User Instructions & Technical Documentation for MEBCalc™

Prepared by :
Dr. Jeffrey Morris
Sound Resource Management Group, Inc.
Olympia, WA

February 2013

Table of Contents

User Instructions & Technical Documentation for MEBCalc^{TM}

The latest version MEBCalc^{TM} (Measuring the Environmental Benefits Calculator), a trade-marked Excel workbook for calculating the environmental impacts of a solid waste management system, has been substantially updated from the previous version. The changes include:

- Incorporation of TRACI 2.0 characterization factors that became available in early 2011 for aggregating pollutant emissions into the seven categories of environmental impacts included in MEBCalc^{TM}. This update affects all impact assessment calculations.
- Incorporation of economic input-output life cycle assessment modeling based on the Carnegie Mellon University (CMU) Green Design Institute's Economic Input-Output Life Cycle Assessment (EIO-LCA) tools for 2002 that replace 1997 EIO-LCA outputs used in previous versions of MEBCalc^{TM}. The 2002 models are derived from the latest US Bureau of Economic Analysis 428 sector input-output model for the US economy.
- Incorporation of fall 2010 updates to EPA's WARM calculator wherever WARM data are used in MEBCalc^{TM}.
- Addition of wet and dry anaerobic digestion impact assessments.
- Addition of impact assessments for multi-family/commercial, construction & demolition (C&D), self-haul and deposit-return collection systems.
- Addition of biweekly collection impact assessments for residential collection of garbage, organics and recyclables.
- Addition of impact assessments for CNG fueled trucks for residential, multi-family/commercial, and C&D collection systems.
- Addition of copper, carpet, household batteries, paint and gypsum wallboard to the list of materials included in MEBCalc^{TM} diversion impact assessments.
- Addition of user choices for landfill gas capture rate, in-landfill fugitive methane oxidation rates, and landfill annual methane generation rate (based on precipitation at landfill locale).
- Connection of landfill leachate emissions to precipitation levels.

The latest MEBCalc^{TM} workbook contains 18 separate spreadsheets, some of which are linked to each other, and many of which are also linked to Excel files external to the MEBCalc^{TM} workbook.[1] The first spreadsheet includes input data provided by the calculator's user. The next two provide calculation of a greenhouse gas (GHG) inventory for a municipal solid waste (MSW) management system. The fourth provides per ton waste prevention benefits for a number of the products and packaging materials assessed in MEBCalc^{TM}. The

[1] When opening the workbook the user should choose the "Don't Update" button for these links. The external Excel spreadsheets contain confidential life cycle inventory data and calculations that are not included with the MEBCalc^{TM} model.

following four spreadsheets summarize total, disaggregated and per ton environmental benefits of diversion efforts. The remaining nine spreadsheets lay out the environmental impacts, both from the various activities required to divert materials from disposal to beneficial uses and from disposal activities that are avoided when waste materials are recovered.

The 18 spreadsheets are identified in the workbook with tabs having the following names:

1. User Inputs
2. MSW GHG Inventory
3. Per Ton GHG Offsets
4. Waste Prevention
5. Summary Graphs
6. Diversion Benefit Results
7. Diversion Results Detail
8. Disaggregated Diversion Results
9. Per Ton Impacts
10. SF Collections
11. Commingled MRFs
12. Other Processing
13. Composting
14. Landfills
15. WTE
16. Hauling
17. Self-Hauling
18. Upstream

The MEBCalc™ workbook is set for automatic recalculation, so that as the user enters data in the User Inputs spreadsheet the seven results spreadsheets are automatically updated. In other words, the user does not have to do anything other than enter the appropriate input data for the particular year and/or scenario which the user wants to evaluate. Results calculations are automatic.

Cells of the User Inputs spreadsheet for entering user inputs are shaded **tan** Unless the user is very experienced with using MEBCalc™, the tan shaded cells in the User Inputs spreadsheet and the few tan shaded cells in the MSW GHG Inventory spreadsheet are the only cells in the 18 MEBCalc™ spreadsheets that should be changed by users.

The following sections describe the 18 spreadsheets in more detail.

User Inputs Spreadsheet

The User Inputs spreadsheet includes the following input data provided by the calculator's user:

- ***Section I. Collection and Recovery Quantities (tons by material and collection method)*** – The user enters recovered quantities which are used to back calculate collection quantities based on user inputs of processing residue rates in Section III.

- ***Section II. Allocation of Avoided Disposal & Selection of Landfill Gas Capture, Fugitive Methane Oxidation, and Biodegradables Methane Generation Rate*** – This section has the user specify the distribution of disposal quantities among (1) anaerobic landfills that collect landfill gas (LFG) and use it to generate electricity, (2) anaerobic landfills that collect LFG and flare it, (3) landfills that operate under aerobic conditions or that handle relatively inert materials so that no methane is generated, and (4) waste-to-energy incineration facilities.

  This section also asks the user to input landfill gas capture rate for anaerobic landfills (average over a 100 year time frame), fugitive methane oxidation rate for anaerobic landfills (reduction of non-captured methane to carbon dioxide due to oxidation within the landfill itself before the methane reaches the landfill surface and is released to the atmosphere), and methane generation rate in anaerobic landfills based on precipitation levels where the landfills are located. The user may find it helpful to review documentation (available at http://www.epa.gov/ttncatc1/dir1/landgem-v302-guide.pdf) for EPA's LandGEM model for assistance in choosing values for these entries.

