EXECUTIVE SUMMARY: BACKGROUND AND FINDINGS

In the 21st century, management of municipal solid waste (MSW) continues to be an important environmental challenge facing the United States. In 2003, the United States generated 236.2 million tons[1] of MSW, an increase of 15 percent over 1990 generation levels and 168 percent over 1980 levels.[2] Climate change is also a serious issue, and the United States is embarking on a number of voluntary actions to reduce the emissions of greenhouse gases (GHGs) that can intensify climate change. By presenting material-specific GHG emission factors for various waste management options, this report examines the interrelationship between MSW management and climate change.

Among the efforts to slow the potential for climate change are measures to reduce emissions of carbon dioxide (CO_2) from energy use, decrease emissions of methane (CH_4) and other non-carbon-dioxide GHGs, and promote long-term storage of carbon in forests and soil. Management options for MSW provide many opportunities to affect these processes, directly or indirectly. This report integrates information on the GHG implications of various management options for some of the most common materials in MSW. To EPA's knowledge, this work represents the most complete national study on GHG emissions and sinks from solid waste management practices. The report's findings may be used to support a variety of programs and activities, including voluntary reporting of emission reductions from waste management practices.

ES.1 GHGs AND CLIMATE CHANGE

Climate change is a serious international environmental concern and the subject of much research. Many, if not most, of the readers of this report will have a general understanding of the greenhouse effect and climate change. However, for those who are not familiar with the topic, a brief explanation follows.[3]

A naturally occurring shield of "greenhouse gases" (primarily water vapor, CO_2, CH_4, and nitrous oxide), comprising 1 to 2 percent of the Earth's atmosphere, absorbs some of the solar radiation that would otherwise be radiated into space and helps warm the planet to a comfortable, livable temperature range. Without this natural "greenhouse effect," the average temperature on Earth would be approximately -2 degrees Fahrenheit, rather than the current 57 degrees Fahrenheit.[4]

Many scientists are concerned about the significant increase in the concentration of CO_2 and other GHGs in the atmosphere. Since the preindustrial era, atmospheric concentrations of CO_2 have increased by nearly 30 percent and CH_4 concentrations have more than doubled. There is a growing international scientific consensus that this increase has been caused, at least in part, by human activity, primarily the

[1] All references to tonnage of waste in this report are in short tons. All references to tons of carbon or CO_2 equivalent are in metric tons (i.e., MTCE per short ton of material).

[2] EPA Office of Solid Waste, Municipal Solid Waste in the United States: 2003 Facts and Figures, EPA (2005), p. 2.

[3] For more detailed information on climate change, please see the 2005 *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2003*, available online at: http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissions.html (September 2005); and *Climate Change 2001: The Scientific Basis* (J.T. Houghton, et al., eds. Intergovernmental Panel on Climate Change [IPCC]; published by Cambridge University Press, 2001). To obtain a list of additional documents addressing climate change, access EPA's global warming Web site at http://yosemite.epa.gov/oar/globalwarming.nsf/content/index.html.

[4] Climate Change 2001: The Scientific Basis, op. cit., pp. 89-90.

burning of fossil fuels (coal, oil, and natural gas) for such activities as generating electricity and driving cars.[5]

Moreover, in international scientific circles a consensus is growing that the buildup of CO_2 and other GHGs in the atmosphere will lead to major environmental changes such as (1) rising sea levels that may flood coastal and river delta communities; (2) shrinking mountain glaciers and reduced snow cover that may diminish fresh water resources; (3) the spread of infectious diseases and increased heat-related mortality; (4) possible loss in biological diversity and other impacts on ecosystems; and (5) agricultural shifts such as impacts on crop yields and productivity.[6] Although reliably detecting the trends in climate due to natural variability is difficult, the most accepted current projections suggest that the rate of climate change attributable to GHGs will far exceed any natural climate changes that have occurred during the last 1,000 years.[7]

Many of these changes appear to be occurring already. Global mean surface temperatures already have increased by about 1 degree Fahrenheit over the past century. A reduction in the northern hemisphere's snow cover, a decrease in Arctic sea ice, a rise in sea level, and an increase in the frequency of extreme rainfall events all have been documented.[8]

Such important environmental changes pose potentially significant risks to humans, social systems, and the natural world. Many uncertainties remain regarding the precise timing, magnitude, and regional patterns of climate change and the extent to which mankind and nature can adapt to any changes. It is clear, however, that changes will not be easily reversed for many decades or even centuries because of the long atmospheric lifetimes of GHGs and the inertia of the climate system.

ES.2 CLIMATE CHANGE INITIATIVES IN THE UNITED STATES

In 1992, world leaders and citizens from some 200 countries met in Rio de Janeiro, Brazil, to confront global ecological concerns. At this "Earth Summit," 154 nations, including the United States, signed the United Nations Framework Convention on Climate Change (UNFCCC), an international agreement to address the danger of global climate change. The objective of the Convention was to stabilize GHG concentrations in the atmosphere over time at a level at which manmade climate disruptions would be minimized.

By signing the Convention, countries made a voluntary commitment to reduce GHGs or take other actions to stabilize emissions of GHGs. All Parties to the Convention were required to develop and periodically update national inventories of their GHG emissions. The United States ratified the Convention in October 1992. One year later, the United States issued its *Climate Change Action Plan* (CCAP), which calls for cost-effective domestic actions and voluntary cooperation with states, local governments, industry, and citizens to reduce GHG emissions.

In order to achieve the goals outlined in the *Climate Change Action Plan*, EPA initiated several voluntary programs to realize the most cost-effective opportunities for reducing emissions. For example, in 1994 EPA created the Landfill Methane Outreach Program, which aims to reduce landfill CH_4 emissions by facilitating the development of projects that use landfill gas to produce energy.[9] In the same year, EPA introduced the Climate and Waste Program to capture the climate benefits of a broader set of waste-related initiatives (e.g., recycling, source reduction). In 2001 EPA started the Green Power Partnership. This partnership aids organizations that want to obtain some or all of their power from

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[5] *Ibid.*, p. 7.
[6] J.J. McCarthy, et al., eds. 2001. *Climate Change 2001: Impacts, Adaptation, and Vulnerability*. IPCC. Cambridge University Press. pp. 9-13.
[7] Climate Change 2001: The Scientific Basis, op. cit., p. 2.
[8] *Ibid.*, p. 4.
[9] Available at the U.S. Environmental Protection Agency's Landfill Methane Outreach Program website: http://www.epa.gov/lmop. Toll-free hotline number: 800-782-7937.

renewable energy sources, including landfill gas. The program has more than 500 partners, whose green power purchasing commitments now exceed two million megawatt-hours.

To date, EPA's voluntary partnership programs for climate protection have achieved substantial environmental results. In 2004 alone, these programs reduced GHG emissions by 57 million metric tons of carbon equivalent (MMTCE)—the equivalent of eliminating the annual emissions from approximately 45 million cars.[10] In addition, substantial CH_4 emission reductions—estimated at more than one MMTCE for the period from 1999–2000—are being obtained as an ancillary benefit of Clean Air Act (CAA) regulatory requirements that were promulgated in 1996, limiting emissions from landfills.

