WASTE MANAGEMENT AND ENERGY SAVINGS: BENEFITS BY THE NUMBERS

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The environmental impacts of waste management are more far-reaching than you may think. In addition to affecting soil, water, and air quality, waste management practices have impacts on energy consumption. In 2003, the United States generated just over 236 million tons of municipal solid waste (MSW). If this waste was managed with energy implications in mind, significant energy savings could be achieved.

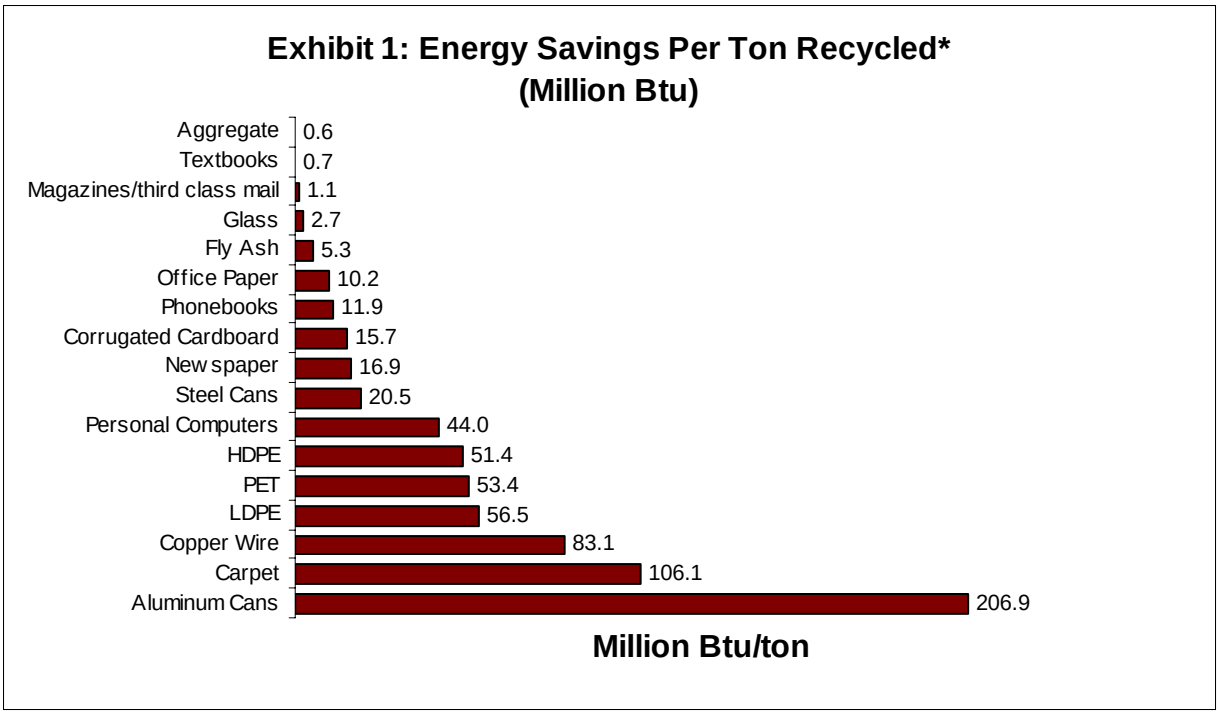
Products that enter the waste stream have energy impacts (and associated GHG emissions) at each stage of their life cycle. These stages include: the acquisition of raw materials, the manufacture of raw materials into products, product use by consumers, and product disposal. Waste *reduction* practices, such as recycling and reuse, reduce the demand for raw material and energy inputs to the manufacturing stage of the life cycle, thereby conserving energy and reducing GHG emissions. Energy savings can also result from waste *disposal* practices, such as waste combustors and landfill gas to energy systems.