- ***Section III. Processing Residue Rates*** – This section asks the user to estimate residue rates from processing collected materials. These residues may depend on the degree of commingling in collection systems, as well as the type of processing required to clean and package recycled materials so that they meet market specifications. Hence, there are 11 specific processing residue rates for the user to estimate. Processing residues typically are sent for disposal and, thus, the residue quantities should be included in the disposal quantities inputs in Section VIII.

  MEBCalc™ uses the processing residue percentages to convert quantities recovered back to quantities originally collected for recovery. These collection quantities are needed to calculate environmental impacts of collection and processing.

- ***Section IV. Composition of Mixed Paper*** – Mixed paper collected for recycling contains a variety of paper types from cardboard to printing/writing paper and junk mail. The exact combination will depend on the types of paper collected separately from mixed paper (e.g., newspapers and/or cardboard boxes). The spreadsheet provides some examples that may help the user estimate the composition of mixed paper collected for recycling.

- ***Section V. Allocation of Materials to End Markets*** – Glass containers, electronics, tires, clean wood, yard debris, food scraps, soiled paper, carpet and household alkaline batteries recovered for recycling, composting or beneficial use for energy have a variety of end markets. Some of these are included in the life cycle calculations of MEBCalc™. This section requires inputs on the percentage of each material that is sent to each of the listed end markets for each material. Dry and wet anaerobic digestion are now included as options for organics. Engineered wood is also included as an end market for clean wood.

- ***Section VI. Estimated Distance (miles) and Mode to End Markets*** – Inputs in this section are for estimated distances and transport mode (truck, train, ship/barge) for each recycled material and each end market. The distribution of shipments among transport modes is also an input for this section.

- ***Section VII. Scrap Value ($/ton marketed -- FOB MRF)*** – If the user desires to compare environmental and financial values for recycled materials in the Diversion Benefit Results spreadsheet, they enter end market prices for recovered materials here.

- ***Section VIII. Disposal Quantities (by material)*** – If the user wants to calculate their MSW system's GHG inventory, they need to enter disposal quantities for each material type and the distribution among single family, multi-family/commercial and self-haul garbage collection modes used for each material.

- ***Section IX. Deposit-Refund Beverage Container Collection System Parameters*** – If the user has a beverage container deposit-refund collection system in their jurisdiction, this section provides input parameters for estimating the environmental impacts of that collection system, including hauling of consolidated containers to processing facilities. The Household Return to Retail parameter inputs include the percent of return trips that are dedicated only to returning beverage containers and do not include other trip destinations. Alternatively, this parameter also can be interpreted as the average additional kilometers, out of the average total round trip kilometers traveled for errands, which are needed to return beverage containers for deposit refund. Other parameter inputs for Return to Retail include average pounds of containers returned per trip, average round trip distance per trip, and average household vehicle fuel efficiency.

The two user input parameters for the Deposit-Refund Returned Containers Collection System are the average miles hauled per ton collected and the additional fuel usage per ton mile for the short trips with frequent stops compared with non-stop long distance hauls.

- ***Section X. Route Collection Parameters*** – Here the user enters the distribution of collection truck fuel types between diesel and CNG (compressed natural gas) for single-family residential collections, for multi-family/commercial collection routes, and for collection of C&D (construction and demolition) materials for recycling. The user also indicates whether single-family residential collection routes for garbage, recycling and organics have weekly or biweekly frequency.

- ***Section XI. Self-Haul Parameters*** – This section asks the user to enter parameters that characterize self-hauling of recyclables, organics and garbage. The user entries include average round trip distance for self-haul trips, average amount of garbage per trip, average amount of recyclables per trip, average amount of organics for composting per trip, and average household/business self-hauler vehicle fuel efficiency.

- ***Section XII. Anaerobic Digestion (AD) Parameters*** – If the user's solid waste system sends any organics to AD this section asks the user to estimate biogas generation rate in cubic meters per metric ton, the percentage of that biogas that is comprised of methane, the loss of output compost as a result of conversion of some input organics to biogas during anaerobic digestion, and the parasitic energy use for the AD facility. Default values are provided for these parameters. Whether the model's environmental benefits calculations involve dry or wet or both types AD is determined by the allocations of organic materials specified in Section V.

- ***Section XIII. Environmental Values*** – This section provides the estimates of environmental and public health costs per ton for each of the seven environmental and public health impact categories included in MEBCalc™. Default cost estimates are provided based on referenced literature so that the user can use these researched valuations if they so choose.

- ***Section XIV. Recycled Content of Product/Packaging Materials Production Prevention*** – This section provides the estimates of recycled content for products and packaging materials that may be targeted by a community's waste prevention and reduction programs or policies.

These inputs, except for the environmental values, can be based on actual data for some historical period such as the most recent year. All inputs, including environmental values, can be used to conduct “what if” and scenario analyses.

Cells of the User Inputs spreadsheet for entering user inputs are shaded **tan**. Unless the user is very experienced with using MEBCalc™, the tan shaded cells in the User Inputs spreadsheet and the few tan shaded cells in the MSW GHG Inventory spreadsheet are the only cells in the 18 MEBCalc™ spreadsheets that should be changed by users.