Many corporations that are concerned about climate change and wish to take action have joined EPA's Climate Leaders program. Participating corporations set reduction targets for themselves and agree to report their emissions annually and monitor progress toward their target. Participants come from a broad range of sectors, including energy and oil, pharmaceuticals, banking, high-tech, and manufacturing.[11] As of April 2006, there were 86 Climate Leaders, 46 of whom had set reduction targets. Together, these 79 companies account for about 8 percent of U.S. GHG emissions; the targets, if met, will prevent emissions of more than eight MMTCE per year.[12]

The U.S. Department of Energy (DOE) administers a voluntary GHG reporting program under section 1605(b) of the Energy Policy Act of 1992. This program enables companies and other entities to report their GHG emissions and to gain recognition for reductions they have implemented, including reductions through MSW management innovations. The 1605(b) program is currently finalizing revised guidelines and provisions.[13]

There has been significant action on the regional level as well. The six New England states (Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, and Vermont) joined with the eastern Canadian provinces in 2001 to write the New England Governors/Eastern Canadian Premiers (NEG/ECP) Climate Change Action Plan. The Governors and Premiers agreed to commit their states and provinces to write and implement action plans that will achieve the goals of reducing emissions to 1990 levels by 2010, and to 10 percent below 1990 emissions by 2020.[14] Some of these states were among the first to write climate change action plans, as a result of commitment to the NEG/ECP goals. Seven northeastern states (plus four observer states) have joined together to form the Regional Greenhouse Gas Initiative (RGGI), which, when it comes into effect, will be a cap-and-trade system for power plant GHG emissions, the first of its kind in the US. The West Coast Governors' Global Warming Initiative was started by the Governors of California, Oregon, and Washington in 2003. The goals of the initiative include combining purchasing power to improve the efficiency of vehicle fleets and improving appliance efficiency standards. They are considering the creation of a regional cap-and-trade system. California is also contemplating a cap-and-trade system that would include not just power plants, but also other stationary sources of GHG emissions, such as semiconductor manufacturers.

Meanwhile, an increasing number of states have instituted their own voluntary actions to reduce emissions. Forty-two states and Puerto Rico have inventoried their GHG emissions. Twenty-eight states

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[10] EPA Press Release, "10 Billion Saved on Energy Bills," 4 October 2005; car equivalent calculation available online at the U.S. Climate Technology Cooperation Gateway's Greenhouse Gas Equivalencies Calculator: http://www.usctcgateway.net/tool/.

[11] Available at the EPA's Climate Leaders website: http://www.epa.gov/climateleaders

[12] John Millet, "Five Climate Leaders Companies Reach Their Greenhouse Gas Reduction Goals," U.S. Environmental Protection Agency press release. 18 January 2006.

[13]DOE, "Enhancing DOE's Voluntary Reporting of Greenhouse Gases (1605(b)) Program." Department of Energy. Available online at: http://www.pi.energy.gov/enhancingGHGregistry

[14]The New England Governors/Eastern Canadian Premiers website: http://www.negc.org/premiers.html

and Puerto Rico have completed or initiated state action plans, which outline steps to reduce emissions. [15] Twenty-five of these action plans have incorporated the reduction of waste into their GHG mitigation strategies. Finally, at least 11 states—including California, Illinois, New Hampshire, and Wisconsin—are in the process of establishing GHG registries, which enable companies and other entities to report voluntary emission reductions.[16]

Many states are engaging in further study of climate change implications and, in some cases, enacting legislation. For example, 22 states and the District of Columbia have renewable portfolio standards (RPS), requiring that electricity producers obtain a certain amount of their power from renewable sources. In most of these states, waste-to-energy facilities and landfill gas are permitted energy sources.

Oregon recently created its Strategy for Greenhouse Gas Reductions, outlining recommended actions to reduce GHG emissions at the state level. Ten of these actions fall under the category "Materials Use, Recovery, and Waste Disposal" and include such strategies as increasing "Bottle Bill" refunds to 10 cents from 5 and widening the scope to include all beverage containers except milk.

Cities and towns also are taking action. More than 160 municipalities in the United States have joined the Cities for Climate Protection (CCP) campaign run by ICLEI (Local Governments for Sustainability). CCP members agree to inventory their GHG emissions, set a reduction target, write an action plan to reduce emissions, and implement the plan. One of the key sectors that the CCP program focuses on is waste, and many cities have taken action on this issue. For example, Seattle has increased its recycling rate, reduced landfill CH_4 emissions, and banned recyclables from garbage.

ES.3 MUNICIPAL SOLID WASTE AND GHG EMISSIONS

What does MSW have to do with rising sea levels, higher temperatures, and GHG emissions? For many wastes, the materials in MSW represent what is left over after a long series of steps: (1) extraction and processing of raw materials; (2) manufacture of products; (3) transportation of materials and products to markets; (4) use by consumers; and (5) waste management.

Virtually every step along this "life cycle" impacts GHG emissions. Solid waste management decisions can reduce GHGs by affecting one or more of the following:

(1) Energy consumption (specifically, combustion of fossil fuels) associated with making, transporting, using, and disposing the product or material that becomes a waste.

(2) Nonenergy-related manufacturing emissions, such as the CO_2 released when limestone is converted to lime (e.g., steel manufacturing).

(3) CH_4 emissions from landfills where the waste is disposed.

(4) CO_2 and nitrous oxide (N_2O) emissions from waste combustion.

(5) Carbon sequestration, which refers to natural or manmade processes that remove carbon from the atmosphere and store it for long periods or permanently.

The first four mechanisms *add* GHGs to the atmosphere and contribute to global warming. The fifth—carbon sequestration—*reduces* GHG concentrations by removing CO_2 from the atmosphere.

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[15] EPA's Global Warming—Actions, "State" webpage. Available at: http://yosemite.epa.gov/oar/globalwarming.nsf/content/ActionsState.html.

[16] Progressive Policy Institute, State Greenhouse Gas Registries, 5 September 2003. Available at: http://www.ppionline.org/ppi_ci.cfm?knlgAreaID=116&subsecID=900039&contentID=251287

Forest growth is one mechanism for sequestering carbon; if more biomass is grown than is removed (through harvest or decay), the amount of carbon stored in trees increases, and thus carbon is sequestered.

Different wastes and waste management options have different implications for energy consumption, CH_4 emissions, and carbon sequestration. Source reduction and recycling of paper products, for example, reduce energy consumption, decrease combustion and landfill emissions, and increase forest carbon sequestration.

ES.4 GENESIS AND APPLICATIONS OF THE REPORT

Recognizing the potential for source reduction and recycling of municipal solid waste to reduce GHG emissions, EPA included a source reduction and recycling initiative in the original 1994 Climate Change Action Plan and set an emission reduction goal based on a preliminary analysis of the potential benefits of these activities. It was clear that a rigorous analysis would be needed to gauge more accurately the total GHG emission reductions achievable through source reduction and recycling.

