life cycle involves:

- extracting raw materials from nature's ecosystems,
- refining those virgin resources into industrial feedstocks,
- manufacturing the product from these feedstock,
- using the product by its consumers, and
- disposition of product discards by recycling, recovery or disposal.

The first three phases (extraction, refining and manufacturing) are often termed the *upstream phase* in the product life cycle. The last phase (recycling, composting, waste-to-energy, landfill) is often termed the *downstream* or post-consumer phase.

The feedback loops in Figure 1 show how recycling and composting bypass a portion of the upstream phase. This conserves the energy already embodied in products and reduces the waste and pollution that result when new goods and services are produced. Most of the environmental benefit of recycling and composting comes from energy and pollution reductions in the upstream phase when recycled materials replace raw materials and compost replaces petroleum-based fertilizers. In addition, compost provides some product use phase benefits when reduced use of pesticides decreases human exposure to toxics from pesticide applications, as well as when reduced use of synthetic fertilizers reduces eutrophication of waterways as a result of decreased runoff of water soluble nitrogen in synthetic fertilizer.

Figure 1: Product Life Cycle Phases
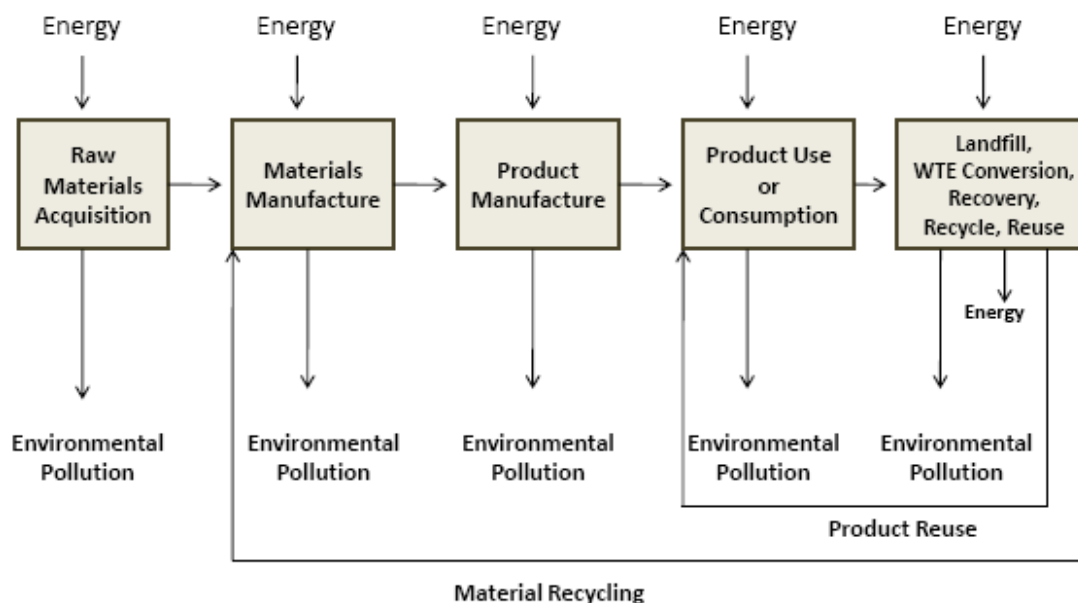
To estimate the environmental value for recycling and composting in the Metro region, SRMG uses the comprehensive life cycle assessment calculator – Metro MEBCalc[2] -- developed for this purpose. The calculator includes a "best-of" compendium of life cycle data from a number of environmental life cycle inventory and assessment models, including:

- US EPA's WARM life cycle inventory spreadsheet calculator for greenhouse gas (GHG) emissions and the associated report (EPA 2006).[3]
- US EPA's MSW Decision Support Tool and database.[4]
- Carnegie Mellon University Green Design Institute's Economic Input-Output Life Cycle Assessment model.[5]
- US NIST's BEES model.[6]
- US EPA's TRACI model.[7]

MEBCalc also uses life cycle data from the Consumer Environmental Index (CEI) model we developed for the Washington State Department of Ecology[8], as well as from peer-reviewed journal articles including Morris (1996), Morris (2005), and Morris and Bagby (2008).