Since the energy implications of waste management practices for specific products accrue throughout the life cycle, product-specific energy factors typically require a life-cycle analysis to quantify. During the 1990's EPA began an ongoing analysis of the life-cycle greenhouse gas (GHG) impacts of waste management activities. This GHG research was initially presented in a 1999 EPA report and was subsequently updated in a 2002 report entitled "Solid Waste Management and Greenhouse Gases: A Life-Cycle Assessment of Emissions and Sinks" (EPA530-R-02-006). These reports used detailed life-cycle information on specific products and material types to generate GHG emission factors for five waste management practices—source reduction, recycling, composting, combustion, and landfilling. The purpose of this research was to aid waste planners in assessing the benefits of waste reduction activities (e.g., recycling, source reduction) as compared to traditional waste disposal practices (e.g., combustion, landfilling) from a GHG perspective. The research underpinning the report continues today; since the completion of the 2002 report, EPA has developed GHG factors for nine additional materials: copper wire, grass, leaves, branches, carpet, personal computers, clay bricks, aggregate, and fly ash.

The quantification of energy related emissions are an important element of the streamlined life-cycle analysis conducted in the GHG report, thus EPA already had available the necessary life-cycle data to develop energy factors for improved waste management at the commodity level. The remainder of this paper presents the results of EPA's efforts to extract the life-cycle energy implications of waste management practices from the overall GHG research mentioned above; puts the energy impacts in perspective with respect to overall GHG impacts; and applies these energy emission factors to estimate the energy savings that could be achievable at a national scale through improved waste management practices.

Energy Implications of Waste Management Practices

Using life-cycle data from its GHG emissions research effort, EPA developed energy factors that capture the energy impacts of waste management measures. Exhibit 1 presents energy savings associated with recycling a selection of materials in units of British thermal units (Btu) per ton. As the exhibit indicates, the energy impacts vary significantly by material type, but recycling results in some energy savings for all of these materials.



* Assumes recycled materials would otherwise have been landfilled. Includes embedded energy.

Energy savings associated with recycling various materials are driven largely by the difference between manufacturing the material using virgin inputs and manufacturing the material using recycled inputs. As you can see in Exhibit 1, recycling aluminum cans results in the most significant energy savings per ton. These savings reflect the nature of aluminum production; manufacturing aluminum cans from virgin inputs is very energy intensive, whereas relatively little energy is required to manufacture cans from recycled aluminum.

Exhibit 2 (on the next page) presents the net energy factors for four waste management options: source reduction, recycling, combustion, and landfilling. Energy impacts are shown in Million Btu per ton of material; negative values indicate net energy savings. These energy factors are based on direct fossil fuel and electricity consumption associated with raw material acquisition and manufacturing; electricity offsets; fossil fuel consumption for transportation; and embedded energy.

As the exhibit indicates, waste reduction efforts such as source reduction and recycling can result in significant energy savings. Source reduction techniques, such as double-sided copying and light-weighting, are in most cases more effective at reducing energy than recycling. This is because source reduction significantly reduces energy consumption associated with raw material extraction and manufacturing processes.

Since these energy factors are based on a life-cycle analysis, they must be utilized by comparing different scenarios against each other. To evaluate the energy impacts of different waste management practices you must subtract the energy consumed in a baseline disposal scenario from energy that would be consumed in an alternate disposal scenario. As Exhibit 3 demonstrates, someone interested in understanding the energy benefits of recycling aluminum cans could subtract the energy impact of landfilling 1 ton of aluminum cans from the energy impact of recycling 1 ton of aluminum cans. The

Exhibit 3: Estimating the Energy Impacts of Waste Reduction

Baseline: landfill 1 ton of aluminum cans
1 ton x 0.53 million Btu/ton = 0.53 million Btu

Alternate: recycle 1 ton of aluminum cans
1 ton x -206.42 million Btu/ton = -206.42 million Btu

Energy Savings:
-206.42 million Btu - 0.53 million Btu =
-206.9 million Btu

result would be the energy savings associated with the change in disposal practices from landfilling to recycling.