That *all* of the options for managing MSW should be considered also became clear. By addressing a broader set of MSW management options, a more comprehensive picture of the GHG benefits of voluntary actions in the waste sector could be determined, and the relative GHG impacts of various waste management approaches could be assessed. To this end, EPA launched a major research effort, the results of which were published in the first edition of this report in September 1998. A second edition of the report was published in May 2002. This third edition of the report includes additional materials and incorporates updated data affecting some of the material-specific results. The emission factors[17] presented will continue to be updated and improved as more data become available. The latest emission factors, reflecting these ongoing revisions, can be found on EPA's "Measuring Greenhouse Gas Emissions from Waste" website.[18]

The primary application of the GHG emission factors in this report is to support waste-related decisionmaking in the context of climate change. By quantifying the climate impacts of waste management decisions, the factors in this report enable municipalities, companies, and other waste management decisionmakers to measure the benefits of their actions. In recent years, the emission factors have been applied for this purpose in a number of ways. In conjunction with the DOE, EPA has used these estimates to develop guidance for voluntary reporting of GHG reductions, as authorized by Congress in Section 1605(b) of the Energy Policy Act of 1992. However, under the new, more rigorous 1605(b) reporting guidelines, emissions reductions from solid waste management practices would be reported separately under "other indirect emissions" and not included in the main corporate inventory.

Other applications have included quantifying the GHG reductions from voluntary programs aimed at source reduction and recycling, such as EPA's WasteWise, Pay-As-You-Throw, and Coal Combustion Products Partnership (C^2P^2) programs. EPA also has worked with the Climate Neutral Network to develop company-specific GHG "footprints" for the network's member companies, who have pledged to become GHG "neutral" through emission reductions or offset activities.

Currently, Climate Leaders does not record GHG emissions reductions from the purchase of recycled-content paper or the recycling of waste paper in a Partners' inventory. Climate Leaders focuses on corporate-level GHG inventory emissions calculations and reporting. Calculating GHG emission reductions from recycling uses a project-level approach which can involve a high level of uncertainty from the calculation of avoided emissions. The approach used to calculate a corporate GHG emissions inventory uses activity data, such as fuel consumption, which allow for a higher level of accuracy than the

[17] An amount of waste (in short tons) is multiplied by an emission factor (in MTCE/ton) to yield GHG emissions in MTCE. Each emission factor is specific to a particular waste management practice and to a particular material type.
[18] EPA's Global Warming—Waste, "Measuring Greenhouse Gas Emissions from Waste" webpage. Available at: http://www.epa.gov/mswclimate

avoided emissions approach. Therefore, Climate Leaders does not currently count these GHG emissions reductions from avoided emissions. However, as the methodology for calculating project level reductions from the use of recycled paper and the recycling of waste paper evolves, EPA will reconsider recognizing Partners for these activities. Since the reductions from improved materials management activities do lead to global reductions in GHG emissions -- EPA encourages Partners to continue efforts in promoting these programs and measuring their impact.

The international community has shown considerable interest in using the emission factors—or adapted versions—to develop GHG emission estimates for non-U.S. solid waste streams.[19] For example, Environment Canada and Natural Resources Canada recently employed EPA's life-cycle methodology and components of its analysis to develop a set of Canada-specific GHG emission factors to support analysis of waste-related mitigation opportunities.[20]

Additionally, EPA worked with ICLEI to incorporate GHG emission factors into its municipal GHG accounting software. Currently, more than 600 communities worldwide participate in ICLEI's Cities for Climate Protection Campaign, which helps them establish a GHG emission reduction target and implement a comprehensive local action plan designed to achieve that target. Currently, EPA is exploring other options for broadening the use of its research internationally.

To make it easier for organizations to use these emission factors, EPA created the Waste Reduction Model (WARM), the Recycled Content (ReCon) Tool, and the Durable Goods Calculator (DGC). All of these tools are discussed in more detail in Section ES.7, below.

ES.5 THE IMPACT OF MUNICIPAL SOLID WASTE MANAGEMENT ON GHG EMISSIONS

To measure the GHG impacts of MSW, EPA first decided which wastes to analyze. The universe of materials and products found in MSW was surveyed and those that are most likely to have the greatest impact on GHGs were identified. These determinations were based on (1) the quantity generated; (2) the differences in energy use for manufacturing a product from virgin versus recycled inputs; and (3) the potential contribution of materials to CH_4 generation in landfills. By this process, EPA limited the analysis to the following 21 single-material items:[21]

- Three categories of metal:
  - Aluminum Cans;
  - Steel Cans;
  - Copper Wire;
- Glass;
- Three types of plastic:
  - HDPE (high-density polyethylene);
  - LDPE (low-density polyethylene);
  - PET (polyethylene terephthalate);

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[19] Note that waste composition and product life cycles vary significantly among countries. This report may assist other countries by providing a methodological framework and benchmark data for developing GHG emission estimates for their solid waste streams.

[20] Environment Canada. 2001. *Determination of the Impact of Waste Management Activities on Greenhouse Gas Emissions*. Prepared by ICF Consulting, Torrie-Smith Associates, and Enviros-RIS.

[21] The following materials are new to this edition: copper wire, clay bricks, concrete, fly ash, tires, carpet, and personal computers.

- Six categories of paper products:
    - Corrugated Cardboard;
    - Magazines/Third-class Mail;
    - Newspaper;
    - Office Paper;
    - Phonebooks;
    - Textbooks;
- Two types of wood products:
    - Dimensional Lumber;
    - Medium-density Fiberboard;
- Food Discards;
- Yard Trimmings;
- Clay Bricks;
- Concrete;
- Fly Ash; and
- Tires.

EPA's researchers also included two products that are composites of several materials:

- Carpet; and
- Personal Computers.

The foregoing materials constitute more than 65 percent, by weight, of MSW, as shown in Exhibit ES-1 (this figure excludes clay bricks, concrete, copper wire, fly ash, and medium-density fiberboard, which were not included in the waste characterization report cited here).[22]

In addition to the materials listed above, EPA examined the GHG implications of managing mixed plastics, mixed metals, mixed organics, mixed recyclables, mixed MSW, and three definitions of mixed paper. Each of these mixed categories is summarized below.

- *Mixed plastics* are composed of HDPE, LDPE, and PET and are estimated by taking a weighted average of the 2003 recovery rates for these three plastic types.
- *Mixed metals* are composed of steel cans and aluminum cans and are estimated by taking a weighted average of the 2003 recovery rates for these two metal types.
- *Mixed organics* are a weighted average of food discards and yard trimmings, using generation rates for 2003.
- *Mixed recyclables* are materials that are typically recycled. As used in this report, the term includes the items listed in Exhibit ES-1, except food discards and yard trimmings. The emission factors reported for mixed recyclables represent the average GHG emissions for these materials, weighted by the tonnages at which they were recycled in 2003.

[22] Note that these data are based on national averages. The composition of solid waste varies locally and regionally; local or state-level data should be used when available.

- *Mixed MSW* comprises the waste material typically discarded by households and collected by curbside collection vehicles; it does not include white goods (e.g., refrigerators, toasters) or industrial waste. This report analyzes mixed MSW on an "as-disposed" (rather than "as-generated") basis.

- *Mixed paper* is recycled in large quantities and is an important class of scrap material in many recycling programs. Presenting a single definition of mixed paper is difficult, however, because recovered paper varies considerably, depending on the source. For purposes of this report, EPA identified three categories of mixed paper according to the dominant source—broad (includes most categories of recyclable paper products), office, and residential (see Exhibit 3-2 for definitions of mixed paper categories).