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[2] The model is reviewed in Morawski (2008a and 2008b).
[3] WARM is available at http://www.epa.gov/climatechange/wycd/waste/calculators/Warm_home.html .
[4] See Research Triangle Institute (1999a and 1999b) and EPA *et al* (2003). Both the DST and the database are available through Research Triangle Institute.
[5] Available at http://www.eiolca.net .
[6] Available at http://www.bfrl.nist.gov/oae/software/bees/model.html .
[7] Information about TRACI is available at http://www.epa.gov/nrmrl/std/sab/traci/ . Also see Bare (2002) and Bare *et al* (2003).

In addition, the calculator relies on:

- A life cycle inventory for wood wastes developed recently for Seattle Public Utilities.[9]
- Franklin Associates report on environmental impacts of recycling glass into containers, fiberglass and aggregate.[10]
- R. W. Beck reports on conversion technologies and anaerobic digestion.[11]

MEBCalc estimates pollution reductions that are caused across all phases of product life cycles by diverting material discards to recycling or composting. The calculator accounts for the effects of recycling and composting on waste management system pollution emissions from collection vehicles, recyclables processing facilities, composting facilities, disposal facilities, shipping of processed materials to end users, and production of recycled-content and virgin-content products by those end users.

Use phase discussion

Metro MEBCalc evaluates the potential effects of recycling and composting for seven categories of impacts to public health, the environment and ecosystems[12]:

- Climate change – characterizes the potential increase in greenhouse effects due to anthropogenic emissions. Carbon dioxide (CO_2) from burning fossil fuels is the most common source of greenhouse gases (GHGs). Methane from anaerobic decomposition of organic material is another large source of greenhouse gases.
- Human respiratory disease and death from particulates – characterizes potential human health impacts from anthropogenic releases of coarse particles known to aggravate respiratory conditions such as asthma, releases of fine particles that can lead to more serious respiratory symptoms and disease, and releases of particulate precursors such as nitrogen oxides and sulfur oxides.
- Human disease and death from toxics -- characterizes potential human health impacts from releases of chemicals that are toxic to humans. There are a large number of chemical and heavy metal pollutants that are toxic to humans, including 2,4-D, benzene, DDT, formaldehyde, permethrin, toluene, chromium, copper, lead, mercury, silver, and zinc.
- Human disease and death from carcinogens -- characterizes potential human health impacts from releases of chemicals that are carcinogenic to humans. There are a large number of chemical and heavy metal pollutants that are carcinogenic to humans, including 2,4-D, benzene, DDT, formaldehyde, kepone, permethrin, chromium, and lead.

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[8] The CEI model is detailed in Morris *et al* (2007).
[9] Available in the monographs Morris (2008a) and Morris (2008b).
[10] Available in the monograph Franklin (1998).
[11] Available in the Beck (2004) and Beck (2007) reports.
[12] See Bare *et al* (2003) and Lippiatt (2007) for a detailed description and discussion of these environmental impact categories.

- Eutrophication -- characterizes the potential environmental impacts from addition of mineral nutrients to the soil or water. In both media, the addition 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.

- Acidification -- characterizes 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 oxides, sulfuric acid, nitrogen oxides, hydrochloric acid (HCL), and ammonia.

- Ecosystems toxicity -- characterizes the relative potential for chemicals released into the environment to harm terrestrial and aquatic ecosystems, including wildlife. There are a large number of chemical and heavy metal pollutants that are toxic to ecosystems, including 2,4-D, benzene, DDT, ethyl benzene, formaldehyde, kepone, permethrin, toluene, chromium, copper, lead, silver, and zinc.