Exhibit 2: Energy Consumed/Avoided from MSW Management Options (Million Btu/Ton)

Material	Source Reduction for Current Mix of Inputs*	Recycling	Combustion	Landfilling
Aluminum Cans	-126.18	-206.42	0.12	0.53
Steel Cans	-30.79	-19.97	-17.54	0.53
Copper Wire	-122.31	-82.59	0.10	0.53
Glass	-7.53	-2.13	0.08	0.53
HDPE	-63.68	-50.90	-6.66	0.53
LDPE	-73.92	-56.01	-6.66	0.53
PET	-70.67	-52.83	-3.46	0.53
Corrugated Cardboard	-21.91	-15.42	-2.21	0.30
Magazines/third class mail	-33.21	-0.69	-1.58	0.44
Newspaper	-36.45	-16.49	-2.54	0.45
Office Paper	-36.58	-10.08	-2.13	0.13
Phonebooks	-39.87	-11.42	-2.54	0.45
Textbooks	-35.30	-0.53	-2.13	0.13
Dimensional Lumber	-3.53	0.59	-2.66	0.41
Medium Density Fiberboard	-11.51	0.86	-2.66	0.41
Food Scraps**	NA	0.58	-0.55	0.38
Yard Trimmings**	NA	0.58	-0.70	0.44
Grass**	NA	0.58	-0.70	0.48
Leaves**	NA	0.58	-0.70	0.43
Branches**	NA	0.58	-0.70	0.41
Mixed Paper				
Broad Definition	NA	-22.94	-2.22	0.31
Residential Definition	NA	-22.94	-2.21	0.32
Office Paper Definition	NA	-13.95	-2.02	0.31
Mixed Metals	NA	-102.99	0.39	0.53
Mixed Plastics	NA	-52.42	-5.09	0.53
Mixed Recyclables	NA	-16.91	-2.06	0.36
Mixed Organics**	NA	0.58	-0.58	0.41
Mixed MSW	NA	NA	-1.49	0.33
Carpet	-61.68	-105.58	-4.78	0.53
Personal Computers	-950.16	-43.43	-0.55	0.53
Clay Bricks	-5.13	NA	NA	0.53
Aggregate	NA	-0.11	NA	0.53
Fly Ash	NA	-4.77	NA	0.53

*"Current mix" refers to the current mix of virgin and recycled inputs. Most new materials are produced using some percentage of recycled inputs. These calculations account for this percentage, rather than assuming new products are produced from 100 percent virgin inputs. Embedded energy (e.g., energy content of the carbon anode used to make aluminum) is also included.
** For these materials, "recycling" values reflect energy consumption associated with composting. Energy is required to turn the compost piles and to transport the organics to a centralized composting facility.
"NA" indicates that an energy factor for this waste management option is not available for a given material type. Food scraps and yard trimmings (including grass, leaves, and branches) are not manufactured in a traditional sense and therefore cannot be source reduced (e.g., through light-weighting). There are no energy factors for source reducing "mixed" material types because source reduction tends to be material specific (i.e., it would be difficult to conceive of source reducing mixed reyclables). Aggregate and fly ash are byproducts of other processes; therefore, source reduction is not a waste management option for these materials. Clay bricks and mixed MSW are not typically recycled; therefore, there are no factors for recycling these materials. Because clay bricks, aggregate, and fly ash are not typically combusted, there are no energy factors for combusting these materials.

Energy Savings Compared to Total GHG Benefits

As noted above, the energy factors presented in this paper are derived from a life-cycle study focusing on GHG impacts. In that study, EPA analyzed both energy and non-energy related emissions.[1] In the study, energy and non-energy related emissions were combined to determine the overall GHG emission impacts from the production of one ton of a given material.

Energy-related emissions are primarily due to the combustion of fossil fuels for electricity generation, process heating, and transportation components of the manufacturing process. The energy GHG emissions are a product of the energy requirements by fuel type (e.g., 20 million Btu of diesel fuel) to manufacture the material, and the carbon content of each fuel type. The fraction of overall GHG emission benefits derived from energy savings varies dramatically by material type. Exhibit 4 shows (1) the GHG emission impacts of recycling and landfilling aluminum and (2) the GHG emission impacts broken down into energy and non-energy related components.