Exhibit ES-1
U.S. Generation of MSW For Materials in This Report

Material	MSW Generation by Weight (percent)
Aluminum Cans	0.6%
Steel Cans	1.1%
Copper Wire	N/A
Glass	4.5%
HDPE	1.6%
LDPE	1.3%
PET	0.9%
Corrugated Cardboard	12.6%
Magazines/Third-class Mail	3.2%
Newspaper	5.4%
Office Paper	3.0%
Phonebooks	0.3%
Textbooks	0.4%
Dimensional Lumber[a]	3.5%
Medium-density Fiberboard	N/A
Food Discards	11.0%
Yard Trimmings	12.1%
Carpet	1.2%
Personal Computers	N/A
Clay Bricks	N/A
Concrete	N/A
Fly Ash	N/A
Tires	2.0%
TOTAL	**64.8%**

[a] Listed in Municipal Solid Waste in the United States: 2003 Facts and Figures as "Wood—Containers and Packaging.
Source: EPA. 2005. Municipal Solid Waste in the United States: 2003 Facts and Figures, EPA 530-F-05-003.

The EPA researchers developed a streamlined life-cycle inventory for each of the selected materials. The analysis is streamlined in the sense that it examines GHG emissions only and is not a comprehensive environmental analysis of all emissions from municipal solid waste management options.[23]

EPA focused on those aspects of the life cycle that have the potential to emit GHGs as materials change from their raw states to products and then to waste. Exhibit ES-3 shows the steps in the life cycle at which GHGs are emitted, carbon sequestration is affected, and utility energy is displaced. As shown, EPA examined the potential for these effects at the following points in a product's life cycle:

- Raw material acquisition (fossil fuel energy and other emissions, and changes in forest carbon sequestration);

[23] EPA's Office of Research and Development (ORD) performed a more extensive application of life-cycle assessment for various waste management options for MSW. A decision support tool (DST) and life-cycle inventory (LCI) database for North America have been developed with funding by ORD through a cooperative agreement with the Research Triangle Institute (RTI) (CR823052). This methodology is based on a multimedia, multipollutant approach and includes analysis of GHG emissions as well as a broader set of emissions (air, water, and waste) associated with MSW operations. The LCI database is expected to be released in the summer of 2006. The website address for further information is: http://www.rti.org/, then search the term "DST."

- Manufacturing (fossil fuel energy emissions); and
- Waste management (CO_2 emissions associated with composting, nonbiogenic CO_2 and N_2O emissions from combustion, and CH_4 emissions from landfills); these emissions are offset to some degree by carbon storage in soil and landfills, as well as avoided utility emissions from energy recovery at combustors and landfills.

At each point in the material life cycle, EPA also considered transportation-related energy emissions. Estimates of GHG emissions associated with electricity used in the raw materials acquisition and manufacturing steps are based on the nation's current mix of energy sources,[24] including fossil fuels, hydropower, and nuclear power. However, when estimating GHG emission reductions attributable to utility emissions avoided, the electricity use displaced by waste management practices is assumed to be 100 percent fossil-derived.[25]

EPA did not analyze the GHG emissions typically associated with consumer use of products because the primary concern of this report was end-of-life management. Although the consumer-use stage of life can in some cases (e.g., personal computers) account for significant energy consumption, the energy consumed during use would be approximately the same whether the product was made from virgin or recycled inputs.

Improvements to the New Edition

This report is the third edition of *Greenhouse Gas Emissions from Management of Selected Materials in Municipal Solid Waste*. This edition includes the following improvements:

- Develops emission factors for seven new material types: copper wire, clay bricks, concrete, fly ash, tires, carpet, and personal computers;
- Incorporates new energy data into calculations of utility offsets;
- Updates U.S. landfill gas collection characteristics to reflect the latest values from the U.S. Greenhouse Gas Inventory;
- Revises carbon coefficients and fuel use for national average electricity generation;
- Includes a discussion of emerging issues in the area of climate change and waste management;
- Includes a chapter on the energy reduction benefits of solid waste management.
- Provides an updated list of suggested proxy values for voluntary reporting of GHG emission reductions;
- Includes a discussion of open-loop recycling, as it relates to EPA's factors for fly ash, carpet, personal computers, and mixed paper;
- Adds retail transport to the methodology;
- Updates the current mix of recycled/virgin inputs for various materials; and
- Includes an updated analysis of forest carbon sequestration and moves the discussion into the recycling chapter.

These changes and/or revisions are described in more detail throughout the report and in Appendix C.

To apply the GHG estimates developed in this report, one must compare a baseline scenario with an alternative scenario, on a life-cycle basis. For example, one could compare a baseline scenario, where 10 tons of office paper are manufactured, used, and landfilled, to an alternative scenario, where 10 tons are manufactured, used, and recycled.

Exhibit ES-2 shows how GHG sources and sinks are affected by each waste management strategy. For example, the top row of the exhibit shows that source reduction[26] (1) reduces GHG

[24] The emissions are based on the current national grid mix, as opposed to regional grids.
[25] EPA adopted this approach based on suggestions from several reviewers who argued that fossil fuels should be regarded as the marginal fuel displaced by waste-to-energy and landfill gas recovery systems.
[26] The source reduction techniques the EPA researchers analyzed involve using less of a given product—e.g., by making aluminum cans with less aluminum ("lightweighting"); double-sided rather than single-sided photocopying;

emissions from raw materials acquisition and manufacturing; (2) results in an increase in forest carbon sequestration; and (3) does not result in GHG emissions from waste management. The sum of emissions (and sinks) across all steps in the life cycle represents net emissions.

Exhibit ES-2 Components of Net Emissions for Various MSW Management Strategies

MSW Management Strategy	GHG Sources and Sinks		
	Raw Materials Acquisition and Manufacturing	**Changes in Forest or Soil Carbon Storage**	**Waste Management**
Source Reduction	Decrease in GHG emissions, relative to the baseline of manufacturing	Increase in forest carbon sequestration (for organic materials)	No emissions/sinks
Recycling	Decrease in GHG emissions due to lower energy requirements (compared to manufacture from virgin inputs) and avoided process nonenergy GHGs	Increase in forest carbon sequestration (for organic materials)	Process and transportation emissions associated with recycling are counted in the manufacturing stage
Composting (food discards, yard trimmings)	NA	Increase in soil carbon storage	Compost machinery emissions and transportation emissions
Combustion	NA	NA	Nonbiogenic CO_2, N_2O emissions, avoided utility emissions, and transportation emissions
Landfilling	NA	NA	CH_4 emissions, long-term carbon storage, avoided utility emissions, and transportation emissions