Life cycle analysis and environmental risk assessments provide the methodologies for connecting pollution of various kinds to these seven categories of environmental damage. For example, releases of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), chlorofluorocarbons (CFCs) and other pollutants cause global warming which leads to climate change. The United Nations Intergovernmental Panel on Climate Change (IPCC) has conducted and reviewed scientific data to determine the strength of each pollutant relative to carbon dioxide in causing global warming. For example, over a hundred year time frame methane is 25 times and nitrous oxide 298 times more harmful than CO_2. Based on these global warming potential factors we can aggregate the emissions of all greenhouse gas pollutants into a single indicator quantity for global warming potential. This quantity is CO_2 equivalents (herein denoted eCO_2).

Similar scientific efforts enable us to express the quantity of pollutant releases in terms of a single indicator quantity for the other six categories of environmental damage. This greatly simplifies reporting and analysis of different levels of pollution. By categorizing pollution impacts into a handful of categories, the environmental costs and benefits model is able to reduce the complexity of following trends for hundreds of pollutants. This simplifies life for policy makers. The trade-off is that we have to sort through complex pollutant aggregation and weighting methodologies. As described in SRMG's report on our development of a Consumer Environmental Index (CEI) for the Washington State Department of Ecology, a "best-of" methodology is in development by the United Nations Environment Program (UNEP)

and the Society of Environmental Toxicology and Chemistry (SETAC).[13] Until that study is released, the environmental valuation calculator relies on the methodologies used by the IPCC, US EPA's TRACI (Tool for the Reduction and Assessment of Chemical and other environmental Impacts) model and the Lawrence Berkeley National Laboratory's CalTOX model.[14, 15]

The methodology for aggregating pollutants into environmental impact categories yields total pollution reductions in terms of an indicator pollutant for each impact category. These indicators are:

- Climate change – carbon dioxide equivalents (eCO2),
- Human health-particulates – particulate matter less than 2.5 microns equivalents (ePM2.5),
- Human health-toxics – toluene equivalents (eToluene),
- Human health-carcinogens – benzene equivalents (eBenzene),
- Eutrophication – nitrogen equivalents (eN),
- Acidification – sulfur dioxide equivalents (eSO2), and
- Ecosystems toxicity – herbicide 2,4-D equivalents (e2,4-D).

Valuation of Life Cycle Environmental Impacts

The final step in estimating an environmental value for recycling and composting is, then, to determine a dollar value for the damage to public health and/or ecosystems caused by each of the indicator pollutants. The following list shows these estimated damage valuations. The remainder of this section discusses the sources and justifications for these valuations.

- eCO2 -- $40 per ton.
- ePM2.5 -- $10,000 per ton. based on Eastern Research Group (2006).
- eToluene -- $118 per ton.
- eBenzene -- $3,030 per ton. based on Eastern Research Group (2006).
- eN -- $4 per ton.
- eSO2 -- $485 per ton.
- e2,4-D -- $3,280 per ton.

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[13] See Morris *et al* (2007).
[14] Bare (2002) and Bare *et al* (2003).
[15] See a description of the CalTOX model, references, and downloadable manual and software at
http://eetd.lbl.gov/IED/ERA/caltox/index.html .

The value of greenhouse gas (i.e., eCO2) emissions reductions

There is a very wide range in estimated costs for greenhouse gas emissions and valuations for the benefits of reductions in those emissions. The low end for valuations is the trading price for voluntary greenhouse gas emission reductions. Operating much as the markets in sulfur dioxide emissions permits do, several markets are available for trading voluntary greenhouse gas emissions reduction pledges. One of these is the Chicago Climate Exchange (CCX). Trading values on the CCX for CO2 reductions have been between $1 and $4 per ton of carbon dioxide over the past several years. Values on European carbon markets have been ten times higher than trading prices on the CCX due to the mandatory CO2 emissions caps imposed on European greenhouse gas generators.

The upper end of the range for estimated costs of climate change is found in recent studies such as the review of the economics of climate change conducted by Nicholas Stern (2007). That study determined that a reasonable estimate for the cost of current greenhouse gas emissions was $85 per metric ton, based on the risk of catastrophic environmental impacts in the future if substantial reductions in greenhouse gas emissions are not implemented today.

MEBCalc uses $40 per ton for the cost of greenhouse gas emissions. This is in the middle of the range between market values for voluntary emissions reductions and estimated costs of severe climate change impacts if today's emissions levels are not substantially reduced.