The data units for the User Inputs spreadsheet are mostly in tons, miles, percentages and dollars per ton. Biogas generation for anaerobic digestion is measured as cubic meters per metric ton. It is very important that input data be in the specified units. For example, MEBCalc™'s calculations of environmental impacts and benefits assume that recycled quantities entered in the User Inputs spreadsheet are tons and that the distances entered in that spreadsheet are miles. In addition, warnings are built into the spreadsheet to alert the user if allocation percentages entered do not sum to 100%.

MSW GHG Inventory Spreadsheet

This spreadsheet summarizes and also details by material type and recovery versus disposal the GHG emissions related to a community’s MSW management system. GHG emissions are estimated for collection, processing, hauling/shipping, and disposal aspects of MSW management.

The inventory shows a separate line item for Energy Production Offsets. This line item estimates the avoided GHG emissions from displacing natural gas fired electricity generation with electricity generated from AD, collected landfill gas and/or combustion of materials in a waste-to-energy incineration facility.

The inventory also includes, as memo items, GHG emissions for resource extraction, resource refining, and product or packaging material manufacturing over the life cycle of each MSW material managed for diversion or disposal. This aspect of the MSW management life cycle is often referred to as the upstream portion of a product’s life cycle. GHG emissions for the upstream portion of a diverted product or material are based on the recycled-content product manufactured from the diverted material. Upstream GHG emissions for a disposed product or packaging material are based on production of virgin-content products and packaging.

For tires, wood or yard debris diverted to energy recovery at industrial facilities, upstream emissions include GHGs emitted when the material is combusted in an industrial boiler or furnace.

All GHG estimates reported in this spreadsheet are based on estimated actual emissions to the atmosphere of fossil carbon dioxide, methane, nitrous oxide and other carbon compounds, except for biogenic carbon dioxide. Carbon dioxide emissions from biodegradation or combustion of biogenic materials are not included in the inventory totals. However, storage/sequestration of biogenic carbon in landfills, compost and recycled wood products is counted as a sink in the inventory. For example, anaerobic landfills store biogenic carbon that is not biodegraded by methanogenesis. This stored carbon counts as a deduction from the GHG emissions of a landfill. I.e., carbon storage is an offset to GHG emissions. This is the accounting protocol used in U.S. EPA's WARM GHG impacts calculator. It is also the protocol recommended in the U.S. EPA Science Advisory Board's review of EPA's proposed accounting methods for biogenic carbon emissions.

An alternative accounting protocol would be to include biogenic carbon dioxide emissions as a GHG. In this case one would not count biogenic carbon storage/sequestration as a sink in order to avoid double counting issues when comparing climate impacts of waste management methods such as landfills and waste-to-energy incineration facilities.
The reasoning for this alternative accounting methodology is based on the fact that the atmosphere's chemistry and physics are affected the same way when carbon dioxide is emitted from a fossil or biogenic source. Furthermore, there is typically little or no connection between decisions regarding management of biogenic materials in a waste management system and decisions regarding forestry or agricultural activities that may result in sequestration of carbon dioxide.

The choice of the carbon accounting methodology used in MEBCalc™ is in large measure driven by the 100-year time frame for evaluating compost and landfill emissions. Over that long time frame the climate impacts of the biogenic materials in solid wastes are constrained by the naturally occurring carbon cycle that sequesters carbon from the atmosphere as plants and trees grow, then releases that carbon as plants and trees biodegrade, only to have the carbon sequestered once again in new growth of plants and trees that occupy the same land space as the harvested plants and trees that have biodegraded once did. The only interruption to this carbon cycling occurs via long term carbon storage in landfills, long-lived and/or continually recycled biogenic carbon products, and carbon storage in soils from, or induced by, compost applications to that soil.

Per Ton GHG Offsets Spreadsheet

This spreadsheet contains data used to separately identify GHG emissions offsets per ton that are credited to specific materials and waste management facilities that produce electrical power. These offsets are for GHG emissions from power produced through natural gas fired combined cycle gas turbines. This is assumed to be the type of power that is displaced by the power generated through combustion of methane from anaerobic digestion, methane from captured landfill gas, or materials at a WTE (waste-to-energy) facility. The GHG emissions offsets from displaced natural gas usage are reflected on the MSW

GHG Inventory spreadsheet summary table in the Energy Production Offsets line item.

This spreadsheet also shows landfill carbon storage amounts per ton for biogenic materials buried in an anaerobic landfill. These amounts are used to compute the two memo items for landfill carbon storage shown ate the bottom of the MSW GHG Emissions table in the MSW GHG Inventory spreadsheet. The memo item in the Garbage column of that table is an offset for the Disposal item in the Garbage column. In other words, the disposal line item includes an offset in the amount shown for landfill carbon storage. Total emissions excluding landfill carbon storage offsets from garbage disposal are, thus, equal to the landfill storage memo amount plus the line item amount shown for garbage disposal.

Similarly, the Garbage Collection/Disposal Offset line item in the Recovery column is reduced by the landfill carbon storage that is foregone when materials are diverted from disposal. Total disposal emissions avoided by diversion programs, excluding the landfill carbon storage sink, are equal to the Garbage Collection/Disposal Offset line item amount minus the Foregone Landfill Carbon Storage line item amount.