NA = Not Applicable

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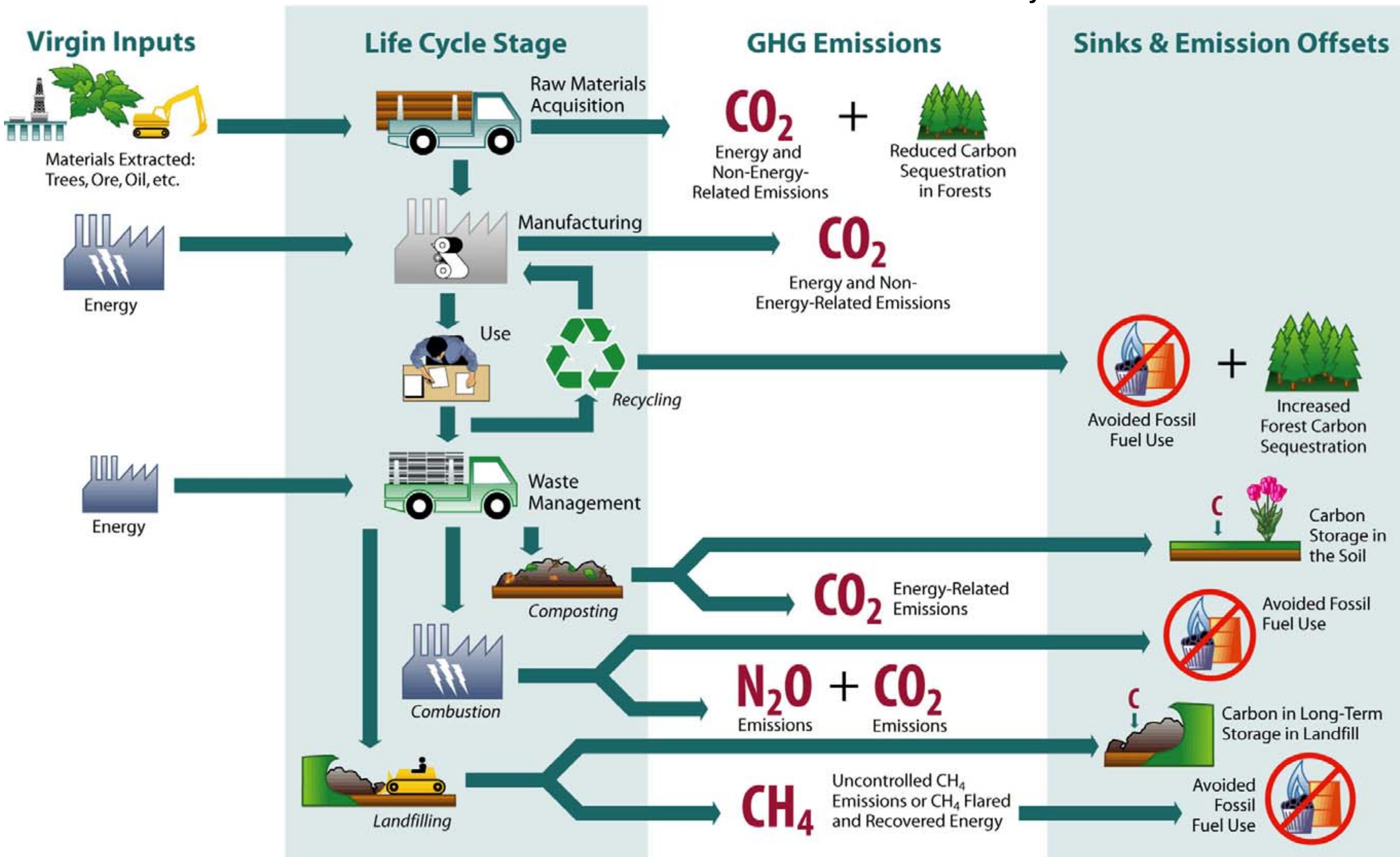
or reuse of a product. EPA did not analyze source reduction through material substitution (except in the special case of fly ash)—e.g., substituting plastic boxes for corrugated paper boxes. Nor did EPA estimate the potential for source reduction of chemical fertilizers and pesticides with increased production and use of compost. For a discussion of source reduction with material substitution, see Section 3.3.

Exhibit ES-3 Greenhouse Gas Sources and Sinks Associated with the Material Life Cycle



ES.6 RESULTS OF THE ANALYSIS

Management of municipal solid waste presents many opportunities for GHG emission reductions. Source reduction and recycling can reduce GHG emissions at the manufacturing stage, increase forest carbon sequestration, and avoid landfill CH_4 emissions. When waste is combusted, energy recovery displaces electricity generated by utilities by burning fossil fuels (thus reducing GHG emissions from the utility sector), and landfill CH_4 emissions are avoided. Landfill CH_4 emissions can be reduced by using gas recovery systems and by diverting organic materials from landfills. Landfill CH_4 can be flared or utilized for its energy potential. When used for its energy potential, landfill CH_4 displaces fossil fuels, as with MSW combustion.

In order to support a broad portfolio of climate change mitigation activities covering a range of GHGs, various methodologies for estimating emissions are needed. The primary result of this research is the development of material-specific GHG emission factors that can be used to account for the climate change benefits of waste management practices.

Exhibit ES-4 presents the GHG impacts of source reduction, recycling, composting, combustion, and landfilling. The impacts are calculated per short ton of waste managed. Please note that the emission factors presented in this report are intended to be compared with one another. They are not meant to reflect absolute values, but instead reflect the impact of choosing one waste management option over another for a given material type. This convention enabled EPA to calculate emission impacts from a waste generation reference point (i.e., from the moment a material is discarded). This process is in contrast to a typical life-cycle analysis, which reflects a raw materials extraction reference point. “Upstream” emissions and sinks are captured in EPA’s streamlined methodology once a baseline waste management practice is compared to an alternative waste management practice.

In addition, this report does not include emissions from the use phase of a product’s life, since use does not have an effect on the waste management emissions of a product. EPA took this approach because expert review of the first edition indicated that a waste management perspective would be more useful and comprehensible to waste managers, at whom this report is chiefly aimed.[27] The results are the same in the end, because it is the difference between the baseline and the alternative waste disposal scenarios that show the GHG savings from different treatment options; therefore, all tables and analyses in this report use a “waste generation” reference point. Exhibit ES-4 presents these values in MTCE/short ton of waste.[28] In these tables, emissions for 1 ton of a given material are presented across different management options. The life-cycle GHG emissions for each of the first four waste management strategies—source reduction, recycling, composting, and combustion—are compared to the GHG emissions from landfilling in Exhibit ES-5. These exhibits show the GHG values for each of the first four management strategies, minus the GHG values for landfilling. With these exhibits, one may compare the GHG emissions of changing management of 1 ton of each material from landfilling (often viewed as the baseline waste management strategy) to one of the other waste management options.

All values shown in Exhibit ES-4 and Exhibit ES-5 are for national average conditions (e.g., average fuel mix for raw material acquisition and manufacturing using recycled inputs; typical efficiency of a mass burn combustion unit; and national average landfill gas collection rates). GHG emissions are sensitive to some factors that vary on a local basis, and thus site-specific emissions will differ from those summarized here.

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[27] For the same results using a raw material extraction reference point, please see Appendix A.

[28] For the same results in $MTCO_2E$, please see Appendix B.