The value of particulates (i.e., ePM2.5) emissions reductions

Eastern Research Group (2006) reports the following:

"Epidemiological studies have linked exposure to increased particulate matter (PM) levels to mortality and morbidity from chronic bronchitis and cardio-vascular disease. Time-series data from the 20 largest U.S. cities indicate a linear relationship between particulate air pollution and mortality.[16] The number of years of life lost from premature death, and well being lost from illness, due to PM exposure depends on the age distribution and size of the exposed population. Many factors enter into the assessment of illness from PM exposure including weather, types of emissions, and health of the population. These analyses must be conducted at a local level in order to incorporate all of these factors."

"National estimates of the "per ton" benefits of reducing PM emissions are not often calculated. The importance of local factors in the effects of PM emissions makes such broad estimates highly uncertain. In order to compare the benefits and costs of regulations that federal agencies had chosen not to monetize, the Office of Management and Budget (OMB) calculated a broad national value of the benefits of reducing PM emissions by one ton of

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[16] M. J. Daniels, et al. 2000. Estimating particulate matter mortality dose-response curves and threshold levels: An analysis of daily time series for the 20 largest U. S. cities. *American Journal of Epidemiology*, 10:606-617.

$10,000 to $100,000 ($2001).[17] OMB based this estimate on the 1997 NAAQS benefit assessment, though their method is not described."

Based on this analysis by Eastern Research Group, MEBCalc incorporates a cost valuation of $10,000 per ton for emissions of PM2.5.

The value of human toxics (i.e., eToulene) emissions reductions

As with the valuation of the costs of greenhouse gas emissions, there is a wide range in the estimated costs for emissions of pollutants that are toxic to humans. Eastern Research Group (2006) found estimates ranging up to $2,700 per ton of eToluene for the human health costs of toxic air pollutant emissions. MEBCalc's very conservative estimate of monetary costs for toxic air emissions is based on a peer-reviewed study on the health effects of atmospheric emissions of mercury. That study was sponsored by the Northeast States for Coordinated Air Use Management (NESCAUM) and conducted by scientists at the Harvard Center for Risk Analysis (Rice and Hammitt 2005). The study evaluated neurological and possible cardiovascular health impacts from exposure to methyl mercury through fish consumption, where atmospheric releases of mercury result in depositions of mercury in water bodies within and bordering the U.S. These depositions lead to increases in methyl mercury concentrations in fish.

The NESCAUM study evaluated three main health effects from methyl mercury exposure – neurological decrements associated with intrauterine exposure, myocardial effects associated with adult exposure, and elevated childhood blood pressure and cardiac rhythm effects associated with *In Utero* exposure. MEBCalc relies on the economic cost estimated in the study for only the first effect. The decrease in cognitive ability as a result of intrauterine exposure to methyl mercury is well documented and understood, whereas research on the other two health effects is not yet as extensive or thoroughly peer-reviewed.

The NESCAUM study's neurotoxicity health cost estimate for exposure to methyl mercury from consumption of fish that have bioaccumulated that toxin as a result of mercury air pollution is $10.5 million in year 2000 dollars per ton of mercury emitted to the atmosphere. Inflating that estimate to current dollars and converting the cost to toluene emissions, the indicator substance for human toxicity, yields $118 per ton of eToluene for the cost of pollutant emissions that are toxic to human health. This is the value MEBCalc attributes to reductions in human toxicity that are caused by diverting material resources from disposal to recycling and composting.

The value of human carcinogens (i.e., eBenzene) reductions

Eastern Research Group (2006) reports research suggesting that the cost to human health from benzene exposure could be 950 times greater than toluene. Given a valuation of $118 per ton for toluene, this ratio implies that benzene's valuation should be more than $100,000

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[17] Office of Management and Budget, Office of Information and Regulatory Affairs. 2005. *Validating Regulatory Analysis: 2005 report to Congress on the costs and benefits of federal regulations and unfunded mandates on state, local, and tribal entities.*

per ton. This cost valuation is extremely high. Instead MEBCalc uses $3,030 per ton, which is about 10% above the midpoint of the range $0.06 to $6.00 per kilogram for expected health risks from Benzene releases that is also discussed in the Eastern Research Group study.