Waste Prevention Spreadsheet

The Waste Prevention spreadsheet calculates per ton environmental benefits from not producing a ton of a product or packaging material. The mix of virgin- and recycled-content in the product or material not produced determines the environmental benefits. Typically, preventing or reducing consumption of a product or material with higher recycled-content will have lower environmental benefits than would be the case if the product or packaging material were manufactured from a greater proportion of virgin materials.

This may seem anomalous because the environmental benefits of recycling typically depend on the difference between making a product or material entirely from recycled materials versus entirely from virgin raw materials. The greater the difference between 100% recycled-content production and 100% virgin-content production, the higher will be the environmental benefits of recycling. However, waste prevention affects production of a product or material as it is actually manufactured given the mix of recycled- and virgin-content. The higher the average recycled content of a product or material that is targeted by a waste prevention program or policy, the lower will be the environmental benefits of not manufacturing that product or packaging material. Thus, if the goal is to reduce total environmental impacts, it may at times be better to prevent consumption of fewer tons of a product or material that has low recycled content versus preventing consumption of a product or material with high recycled content.

Summary Graphs Spreadsheet

The Summary Graphs spreadsheet provides four graphs showing results from MEBCalc^{TM} computations.

- Percentage Shares of Environmental Value for Pollution Reductions from Diversion – This pie chart indicates the relative proportion of total environmental value contributed by each of the seven categories of environmental impact.
- Climate Impact Reduction Per Ton Diverted – This bar graph shows climate benefits from diversion in terms of reductions in GHG emissions for each ton of each material diverted from disposal.
- Human Health – Respiratory Impact Reduction Per Ton Diverted – This bar graph shows human health respiratory benefits from diversion in terms of reductions in particulate matter emissions for each ton of each material diverted from disposal.
- Human Health – Non-Cancer Impact Reduction Per Ton Diverted – This bar graph shows human health non-cancer disease benefits from diversion in terms of reductions in emissions of toluene equivalent toxics for each ton of each material diverted from disposal.

Diversion Benefit Results Spreadsheet

This spreadsheet provides estimates of economic value for each of seven environmental benefits that result from recovering a ton of material, as well as the value per ton for all seven environmental impacts summed together. The spreadsheet also contains estimates of total environmental value for the quantities recovered.

These environmental economic values are calculated from user data entered into the User Inputs spreadsheet. The user data are evaluated based on the environmental impacts estimates that are provided by MEBCalc^{TM} in the nine spreadsheets portraying the environmental benefits of the changes in pollutant emissions from waste management system activities that are caused by diverting waste materials from disposal.

Most environmental impacts from recovery are positive. However, when there are substantial emissions from processing of recovered materials, recycled-content manufacturing, energy recovery or hauling distance to market, they can outweigh the avoided impacts of garbage disposal and virgin-content manufacturing. In those situations the value of one or more specific environmental impacts from recovery will have a negative environmental value. This indicates that environmental costs outweigh benefits for that particular environmental impact from recovery of that particular material.

This spreadsheet calculates economic value for environmental effects of recovery according to the estimated economic values for reductions in each environmental impact that are listed in the User Inputs spreadsheet under Section XIII. Environmental Values. Sources for the defaults for environmental valuations are listed in that section of the User Inputs spreadsheet.

The user can do “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 CO2 equivalents (eCO2) default 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.

For each recovered material the Benefit Results spreadsheet also shows scrap market values on a per ton basis and in total for the quantity of each material recovered. These market values are entered in the User Inputs spreadsheet. The Benefit Results spreadsheet compares scrap market values to environmental values for each material, both per ton and in total.

Diversion Results Detail Spreadsheet

This spreadsheet shows the estimated physical totals for environmental impacts from the recovery activities needed to divert each material from disposal. It also shows the total impacts for each environmental impact for each material of the disposal activities that are avoided by diverting each material from disposal. The Diversion Benefit Results spreadsheet uses the data in these two tables, along with environmental impact valuations and total tons diverted, to calculate per ton environmental benefits for each material recovered.

This spreadsheet also provides a net recycling benefits table based on the difference between the impacts of disposal versus the impacts of recycling

Impacts are shown in tons for each of the seven categories of environmental impacts evaluated by MEBCalc^{TM}. For example, the GHG increases (or decreases) caused by recovery or disposal activities are summarized as tons of carbon dioxide equivalents (eCO2) in the column labeled Climate Change in the Recovery Life Cycle Impacts and Avoided Disposal Life Cycle Impacts tables shown in this spreadsheet. The net GHG benefits of recycling are summarized as tons of eCO2 in the column labeled Climate Change in the Net Recycling Life Cycle Environmental Emissions Reductions/(Increases) table, reflecting disposal life cycle GHG impacts minus recycling life cycle GHG impacts for each waste stream material and recovery method assessed by MEBCalc^{TM}.

Disaggregated Diversion Results Spreadsheet

Whereas the Diversion Results Detail spreadsheet shows recovery and disposal impact totals separately for each material, this spreadsheet disaggregates those two totals into their collection, processing, hauling, upstream and specific recovery or disposal practice components. This disaggregation is provided for each of the seven environmental impacts currently included in MEBCalc™.