Following is a discussion of the principal GHG emissions and sinks for each waste management practice and the effect that they have on the emission factors:

- Source reduction, in general, represents an opportunity to reduce GHG emissions in a significant way. For many materials, the reduction in energy-related CO_2 emissions from the raw material acquisition and manufacturing process, and the absence of emissions from waste management, combine to reduce GHG emissions more than other options do.
- For most materials, recycling represents the second best opportunity to reduce GHG emissions. For these materials, recycling reduces energy-related CO_2 emissions in the manufacturing process (although not as dramatically as source reduction) and avoids emissions from waste management. Paper recycling increases the sequestration of forest carbon.
- Composting is a management option for food discards and yard trimmings. The net GHG emissions from composting are lower than landfilling for food discards (composting avoids CH_4 emissions), and higher than landfilling for yard trimmings (landfilling is credited with the carbon storage that results from incomplete decomposition of yard trimmings). Overall, given the uncertainty in the analysis, the emission factors for composting or combusting these materials are similar.
- The net GHG emissions from combustion of mixed MSW are lower than landfilling mixed MSW (under national average conditions for landfill gas recovery). Combustors and landfills manage a mixed waste stream; therefore, net emissions are determined more by technology factors (e.g., the efficiency of landfill gas collection systems and combustion energy conversion) than by material specificity. Material-specific emissions for landfills and combustors provide a basis for comparing these options with source reduction, recycling, and composting.

Exhibit ES-4
Net GHG Emissions from Source Reduction and MSW Management Options (MTCE/Ton)[a]

Material	Source Reduction[b]	Recycling	Composting	Combustion[c]	Landfilling[d]
Aluminum Cans	-2.24	-3.70	NA	0.02	0.01
Steel Cans	-0.87	-0.49	NA	-0.42	0.01
Copper Wire	-2.00	-1.34	NA	0.01	0.01
Glass	-0.16	-0.08	NA	0.01	0.01
HDPE	-0.49	-0.38	NA	0.25	0.01
LDPE	-0.62	-0.46	NA	0.25	0.01
PET	-0.57	-0.42	NA	0.30	0.01
Corrugated Cardboard	-1.52	-0.85	NA	-0.18	0.11
Magazines/Third-class Mail	-2.36	-0.84	NA	-0.13	-0.08
Newspaper	-1.33	-0.76	NA	-0.20	-0.24
Office Paper	-2.18	-0.78	NA	-0.17	0.53
Phonebooks	-1.72	-0.72	NA	-0.20	-0.24
Textbooks	-2.50	-0.85	NA	-0.17	0.53
Dimensional Lumber	-0.55	-0.67	NA	-0.21	-0.13
Medium-density Fiberboard	-0.60	-0.67	NA	-0.21	-0.13
Food Discards	NA	NA	-0.05	-0.05	0.20
Yard Trimmings	NA	NA	-0.05	-0.06	-0.06
Mixed Paper					
Broad Definition	NA	-0.96	NA	-0.18	0.09
Residential Definition	NA	-0.96	NA	-0.18	0.07
Office Paper Definition	NA	-0.93	NA	-0.16	0.13
Mixed Metals	NA	-1.43	NA	-0.29	0.01
Mixed Plastics	NA	-0.41	NA	0.27	0.01
Mixed Recyclables	NA	-0.79	NA	-0.17	0.04
Mixed Organics	NA	NA	-0.05	-0.05	0.06
Mixed MSW as Disposed	NA	NA	NA	-0.03	0.12
Carpet	-1.09	-1.96	NA	0.11	0.01
Personal Computers	-15.13	-0.62	NA	-0.05	0.01
Clay Bricks	-0.08	NA	NA	NA	0.01
Concrete	NA	0.00	NA	NA	0.01
Fly Ash	NA	-0.24	NA	NA	0.01
Tires	-1.09	-0.50[e]	NA	0.05	0.01

Note that totals may not add due to rounding, and more digits may be displayed than are significant.

NA: Not applicable, or in the case of composting of paper, not analyzed.

[a] MTCE/ton: Metric tons of carbon equivalent per short ton of material. Material tonnages are on an as-managed (wet weight) basis.

[b] Source reduction assumes initial production using the current mix of virgin and recycled inputs.

[c] Values are for mass burn facilities with national average rate of ferrous recovery.

[d] Values reflect estimated national average CH_4 recovery in year 2003.

[e] Recycling of tires, as modeled in this analysis, consists only of retreading the tires.

Exhibit ES-5
GHG Emissions of MSW Management Options Compared to Landfilling (MTCE/Ton)[a]
(Management Option Net Emissions Minus Landfilling Net Emissions)

Material	Source Reduction[b] (Current Mix)	Source Reduction (100% Virgin Inputs)	Recycling	Composting[c]	Combustion[d]
Aluminum Cans	-2.26	-4.28	-3.71	NA	0.01
Steel Cans	-0.88	-1.02	-0.50	NA	-0.43
Copper Wire	-2.01	-2.03	-1.35	NA	0.00
Glass	-0.17	-0.19	-0.09	NA	0.00
HDPE	-0.50	-0.55	-0.39	NA	0.24
LDPE	-0.63	-0.65	-0.47	NA	0.24
PET	-0.58	-0.60	-0.43	NA	0.28
Corrugated Cardboard	-1.63	-2.32	-0.96	NA	-0.29
Magazines/Third-class Mail	-2.28	-2.36	-0.76	NA	-0.05
Newspaper	-1.09	-1.39	-0.52	NA	0.03
Office Paper	-2.71	-2.79	-1.31	NA	-0.70
Phonebooks	-1.49	-1.49	-0.49	NA	0.03
Textbooks	-3.03	-3.11	-1.38	NA	-0.70
Dimensional Lumber	-0.42	-0.42	-0.54	NA	-0.08
Medium-density Fiberboard	-0.47	-0.47	-0.54	NA	-0.08
Food Discards	NA	NA	NA	-0.25	-0.25
Yard Trimmings	NA	NA	NA	0.01	0.00
Mixed Paper					
Broad Definition	NA	NA	-1.06	NA	-0.27
Residential Definition	NA	NA	-1.03	NA	-0.25
Office Paper Definition	NA	NA	-1.06	NA	-0.29
Mixed Metals	NA	NA	-1.44	NA	-0.30
Mixed Plastics	NA	NA	-0.42	NA	0.26
Mixed Recyclables	NA	NA	-0.83	NA	-0.20
Mixed Organics	NA	NA	NA	-0.12	-0.12
Mixed MSW as Disposed	NA	NA	NA	NA	-0.15
Carpet	-1.10	-1.10	-1.97	NA	0.10
Personal Computers	-15.14	-15.14	-0.63	NA	-0.06
Clay Bricks	-0.09	-0.09	-0.01	NA	-0.01
Concrete	-0.01	-0.01	-0.01	NA	-0.01
Fly Ash	-0.01	-0.01	-0.25	NA	-0.01
Tires	-1.10	-1.10	-0.51[e]	NA	0.04

Note that totals may not add due to rounding, and more digits may be displayed than are significant.

NA: Not applicable, or in the case of composting of paper, not analyzed.

[a] Values for landfilling reflect projected national average CH_4 recovery in year 2003.

[b] Source reduction assumes initial production using the current mix of virgin and recycled inputs.

[c] Calculation is based on assuming zero net emissions for composting.

[d] Values are for mass burn facilities with national average rate of ferrous recovery.

[e] Recycling of tires, as modeled in this analysis, consists only of retreading the tires.

The ordering of combustion, landfilling, and composting is affected by (1) the GHG inventory accounting methods, which do not count CO_2 emissions from sustainable biogenic sources,[29] but do count emissions from sources such as plastics; and (2) a series of assumptions on sequestration, future use of CH_4 recovery systems, system efficiency for landfill gas recovery, ferrous metal recovery, and avoided utility fossil fuels. On a site-specific basis, the ordering of results between a combustor and a landfill could be different from the ordering provided here, which is based on national average conditions.