The value of reductions in eutrophying emissions (i.e., eN)

In soil or waterways, the addition of large quantities of mineral nutrients, such as nitrogen and phosphorous, results in generally undesirable shifts in the number of species in ecosystems and a reduction in ecological diversity. In water, it tends to increase algae growth, which can lead to lack of oxygen and therefore death of species such as fish. MEBCalc's estimate of the cost of releases of nutrifying compounds is based on EPA's cost-effectiveness analysis for the NPDES regulation on effluent discharges from concentrated animal feeding operations. That analysis estimated that costs up to $4.41 per metric ton of nitrogen ($4.00 per short ton) removed from wastewater effluents were economically advantageous (US EPA 2002, p. E-9).

The value of reductions in acidifying emissions (i.e., eSO2)

We estimate the value of acidification reductions at $661 per ton. This is the average of 2005 ($690), 2006 ($860), 2007 ($433), 2008 ($380), and 2009 ($62) market clearing spot prices in EPA's annual acid rain sulfur dioxide emissions permit allowances auction under the Clean Air Act.

The value of ecosystem toxics (i.e., e2,4-D) reductions

A study estimated the toxicity cost to plants and wildlife from application of a pound of 2,4-D herbicide at $1.64.   This is an updated estimate from Joe Kovach, Integrated Pest Management Program at Ohio State University, based on his research originally reported in Kovach *et al* (1992) on putting an environmental price to pesticide use.[18]   The estimate includes costs for impacts on fish, birds, bees and beneficial arthropods, but not the estimated costs developed by Kovach for impacts on human health as a result of groundwater contamination.   That human health cost is captured in the human toxicity potential impact category.

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[18] Pesticide wash-off may be higher in a hilly urban environment than in a flat agricultural field. To the extent that Kovach relied on agricultural crop studies, his estimate of the cost to non-target plants and wildlife may underestimate the cost of pesticide applications in an urban environment.

Key Assumptions Used in Metro MEBCalc

There are important assumptions that are hard wired into Metro MEBCalc. This section lists a number of those assumptions and provides a discussion on the reasons for their use.

Landfill Gas Capture Efficiency

Metro MEBCalc avoided environmental impacts for MSW landfills are based on an assumed landfill gas (LFG) capture rate of 75%. A lower gas capture rate would yield a higher avoided impact, while a higher rate would yield a lower avoided impact for degradable materials.

The landfill gas capture rate represents the portion of LFG generated by a landfilled material that is captured and combusted so as to prevent the release of its constituent methane, a potent greenhouse gas. The difficulty with estimating the amount of generated LFG from a material landfilled at a particular point in time is that degradation of that material takes place over many years, more than 150 years in a landfill in an area with low precipitation. There also is a good deal of variation in the timing for installation and commencement of operation of an LFG collection system in a new landfill cell. Thus, there may be some time when a material is first buried and a long time after the landfill closes when the material continues to generate LFG.

Based on a review of OR DEQ's analysis of LFG capture rates in current OR landfills serving the Metro region, review of recent literature on landfill gas capture efficiencies in modern landfills, the use of a 75% default capture rate in US EPA's WARM, and the likelihood that regulations on LFG capture are likely to become more stringent as the impacts of climate change play out over the years, MEBCalc uses the default of 75% capture.

Landfill Carbon Storage

Metro MEBCalc uses US EPA's latest estimates in WARM for carbon storage rates. The main purpose of life cycle analysis and assessment of waste management systems is to provide a holistic picture of the environmental impacts of waste management choices. Burial of certain materials such as wood and paper in dry tomb landfills preserves a substantial portion of the carbon stored in those materials when trees were harvested and used to manufacture these products. Not all the carbon that a tree sequesters is released when it is harvested. The portion that is formed into products continues to be stored throughout a product's useful life. Some of this carbon will continue to be stored when the product is landfilled. This stored carbon will not be released to cause climate change and, thus, should not be counted among the GHG releases avoided when a material is recycled rather than landfilled.