As shown in Exhibit 4, energy-related savings account for 78 percent of the overall GHG benefits of recycling aluminum, or 3.19 Metric Tons of Carbon Equivalent (MTCE)/ton. Exhibit 5 shows that the results for PET are even higher (95 percent). In other words the GHG emission benefits associated with recycling PET compared to landfilling are almost exclusively attributable to energy consumption. Exhibit 5 also shows that the energy related benefits of recycling newspaper account for roughly 30 percent of the overall GHG emission benefits. This is because the forest carbon sequestration benefits of recycling newspaper greatly overshadow the energy-related impacts. Negative values indicate an increase in energy emissions associated with recycling.[2]

Exhibit 4: Estimating the Energy-Related GHG Emission Impacts of Recycling Aluminum

Recycling: 1 ton of aluminum cans = -4.07 Metric Tons of Carbon Equivalent (MTCE)/ton
- → Energy related emission impact = -3.18 MTCE/ton
- → Non-energy related emission impact = -0.9 MTCE/ton

Landfilling: 1 ton of aluminum cans = 0.01 MTCE/ton
- → Energy related emission impact = 0.01 MTCE/ton
- → Non-energy related emission impact = 0.0 MTCE/ton

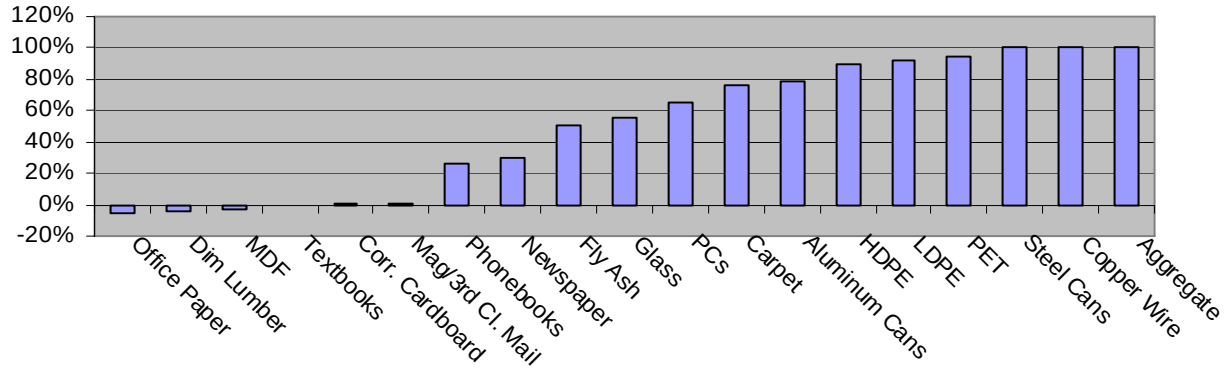
GHG Emission Benefits (Energy and Non-Energy): -4.07MTCE/ton - 0.01 MTCE/ton = -4.08 MTCE/ton

Energy-related GHG emission benefits: -3.18 MTCE/ton - 0.01 MTCE/ton = -3.19 MTCE/ton
Percent of GHG emission benefits related to energy consumption = (-3.19/-4.08) = 78%

[1] An example of an energy-related process that results in GHG emissions is a manufacturing step that requires direct heating through the combustion of fuel oil. An example of a non-energy related process that results in GHG emissions is aluminum smelting and the related perfluorocarbon (PFC) emissions.

[2] Recycling office paper does result in a slight energy savings (10 MMBtu), but because the fuel mix for recycled production (fossil-fuel based) is more GHG emission intensive than that for virgin production (largely biomass), a net increase in energy-related emissions occurs. According to international GHG accounting guidelines, emissions derived from biogenic sources (e.g., biomass) are not counted as they are believed to be part of the natural carbon cycle. For more information on why these emissions are not counted in GHG emission inventories, please see the text box on page 12 of "Solid Waste Management and Greenhouse Gases: A Life-Cycle Assessment of Emissions and Sinks" (EPA530-R-02-006). Recycled production of lumber and medium density fiberboard is more energy intensive than virgin production, which explains why values for these materials are slightly negative.