Per Ton Impacts Spreadsheet

The spreadsheet provides disaggregated results on a per ton basis by material type, MSW management system component, and environmental impact category.

SF Collections Spreadsheet

This spreadsheet is the first of the nine spreadsheets that detail environmental impacts for each component of a community's solid waste management system. In particular, the SF Collections spreadsheet details environmental impacts caused by collection of garbage, recyclables or compostables from single family (SF) households. This spreadsheet, as well as the remaining 8 spreadsheets discussed below, shows these impacts as kilograms (kg) per metric ton (tonne) for each of the seven environmental impacts. The formulas used in the Diversion Results Detail spreadsheet convert kg of impact per tonne recycled or disposed to tons of impact per ton recycled or disposed in order to report impacts in tons in that spreadsheet.

The SF collections spreadsheet is based in part on pollutant emissions profiles for atmospheric and water emissions from diesel collection trucks as exhibited in the Municipal Solid Waste Life-Cycle Database.[2] This database is from the Municipal Solid Waste Decision Support Tool (DST) developed by US EPA, Research Triangle Institute and North Carolina State University to assist municipalities with MSW management. That database's emissions profiles for diesel collection trucks are augmented by emissions profiles for upstream production of compressed natural gas (CNG) from Carnegie Mellon University's EIO-LCA (economic input-output life cycle assessment) model and Waste Management Inc. (WMI) estimates for CNG collection truck emissions.

A Note on Connecting Pollutant Emissions to Environmental Impacts

Life cycle assessment methodology connects emissions inventories or profiles covering hundreds of pollutants to a handful of environmental impacts. As such, it distills the sometimes overwhelming amount of information in emissions profiles down to a level of detail that is more manageable in terms of following complex trends and understanding relative environmental costs and benefits of MSW management options.

The trade-off is that we have to sort through complex pollutant aggregation and weighting methodologies. A "best-of" consensus methodology for human health toxicity and carcinogenicity impacts and ecosystem toxicity impacts has been

[2] Municipal Solid Waste Life-Cycle Database, prepared by Research Triangle Institute for US EPA's National Risk management Research Laboratory Atmospheric Protection Branch, 2002.

developed by the United Nations Environment Program and the Society of Environmental Toxicology and Chemistry. That methodology along with methodologies used by the Intergovernmental Panel on Climate Change (IPCC) for greenhouse gas impacts and US EPA's TRACI (Tool for the Reduction and Assessment of Chemical and other environmental Impacts) model for respiratory particulates, eutrophying pollutants and acidifying pollutants have been catalogued in TRACI 2.0. This is the basis for the aggregations of pollutant releases into the 7 environmental and human health impacts covered by MEBCalc™.

A Note on Collections Other Than from SF Households

The SF Collections spreadsheet accounts for the differences in impacts from collection of garbage compared with collection of recyclables or compostables. Researchers typically find that garbage collection is more efficient per tonne collected, and thus less productive of pollutants, than collection of recyclables. This is indicated in the SF Collections spreadsheet by the lower level impacts for collection of garbage compared with recycling. This spreadsheet also indicates that compostables (organics) curbside collection likely is somewhat more efficient than garbage collection in terms of impacts per tonne collected. This is in part due to the often lower set out frequency for compostables compared with garbage.

For collections from multifamily apartment buildings, businesses and institutions, as well as for collection of construction and demolition (C&D) wastes, MEBCalc™ calculates impacts based on estimated increased efficiency compared with collection from single-family households. These collection efficiencies are mostly due to collecting larger quantities at each stop on a collection route or the use of dedicated drop box hauls for C&D wastes.

Impacts from the other main method of transporting discards from waste generators to waste management facilities – i.e., self-hauling of garbage, recyclables, and organics -- are detailed in a separate spreadsheet discussed below.

Commingled MRFs Spreadsheet

This spreadsheet exhibits environmental impacts for a materials recovery facility (MRF) that accepts commingled recyclables, separates and cleans the recyclables, and packages the separated materials to industry standards for delivery to end use markets. The emissions profile for MRFs is from the same MSW DST Life-Cycle Database that is the source for some of the SF garbage collection pollutant emissions profiles.

This spreadsheet also lists the user input (from a link to the User Inputs spreadsheet) for commingled recyclables processing residues. These residues go to disposal rather than to recycling end markets.

Other Processing Spreadsheet

This spreadsheet calculates environmental impacts from processing source separated recyclables based on default assumptions as to the amount of energy and pollutant releases needed to clean and prepare source separated materials for sale to end markets. The default assumptions are:

- Processing source separated metals results in just 25% of the environmental impact levels of commingled recyclables processing.
- Processing source separated wood, except for reuse, results in 75% of environmental impact levels for processing commingled recyclables.
- Wood processing for reuse is assumed to be only half as GHG intensive as processing wood for other end uses. This is mainly due to the need to chip wood and remove nails and other metals for these other end uses.
- Processing other source separated materials -- excluding electronics, household batteries, paint, and gypsum wallboard -- results in just 25% of environmental impact levels for processing commingled recyclables.
- Processing electronics is assumed to result in 2.1 times the impacts levels of commingled MRFs, based on LCA research by ICF as discussed below.
- Processing household batteries is assumed to result in 75% of the impacts of commingled MRFs processing.
- Processing paint is assumed to result in 75% of the impacts of commingled MRFs processing.
- Processing gypsum wallboard is assumed to result in the same impacts as commingled MRFs processing.