Dioxin Releases from WTE Incineration

Metro MEBCalc does not include the environmental impacts of dioxin/furan emissions from WTE incineration or from other waste management activities that are involved with recycling or disposal of waste materials. There are available estimates of dioxin/furan emissions from WTE incinerators. There are not such estimates for the reciprocating engines used to generate electricity from collected LFG at landfills. Nor are there readily available and statistically robust estimates of dioxin/furan emissions from upstream resource extraction, refining, and manufacturing activities for all waste materials, or from the shipping of recyclables to end markets.

This lack of dioxin/furan emissions data for all waste management activities is particularly problematic because the relative environmental impacts of these pollutants are quite large. Including dioxin/furan emissions for just one or a few activities will greatly exaggerate the relative environmental impacts of those activities in comparison to the activities for which dioxin/furan emissions are unavailable. Until dioxin/furan emissions for all or at least the most significant waste management activities become available, these pollutants will not be included in the environmental impact calculations in MEBCalc. Because dioxins and furans have severe environmental impacts, the user is advised to remain continually cognizant of this omission in the current Metro MEBCalc model.

The Fuel Assumption for Calculating Energy from Wastes Offsets

Another rather critical assumption embedded in the MEBCalc calculations of environmental impacts is that electricity generation from a combined cycle natural gas turbine is used to calculate the avoided environmental impacts when electricity is generated from wastes either at a landfill of WTE incinerator. This is a lower GHG offset than would be provided if one were to use a coal-fired power plant for avoided electricity. This is a higher GHG offset than if one were to use a renewable energy source for electricity such as wind or solar. In fact there would be no GHG offset if electricity from waste were replacing electricity from a renewable energy source.

By comparison with renewable electricity the natural gas offset for energy from waste is quite generous and reduces the calculated GHG reductions for recycling. On the other hand, US EPA's WARM uses the average fossil fuel mix for electricity production in the US. This is a coal heavy mix and thus gives a greater calculated GHG reduction for recycling.

Compost Substitutions for Synthetic Fertilizers & Pesticides

MEBCalc bases its upstream benefits of composting on the following data and assumptions regarding reductions in synthetic fertilizer and pesticide usage as a result of using compost.

Fertilizers
 1. The average yard and garden size in Seattle is about 1/10th acre or 4356 square feet.

2. The rate of fertilization recommended by Washington State University (WSU) Extension Service is 4 pounds nitrogen (N) per 1000 square feet of lawn. MEBCalc assumes the same fertilization rate for garden. This means a household requires between 17 and 17.5 pounds N each year.
3. The average amount of yard debris and food scraps sent for recycling by a household in Seattle and King County is about 1/3 ton. 1/3 ton of organics produces somewhat less than 1/6 tons of finished compost.
4. At that rate of production of compost by a household and 2% N for compost from household yard debris and food scraps, the household can supply 6.7 pounds N from its own yard debris and food scraps, or about 40% of the recommended N needs.
5. Nitrogen in organic fertilizers and compost is less than 10% water soluble, versus "quick release" synthetic fertilizers which are over 75% water soluble. Thus more of the N in compost actually stays around to benefit lawn and garden growth.
6. Based on the lower water solubility of N in compost, it is assumed that the compost user needs to apply 25% less N. As a result, compost use reduces synthetic fertilizer use by 50%.

Pesticides
1. Based on sales data gathered by the Washington Toxics Coalition for King County, each year the average household purchases pesticides and fertilizers containing about 3.5 pounds of active ingredients.
2. Due to healthier plants resulting from use of compost and resulting reduction of 50% in use of synthetic fertilizers, it is assumed that pesticide usage (directly or indirectly in fertilizers) drops at least 25%.

These assumptions were used in the analysis discussed Morris and Bagby (2008), and were not disputed by the peer reviewers of that article.