EPA conducted sensitivity analyses to examine the GHG emissions from landfilling under varying assumptions about (1) the percentage of landfilled waste sent to landfills with gas recovery, and (2) CH_4 oxidation rate and gas collection system efficiency. The sensitivity analyses demonstrate that the results for landfills are very sensitive to these factors, which are site-specific.[30] Thus, using a national average value when making generalizations about emissions from landfills masks some of the variability that exists from site to site.

The scope of this report is limited to developing emission factors that can be used to evaluate GHG implications of solid waste decisions. EPA does not analyze policy options in this report. Nevertheless, the differences in emission factors across various waste management options are sufficiently large as to imply that GHG mitigation policies in the waste sector can make a significant contribution to U.S. emission reductions. A number of examples, using the emission factors in this report, illustrate this point.

- At the firm level, targeted recycling programs can reduce GHGs. For example, a commercial facility that shifts from (a) a baseline practice of landfilling (in a landfill with no gas collection system) 50 tons office paper and 4 tons of aluminum cans to (b) recycling the same materials can reduce GHG emissions by more than 100 MTCE.
- At the community level, a city of 100,000 with average waste generation (4.5 lbs/day per capita), recycling (30 percent), and baseline disposal in a landfill with no gas collection system could increase its recycling rate to 40 percent—for example, by implementing a pay-as-you-throw program—and reduce emissions by more than 3,400 MTCE per year. (Note that further growth in recycling would be possible; some communities already are exceeding recycling rates of 50 percent).
- A city of 1 million, disposing of 650,000 tons per year in a landfill without gas collection, could reduce its GHG emissions by about 260,000 MTCE per year by managing waste in a mass burn combustor unit.
- A town of 50,000 people landfilling a total of 30,000 tons per year could install a landfill gas recovery system with electricity generation and reduce emissions by about 13,500 MTCE per year.
- At the national level, if the United States attains the goal of a 35 percent recycling rate by 2008, emissions will be nearly 59 million MTCE per year lower than if no recycling took place.

[29] Sustainable biogenic sources include paper and wood products from sustainably managed forests. When these materials are burned or aerobically decomposed to CO_2, the CO_2 emissions are not counted. The approach to measuring GHG emissions from biogenic sources is described in detail in Chapter 1.
[30] For details on the sensitivity analyses, see section 6.5 and Exhibits 6-7 and 6-8.

ES.7 OTHER LIFE-CYCLE GHG ANALYSES AND TOOLS

Life-cycle analysis is being used increasingly to quantify the GHG impacts of private and public sector decisions. In addition to the life-cycle analyses that underpin the emission factors in this report, Environmental Defense,[31] ICLEI, Ecobilan, and others have analyzed the life-cycle environmental impacts of various industry processes (e.g., manufacturing) and private and public sector practices (e.g., waste management). In many cases, the results of life-cycle analyses are packaged into software tools that distill the information according to a specific user's needs.

ICF International worked with EPA to create the WARM, ReCon, and DGC tools, in addition to researching and writing this report, and creating the emission factors used here and in the tools. As mentioned earlier, WARM was designed as a tool for waste managers to weigh the GHG and energy impacts of their waste management practices. As a result, the model focuses exclusively on waste sector GHG emissions, and the methodology used to estimate emissions is consistent with international and domestic GHG accounting guidelines. Life-cycle tools designed for broader audiences necessarily include other sectors and/or other environmental impacts, and are not necessarily tied to the Intergovernmental Panel on Climate Change (IPCC) guidelines for GHG accounting or the methods used in the *Inventory of U.S. Greenhouse Gas Emissions and Sinks*.

- WARM is an EPA model that enables users to input several key variables (e.g., landfill gas collection system information, electric utility fuel mix, and transportation distances).[32] The model covers 34 types of materials and five waste management options: source reduction, recycling, combustion, composting, and landfilling. WARM accounts for upstream energy and nonenergy emissions, transportation distances to disposal and recycling facilities, carbon sequestration, and utility offsets that result from landfill gas collection and combustion. The tool provides participants in DOE's 1605(b) program with the option to report results by year, by gas, and by year and gas (although under 1605(b)'s revised guidelines, avoided emissions from recycling must be reported separately under "other indirect emissions" and not included in the main corporate inventory). WARM software is available free of charge in both a Web-based calculator format and a Microsoft® Excel spreadsheet. The tool is ideal for waste planners interested in tracking and reporting voluntary GHG emission reductions from waste management practices and for comparing the climate change impacts of different approaches. To access the tool, visit: http://www.epa.gov/mswclimate, then follow link to Tools.
- Recycled Content (ReCon) Tool was created by EPA to help companies and individuals estimate life-cycle GHG emissions and energy impacts from purchasing and/or manufacturing materials with varying degrees of postconsumer recycled content. The tool covers 17 material types and an analysis of baseline and alternative recycled-content scenarios. ReCon accounts for total "upstream" GHG emissions based on manufacturing processes, carbon sequestration, and avoided disposal that are related to the manufacture of the materials with recycled content. ReCon also accounts for the total energy (based on manufacturing processes and avoided disposal) related to the manufacture of materials with recycled content. The tool is ideal for companies and individuals who want to calculate GHG emissions and energy consumption associated with purchasing and manufacturing using baseline and alternate recycled-content scenarios. To access the tool, visit: http://www.epa.gov/mswclimate, then follow link to Tools.

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[31] Blum, L., Denison, R.A., and Ruston, V.F. 1997. A Life-Cycle Approach to Purchasing and Using Environmentally Preferable Paper: A Summary of the Paper Task Force Report," *Journal of Industrial Ecology*. I:3:15-46. Denison, R.A. 1996. "Environmental Life-Cycle Comparison of Recycling, Landfilling, and Incineration: A Review of Recent Studies"; *Annual Review of Energy and the Environment* 21:6:191-237.

[32] Microsoft Excel and Web-based versions of this tool are available online at the following website: http://www.epa.gov/globalwarming/actions/waste/tools.html.