Based on the 2005 ICF Consulting study Determination of the Impact of Waste Management Activities on Greenhouse Gas Emissions: 2005 Update, Final Report, prepared for Environment Canada and Natural Resources Canada, the energy required to process electronic equipment for recycling -- including shredding and segregating shredded electronics into metals, plastics, glass and other marketable materials – amounts to 2.1 times the energy used to process commingled recyclables. On this basis, processing used electronics for recycling is assumed to cause 2.1 times the environmental impacts of commingled recyclables processing.

The Other Processing spreadsheet also lists the user inputs (from a link to the User Inputs spreadsheet) for processing residues from source separated recyclables, including used electronics, household batteries, paint and gypsum wallboard. These residues go to disposal rather than to recycling end markets.

Composting Spreadsheet

This spreadsheet shows the environmental impacts for operations at an aerobic composting facility that accepts source separated yard debris materials (grass, leaves and branches), composts these organic materials, and produces compost products that meet market requirements for composts to be applied on lawns, gardens and farms, as well for a variety of other uses. The emissions profile for aerobic composting is from the same MSW DST Life-Cycle Database that is the source for some of the SF collection pollutant emissions profiles. However, the DST estimated water emissions levels for cadmium and lead are adjusted down to landfill water emissions levels for those two pollutants to reflect discontinuance of petro-chemical-based plastic bags for collecting organics and the passage of time since the phase out of lead in gasoline.

Upstream climate impacts in MEBCalc™ provide estimated differences among yard debris, food scraps, wood and soiled paper for carbon sinks from compost utilization. This adjustment yields the correct overall estimate for composting climate benefits in MEBCalc™ results. For example, food scraps have only about one third as much carbon content per tonne as wood or paper. As a result upstream climate benefits from compost utilization are somewhat lower for food scraps than for wood or paper.

Otherwise, composting and compost utilization impacts for the biogenic carbon materials are identical for the seven environmental impacts. This is due to a lack of data on variations in environmental performance during composting and compost utilization for the different biogenic materials.

It is also difficult to separate compost utilization benefits by input material type due to the need to use a suitable mix of all biogenic materials to optimize the aerobic composting process. For example, woody materials are a necessary part of the recipe for making good compost as they provide a source for maintaining the requisite high ratio of carbon to nitrogen in the composting input materials mix. They also provide bulky material that enhances the circulation of water and oxygen that is essential to maintain aerobic conditions in the compost pile. Thus, even though woody material has a lower nitrogen component than grass clippings, one cannot make good compost from grass clippings alone. From this point of view the upstream benefits of fertilizer and pesticide displacements attributable to using compost as a soil amendment cannot be allocated to input materials simply on the basis of each material's proportionate share of total nitrogen inputs. For this reason the fertilizer and pesticide production displacements provided by the different biogenic materials are all assumed to be equal.

The composting spreadsheet also exhibits estimated environmental impacts for dry and wet anaerobic digestion (AD) facilities. There are three different aspects to the AD impacts – air emissions from the internal combustion engine (ICE) that burns methane generated from the AD process, offsets of natural gas powered electricity displaced by electricity generated by the ICE, and air and water emissions from aerobic composting of the AD digestate. The user inputs for methane generation from AD, compost loss, and parasitic energy use influence the estimates of environmental impact for these three aspects of AD environmental performance.

The Composting spreadsheet lists the user input (from a link to the User Inputs spreadsheet) for composting residues. These residues go to disposal rather than to recycling end markets.

Landfills Spreadsheet

This spreadsheet shows estimated environmental impacts for MSW landfills based on user inputs of the weighted average landfill gas (LFG) capture rate over a 100-year time frame, fugitive methane oxidation rate and methane generation rate for landfills that capture LFGs and either use the captured methane to generate electricity or flare it. The spreadsheet also exhibits impacts for inert material or C&D material landfills that screen incoming wastes to prevent materials from being landfilled that would create anaerobic conditions in the buried materials. The emissions profiles in the external spreadsheets that generate the environmental impacts shown in this spreadsheet for these three types of landfills are based on a variety of sources:

- Material specific methane generation potentials for anaerobic landfills are based on Jeffrey Morris, Bury or burn North American MSW? LCAs provide answers for climate impacts and carbon neutral power potential, *Environmental Science & Technology*, 44(20) 7944-7949, 2010.
- Air and water pollutant emissions for landfill operations, flaring of captured LFGs, and reciprocating engine combustion of captured LFGs to generate electricity are, for the most part, from the MSW DST Life-Cycle Database.
- Air emissions for an expanded inventory of pollutants are from US EPA's LandGEM (Landfill Gas Emissions Model). This expanded list includes emissions of mercury, vinyl chloride, methyl ethyl ketone, benzene, hydrogen chloride, chloroform, chloromethane, and other hazardous and/or volatile organic compounds that are not included in the DST air emissions inventory.
- Environmental impact offsets for electricity generated from captured landfill methane reflect electricity generated on the grid by combined cycle natural gas turbines. Emissions from the production and combustion of natural gas in combined cycle turbines for electricity production are avoided by electricity generated by reciprocating engines running on captured landfill methane. Air, water and land emissions from production of natural gas are from Carnegie Mellon University (CMU) Green Design Institute's EIO-LCA (Economic Input-Output Life Cycle Assessment) model accessible at www.eiolca.net . Air emissions from combustion of natural gas are from US EPA's AP-42 emissions inventories.
- Water emissions from combustion of natural gas to generate electricity are from the MSW DST Life-Cycle Database.