Human and Ecosystems Toxicity Impacts of Metals Emitted from Wood Combustion

The toxicity impacts of wood combustion in industrial boilers are based on US EPA AP-42 emissions data for clean (i.e., not painted, not treated with pesticides)wood combustion and the CalTOX risk assessment model's assessment of relative toxicities for atmospheric emissions of heavy metals. These toxicity assessments are controversial and are one of the motivating factors for the toxicity factors harmonization process that has been underway under the guidance of UNEP and SETAC. This suggests that one should consider the toxicity results from Metro MEBCalc to be subject to some uncertainty and subject to change once the UNEP-SETAC harmonization process is completed and US EPA has peer reviewed the resultant toxicity characterization factors for heavy metals and other toxics and carcinogens.

Emissions Data from MSW DST

The emissions data from the MSW DST used in Metro MEBCalc are from the first edition of the DST Database published in 2002. The DST Database and the tool itself have recently been made available for purchase or use online at https://webdstmsw.rti.org/prodlist.htm . At

this point in time it is unknown to what extent the database available for purchase differs from the database used to generate the emissions profiles that are embedded in Metro MEBCalc.

Emissions Data from CMU GDI EIO-LCA

The emissions data from Carnegie Mellon University (CMU) Green Design Institute's (GDI) EIO-LCA model are from the 1997 US Department of Commerce Bureau of Economic Analysis (BEA) economic input-output model based on the 1997 US economic census and first available late in 2002. Emissions data in the 1997 EIO-LCA model include US EPA's Toxics Release Inventory (TRI) emissions data for 2000 and criteria air pollutant emissions from US EPA's AIRData Report for 1999. The 1997 EIO-LCA model estimates greenhouse gas emissions based on the Intergovernmental Panel on Climate Change's (IPCC) revised 1996 guidelines for national greenhouse gas inventories, the US Department of Energy's transportation data book for 1999, and US EPA's inventory of greenhouse gas emissions and sinks for 1997.

Late in 2007 the BEA published the US economic input-output model based on the 2002 economic census.[19] CMU GDI has developed a portion of what eventually will become the 2002 EIO-LCA model for the US. That portion includes GHG emissions for 2002. GDI is currently working on incorporating 2002 TRI emissions data into the 2002 EIO-LCA model, and hopes to begin to incorporate 2002 criteria air pollutant emissions data in the near future. Progress on these updates is dependent on staff and funding availability.

Whereas the 1997 EIO-LCA model is available for use at no charge at www.eiolca.net , the 2002 model in its current partially completed form is available only on a subscription basis. The completed 2002 model will likely also be available only by subscription.

Metro MEBCalc Upgrade Policy

SRMG developed MEBCalc during the course of a series of projects for various clients. In this way no single client has had to support the development of the calculator, and previous clients can benefit from improvements made for subsequent clients. SRMG will continue this policy with Metro MEBCalc. For a period of three years following June 30, 2009, When subsequent clients support the development of upgrades and improvements SRMG will provide a revised calculator to Metro at no charge, provided that changes in formats and estimates initiated by subsequent clients are acceptable to Metro so that SRMG does not have to modify the upgraded calculator for some particular characteristics desired by Metro.

Specifically with respect to the UNEP-SETAC harmonization model USEtox for human and ecosystems toxicity, SRMG will provide a no-charge upgrade once US EPA has peer-reviewed USEtox, developed a new matrix of toxicity factors for its TRACI model, made that

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[19] BEA needs nearly 5 years to collate and aggregate data from an economic census into the nearly 500 industry sector economic input-output model of the US economy.

new matrix available to SRMG at no charge, and provided that the new matrix is similar to the matrix of toxicity factors in terms of structure and indicator substances.

With respect to revisions to CMU GDI EIO-LCA environmental impacts data, DST MSW Database updates that may be provided through Research Triangle Institute's online commercial marketing of the database, and DST MSW Database or WARM updates that may occur as a result of the in-progress DST-WARM reconciliation process, SRMG will provide no charge upgrades to Metro MEBCalc on the same basis as the upgrades policy stated in the first paragraph of this section.

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