Exhibit 5: Recycling GHG Benefits Attributable to Energy Savings (Recycling vs. Landfilling)



Understanding Energy Equivalents

For many waste stakeholders, it is difficult to conceptualize Btu's of energy savings and MTCE's of GHG emissions reductions; therefore, energy savings and emissions reductions are frequently converted to common equivalents such as barrels of crude oil or gallons of gasoline. There are some nuances to interpreting these equivalencies that are important to consider. These nuances include converting from results in units of GHGs reduced to equivalent energy savings. This is complicated for two reasons: (1) GHG reductions reflect both energy and non-energy savings and (2) the energy savings reflect savings across a variety of fossil fuels. Thus, converting from total GHG reductions to an equivalency for "barrels of oil" must be done with caution.

Although energy savings are often the driving force behind GHG emissions savings, it would not be accurate to directly convert overall GHG emission benefits into energy consumption equivalents. Equivalencies must remain consistent within the energy or GHG emission context in which they were originally created. As shown in Exhibit 5, energy consumption only accounts for a fraction of the emission benefits associated with recycling newspaper. Because the GHG benefits of newspaper recycling consist of some energy and some non-energy-related savings, this material type demonstrates the difficulties of converting GHG savings to energy equivalents. When the total GHG benefits of recycling newspaper are converted to barrels of oil using the common equivalency factors, the *GHG emission benefits* are equivalent to GHG emissions from the combustion of 622 barrels of oil. In contrast, the *energy savings* associated with recycling newspaper are equivalent to the energy content of 292 barrels of oil.

Equivalency Example:

Recycling 100 tons of Newspaper Compared to Landfilling

GHG Emission Benefits: 73 MTCE

Equivalent to the combustion emissions from *622* barrels of oil.

Energy Savings: 1,693 Million Btu

Equivalent to the energy contained within *292* barrels of oil.

Understanding the differences between these values is very important. Similarly, because energy savings estimates are based on a diverse fuel mix (electricity, natural gas, petroleum, coal, etc.), the results do not mean that 292 barrels of oil will be avoided in the real world. The equivalency "barrels of oil" is simply utilized as a recognizable and understandable unit of energy. In the case of manufacturing newspaper, the primary energy sources are electricity and natural gas with only a fraction of the total energy derived from petroleum products.

Energy Benefits of National Recycling Efforts

The energy savings factors presented in Exhibit 2 can also be used to quantify national energy savings associated with recycling. In 2003, U.S. communities recycled an estimated 30.6 percent—72.3 million tons—of total municipal solid waste (MSW). EPA estimates that those recycling activities account for roughly 1,486 Trillion Btu in energy savings (compared to landfilling/combustion disposal[3])—an amount equivalent to the consumption of 11.9 billion gallons of gasoline or 256 million barrels of crude oil (see Exhibit 6 for common energy conversion factors).

If the U.S. recycling rate were to increase from the current 30.6 percent recovery scenario to 35 percent by 2008, energy savings would increase to an estimated 1,720 Trillion Btu—an amount equivalent to the consumption of 13.7 billion gallons of gasoline or 297 million barrels of crude oil. This increased energy savings would have the same effect as removing 27 million passenger cars from the roadway each year.

Exhibit 6: Common Energy Conversion Factors

Fuel:

Million Btu per Barrel of Oil:	5.8
Gallons Oil per Barrel of Oil:	42
Million Btu per Gallon of Gas:	0.125

Cars ("average" passenger car over one year):

Fuel Consumption (gallons of gas):	502
CO_2 Emissions (metric tons):	4.6

Communities nationwide are doing their part to conserve energy. The energy factors presented in this document demonstrate that conscientious waste management can lead to substantial energy savings as well as GHG emission reductions.

For more information on the climate change impacts of waste management, visit http://yosemite.epa.gov/oar/globalwarming.nsf/content/ActionsWaste.html.

[3] To calculate the total energy savings, the total amount of recycled MSW was segregated by material type and then distributed based on the typical non-recycling disposal scenario for the U.S. (i.e., 80% landfilled and 20% combusted) for the baseline scenario. The alternate scenario assumed this waste was recycled. The energy savings factors were applied to the waste generated for each material type in both scenarios using EPA's Waste Reduction Model (WARM). The difference of these two scenarios represents the theoretical energy savings of recycling.