The Landfills spreadsheet shows the resultant environmental impacts in general by landfill type and for specific materials or categories of materials as appropriate. The columns showing the impacts used in MEBCalc™ calculations are labeled Degradables, Degradables (flare), Non-Degradables, and Inerts.

The Degradables column covers impacts in a landfill capturing LFGs and generating electricity for paper and cardboard, wood, yard debris, and food scraps. The Degradables (flare) column shows impacts for the same materials in a landfill that captures LFGs and flares the captured gases.

The Inerts column covers impacts from glass and aluminum materials in all three types of landfills, as well as impacts of all other materials landfilled in inert or C&D special purpose landfills. The Non-Degradables column shows impacts for most other non-degradable and non-inert materials in anaerobic or non-anaerobic MSW landfills. The MHSW (municipal hazardous or special wastes) and WEEE (waste electronic and electrical equipment) columns reflect impacts for landfilling these types of products.

WTE Spreadsheet

This spreadsheet shows the estimated environmental impacts for WTE facilities. The emissions estimates are based on a variety of sources:

- Air emissions of particulates, nitrogen oxides (NOx), sulfur dioxide (SO2), carbon monoxide (CO), and hydrochloric acid (HCL) are based on Covanta operating and emissions data for their Brooks (OR) facility as supplied to OR DEQ, supplemented by criteria air pollutant emissions data for Massachusetts and British Columbia WTE facilities.
- Other non-GHG air emissions from operation of WTE facilities are from the MSW DST Life-Cycle Database, supplemented by emissions data for heavy metals from the Burnaby, British Columbia, WTE facility.
- GHG air emissions from combustion of MSW materials are based on the Morris 2010 article in *Environmental Science & Technology*.
- Air and water emissions from ash transport and landfilling are from the MSW DST Life-Cycle Database.
- The amount of electricity generated by a WTE facility is based on specific energy content for combustible waste materials as listed in supplemental information for the Morris 2010 *Environmental Science & Technology* article, the mix of materials specified in user inputs, the assumption that 18,000 Btu's, about 19 megajoules, are required to generate a kilowatt hour (kWh) net of parasitic energy needs for the WTE facility itself (this is 19% net efficiency), and an average availability of 88% for a WTE facility.
- Based on electricity generated by a WTE facility for each tonne combusted, the CMU Green Design Institute's EIO-LCA model provides avoided pollutant emissions to air, water and land from production of natural gas needed to generate that same number of kilowatt hours on the electrical grid.

- US EPA's AP-42 air emissions database supplies the air emissions estimates for combustion of natural gas.
- The MSW DST Life-Cycle Database supplies water emissions from combustion of natural gas.

The WTE spreadsheet shows the estimated seven environmental impacts for each metric ton of each MSW material combusted at a WTE facility. These estimates enter into the calculations shown on the Benefits Detail spreadsheet, as well as the other spreadsheets that provide calculation outputs.

Hauling Spreadsheet

This spreadsheet shows estimated environmental impacts from hauling a metric ton of materials one kilometer by truck. This spreadsheet also shows estimated average hauling distances to markets and disposal facilities by truck, ship or barge, and rail based on user data entered in the User Inputs spreadsheet. These hauling distances for the three different transportation modes are converted to truck hauling equivalents under the assumption that ship/barge transit is 6 times more efficient per kilometer than truck transit, and that rail is 3.3 times more efficient than truck transit. The air and water emissions profile for truck transportation is from the MSW DST Life-Cycle Database.

Self-Hauling Spreadsheet

The self-hauling spreadsheet provides estimated environmental impacts for a liter of gasoline burned in a passenger car and a liter of diesel fuel burned in a light truck. When combined with user inputs data these estimates of impacts per liter yield the impacts for self-hauling of garbage, recyclables, compostables, and deposit-refund beverage containers.

Upstream Spreadsheet

This spreadsheet provides environmental impacts caused by virgin- and recycled-content production of cardboard, newsprint, office paper, glass containers, PET pellets, HDPE pellets, LDPE pellets, aluminum sheet, steel sheet/coil, and other products or materials currently included in MEBCalc™. It also provides the emissions profiles for magazines/catalogs and telephone books. These two materials, along with boxboard, gabletop/laminates, and aseptic containers are often included, along with some amount of newspapers, cardboard and office paper, in what is marketed as mixed paper.

The emissions profile for boxboard is estimated as a 50/50 combination of newsprint and magazines; gabletops as 90% cardboard and 10% plastic wrap; and aseptic packages as 70% cardboard and 30% plastic and aluminum wrap. The plastic and aluminum layers in gabletop and aseptic packaging are assumed to be disposed during the recycling process, and so count neither as a beneficial impact for recycling or an avoided impact for the disposal usually avoided by recycling.