- Durable Goods Calculator (DGC) is an EPA model that enables users to calculate the GHG emission and energy implications for various disposal methods of durable goods. The model covers 14 types of durable goods and three waste management options: recycling, landfilling, and combustion. The Durable Goods Calculator was developed for individuals and companies that want to make an informed decision on the GHG and energy impact of disposing of durable household goods. To access the tool, visit: http://www.epa.gov/mswclimate, then follow link to Tools.
- ICLEI Cities for Climate Protection (CCP) Campaign Greenhouse Gas Emission Software was developed by Torrie Smith Associates for ICLEI. This Windows™-based tool, targeted for use by local governments, can analyze emissions and emission reductions on a community-wide basis and for municipal operations alone. The community-wide module looks at residential, commercial, and industrial buildings; transportation activity; and community-generated waste. The municipal operations module looks at municipal buildings, municipal fleets, and waste from municipal in-house operations. In addition to computing GHG emissions, the CCP software estimates reductions in criteria air pollutants, changes in energy consumption, and financial costs and savings associated with energy use and other emission reduction initiatives. A version of the software program was made available for use by private businesses and institutions during the summer of 2001. CCP software subscriptions, including technical support, are available to governments participating in the program. For more information, visit: http://www.iclei.org/ or contact the U.S. ICLEI office at 510– 844–0699, iclei_usa@iclei.org.
- The MSW Decision Support Tool (DST) and life-cycle inventory database for North America have been developed through funding by ORD through a cooperative agreement with the Research Triangle Institute (CR823052). The methodology is based on a multimedia, multipollutant approach and includes analysis of GHG emissions as well as a broader set of emissions (air, water, and waste) associated with MSW operations. The MSW-DST is available for site-specific applications and has been used to conduct analyses in several states and 15 communities, including use by the U.S. Navy in the Pacific Northwest. The tool is intended for use by solid waste planners at state and local levels to analyze and compare alternative MSW management strategies with respect to cost, energy consumption, and environmental releases to the air, land, and water. The costs are based on full cost accounting principles and account for capital and operating costs using an engineering economics analysis. The MSW-DST calculates not only projected emissions of GHGs and criteria air pollutants, but also emissions of more than 30 air- and water-borne pollutants. The DST models emissions associated with all MSW management activities, including waste collection and transportation, transfer stations, materials recovery facilities, compost facilities, landfills, combustion and refuse-derived fuel facilities, utility offsets, material offsets, and source reduction. The differences in residential, multifamily, and commercial sectors can be evaluated individually. The software has optimization capabilities that enable one to identify options that evaluate minimum costs as well as solutions that can maximize environmental benefits, including energy conservation and GHG reductions.

  At the time of the publication of this report, the LCI database for North America was expected to be released in early- to mid-2006. The DST will be available on the Web. The MSW-DST provides extensive default data for the full range of MSW process models and requires minimum input data. However, these defaults can be tailored to the specific communities using site-specific information. The MSW-DST also includes a calculator for source reduction and carbon sequestration using a methodology that is consistent with the IPCC in terms of the treatment of biogenic CO_2 emissions. For more information, refer to the project website: http://www.rti.org/, then search the term "DST," or contact Keith Weitz, Research Triangle Institute, 919–541–6973, kaw@rti.org.

Comparison of EPA/ORD and EPA/OSW Emission Factors

An effort to harmonize previous life-cycle emission factors with the results of work by EPA's Office of Research and Development (ORD) was conducted in October 2000. Noticing significant differences in our bottom line emission factors, EPA compared a range of assumptions, including energy consumption, fuel mix, loss rates, landfill oxidation rate, timing of landfill methane emissions, fraction of landfill gas collected, electricity mix, transportation distances, and carbon storage. The comparison of energy intensities and fuel mixes included process and transportation energy for virgin and recycled production of each material type. Because the previous Office of Solid Waste (OSW) energy values were based on an average of Franklin Associates, Ltd. (FAL) and Tellus data, EPA compared the ORD values to the FAL data, Tellus data, and average of FAL and Tellus data.

This comparison revealed that the differences between the OSW and ORD emission factors are mostly attributable to the different assumptions about energy consumption (i.e., the sum of precombustion, process, and transportation energy), fuel mix, and loss rates. In general, it was found that ORD's total energy values are lower than OSW's energy values for both virgin and recycled materials. Comparing fuel mix, EPA found the most significant differences occurring for electricity, coal, natural gas, and "other" fuel types comprising process energy. The fractions of diesel fuel, residual fuel, and natural gas exhibited the greatest disparities for transportation energy. The comparison of loss rates, which are used to develop the recycling emission factors, showed significant variation for office paper, steel cans, and, to a lesser extent, newspaper.

In an effort to reconcile the remaining differences between ORD and OSW estimates of GHG emissions from the acquisition of raw materials and their manufacture into products, EPA identified additional methodological differences that could be affecting the recycling numbers. In particular, EPA found that ORD simulates closed-loop recycling for all materials, while OSW assumes open-loop recycling for office paper and corrugated cardboard. EPA also found that ORD's estimates do not include non-energy process emissions from perfluorocarbons (PFCs). To isolate any remaining differences between the two analyses, EPA substituted ORD energy intensities, fuel mixes, and loss rates into the OSW model.

Once all methodological differences between ORD and OSW estimates for raw materials acquisition and manufacturing had been identified and resolved, EPA selected the material types for which ORD data could be substituted for the existing OSW data: glass, HDPE, LDPE, PET, corrugated cardboard, magazines/third-class mail, newspaper, office paper, phonebooks, and textbooks. For wood products, ORD did not develop emission factors, while for steel its data was not sufficiently disaggregated to replace the existing OSW data.

- The Tool for Environmental Analysis and Management (TEAM), developed by Ecobilan, simulates operations associated with product design, processes, and activities associated with several industrial sectors. The model considers energy consumption, material consumption, transportation, waste management, and other factors in its evaluation of environmental impacts. For more information, visit: http://www.ecobalance.com/uk_team.php.

ES.8 LIMITATIONS OF THE ANALYSIS

When conducting this analysis, EPA used a number of analytical approaches and numerous data sources, each with its own limitations. In addition, EPA made and applied assumptions throughout the analysis. Although these limitations would be troublesome if used in the context of a regulatory framework, EPA believes that the results are sufficiently accurate to support their use in voluntary programs. Some of the major limitations include the following:

- The manufacturing GHG analysis is based on estimated industry averages for energy usage, and in some cases the estimates are based on limited data. In addition, EPA used values for the average GHG emissions per ton of material produced, not the marginal emission rates per incremental ton produced. In some cases, the marginal emission rates may be significantly different.

- The forest carbon sequestration analysis deals with a very complicated set of interrelated ecological and economic processes. Although the models used represent the state-of-the-art in forest resource planning, their geographic scope is limited. Because of the global market for forest products, the actual effects of paper recycling would occur not only in the United States but in Canada and other countries. Other important limitations include: (1) the model assumes that no forested lands will be converted to nonforest uses as a result of increased paper recycling; and (2) EPA uses a point estimate for forest carbon sequestration, whereas the system of models predicts changing net sequestration over time.
- The composting analysis considers a small sampling of feedstocks and a single compost application (i.e., agricultural soil). The analysis did not consider the full range of soil conservation and management practices that could be used in combination with compost and their impacts on carbon storage.
- The combustion analysis uses national average values for several parameters; variability from site to site is not reflected in the estimate.
- The landfill analysis (1) incorporates some uncertainty on CH_4 generation and carbon sequestration for each material type, due to limited data availability; and (2) uses estimated CH_4 recovery levels for the year 2003 as a baseline.

Finally, throughout most of the report, EPA expresses analytical inputs and outputs as point estimates. EPA recognizes that a rigorous treatment of uncertainty and variability would be useful, but in most cases the information needed to treat these in statistical terms is not available. The report includes some sensitivity analyses to illustrate the importance of selected parameters and expresses ranges for a few other factors such as GHG emissions from manufacturing. EPA encourages readers to provide more accurate information where it is available; perhaps with additional information, future versions of this report will be able to shed more light on uncertainty and variability. Meanwhile, EPA cautions that the emission factors reported here should be evaluated and applied with an appreciation for the limitations in the data and methods, as described at the end of each chapter.