Air and water emissions profiles for virgin- and recycled-content production of some materials are directly from or based on the MSW DST Life-Cycle Database. These profiles provide the basis for the estimates of environmental impacts from production of these materials that are shown in the Upstream spreadsheet. Sources for the estimated upstream environmental impacts of other materials are, as follows:

- For recycled glass manufactured into fiberglass insulation, a Franklin Associates study on glass recycling prepared for the City of Portland.
- For recycled glass and for masonry, asphalt and concrete (MAC) crushed and used as construction aggregate, US EPA's report Background Document for Life-Cycle Greenhouse Gas Emission Factors for Clay Brick Reuse and Concrete Recycling, and US Department of Commerce National Institute for Standards and Technology's BEES (Building for Environmental and Economic Sustainability) model.
- For electronics reuse, CMU Green Design Institute's EIO-LCA model.
- For electronics recycling, MSW DST Life-Cycle database for the constituent materials yielded by shredding and separating the shredded metals, plastics , glass and other materials that make up used electronics products.
- For tire recycling, Sound Resource Management's study Environmental Life Cycle Assessment of Waste Management Strategies with a Zero Waste Objective – Study of the Solid Waste System in Metro Vancouver, British Columbia (prepared for Belkorp Environmental Services, June 2009).
- For clean wood recycling, Sound Resource Management's study Environmental Impacts from Clean Wood Waste Management Methods: Final Updated Life Cycle Assessment (prepared for Seattle Public Utilities, August 2012).
- For upstream benefits of compost use, the peer-reviewed article by J Morris and J Bagby, Measuring Environmental Value for Natural Lawn and Garden Care Practices, International Journal of Life Cycle Assessment, 13(3) 226-234, 2008.
- Upstream benefits of copper wire recycling are based on CMU EIO-LCA model estimates of alumina smelting and primary aluminum production environmental impacts (sector 33131A) compared with impacts for primary smelting and refining of copper (sector 331411) for virgin metals production. Recycled metal upstream impacts for copper modeled as 110% of recycled aluminum impacts based on EPA WARM model GHG estimates for copper versus aluminum recycled content metals, and for other environmental impacts the generally higher contamination in copper wire collected for recycling. Upstream benefits for recycling other types of non-ferrous metals assumed to be equivalent to copper wire recycling.

- Upstream benefits of carpet recycling based on CMU EIO-LCA estimates for carpet and rugs mills (sector 314100), 2002 purchaser price for nylon broadloom carpet of $8.99 per square yard, carpet weight of 4 pounds per square yard, and EIO-LCA structural path analysis for purchases of carpet and rug mills which provides a basis for estimating the offsets to purchases enabled by recycling of used carpet.
- Upstream benefits of alkaline and rechargeable household battery recycling based on CMU EIO-LCA model for primary battery manufacturing (sector 335912) and storage battery recycling (sector 335911), respectively; 2002 prices for alkaline D-cell of $0.99 and for rechargeable D-cell of $2.12; and MIT LCA and ERM LCA (for UK's DEFRA) on battery recycling.
- Upstream benefits of latex paint recycling based on CMU EIO-LCA model for paint and coating manufacturing (sector 325510), 2002 price for latex paint of $13.86 per gallon; weight per gallon for latex paint of 11.3 pounds, and EIO-LCA structural path analysis for purchases of paint and coating manufacturers which provides a basis for estimating the offsets to purchases enabled by recycling of used latex paint into new, 75% recycled-content latex paint.

Key Assumptions in MEBCalc™

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

Landfill Carbon Storage

MEBCalc™ uses estimates in Morris (2010) 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 are 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 if the product is reused, recycled into other wood products, used in making compost or landfilled. This stored carbon will not be released to cause climate change and, thus, should be counted as an offset to the GHG releases of reuse, recycling, composting or landfilling.

Dioxin Releases from WTE Incineration

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 or collected methane from anaerobic digestion. 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 MEBCalc™ model.

The Fuel Assumption for Calculating Energy from Wastes Offsets

Another rather critical assumption embedded in 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, or from organics processed at an AD facility. 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.

By comparison with renewable electricity the natural gas offset for energy from waste or AD 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 about 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, Washington, 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 in pesticides, or indirectly in fertilizers) drops at least 25%.

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

Emissions Data from MSW DST

The emissions data from the MSW DST used in MEBCalc™ are from the first edition of the DST Database published in 2002, and available online at https://webdstmsw.rti.org/resources.htm . At this point in time it is unknown to what extent the database may have been updated for the current version of the DST.

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 2002 US Department of Commerce Bureau of Economic Analysis (BEA) economic input-output model based on 2002 US economic census data first available to the public very late in 2007. Emissions data in the 2002 EIO-LCA models include US EPA's Toxics Release Inventory (TRI) emissions data for 2002 and criteria air pollutant emissions from US EPA's National Emissions Inventory (NEI) for 2002. The 2002 EIO-LCA models estimate greenhouse gas emissions based on the Intergovernmental Panel on Climate Change's (IPCC) 4th Assessment Report, the US Department of Energy's transportation data book for 2002, and US EPA's inventory of greenhouse gas emissions and sinks for 2002.