The Monthly UnEconomist

Recycling versus Incineration: an Energy Conservation Analysis

Part 1

Issues of sustainability, energy efficiency, and other product lifecycle resource impacts need to be raised when discussing source reduction, reuse and recycling. Although we all are aware that the US will not run out of landfill disposal capacity anytime soon, continued disposal of the majority of solid waste poses a substantial and serious threat to Earth's ecosystems. This threat comes from the need to continually acquire new raw materials from those ecosystems to replace the used materials that we continue to throw away in incinerators and landfills.

This current and the two following issues of *The Monthly UnEconomist* serialize and summarize a Sound Resource Management study on energy conserved by recycling compared with energy generated from incinerating municipal solid waste (MSW), Morris, Jeffrey, and Diana Canzoneri, *Recycling Versus Incineration: An Energy Conservation Analysis*, prepared for Pollution Probe (Toronto, Ontario) and Work on Waste USA (Canton, NY) by Sound Resource Management, September 1992.[1] This study illustrates that even the energy recovered by incinerating MSW pales in comparison to the energy saved by recycling rather than burning wastes.

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Incinerating municipal solid waste in an energy-from-waste (EFW) facility recovers a portion of each waste material's heat value, typically as electrical energy. Recycling waste materials conserves energy by replacing virgin raw materials in manufacturing products, thereby reducing acquisition of virgin materials from the natural environment. At the same time, recycling removes materials, some of which have high intrinsic energy content (e.g., paper and plastic), from the stream of MSW available for EFW incineration. Thus, the question: Does recycling conserve more energy than EFW generates?

The analysis that follows shows that for twenty-four of twenty-five waste materials, recycling saves more energy than is produced by incinerating MSW in an EFW facility to generate electricity. This is because burning garbage to produce steam and spin turbines in EFW facilities captures only about 15% of each MSW material's intrinsic heat value. It is also because recycling saves substantial amounts of energy that would otherwise be expended extracting virgin materials (e.g., tree wood, petroleum, natural gas, and metal ores) from the natural environment and transforming them into manufactured products, goods that can also be manufactured from recycled waste materials.

Furthermore, energy conserved by recycling exceeds energy from EFW by enough to cover the additional energy used collecting and processing recycled materials, as well as energy needed for shipping recycled materials to markets. In fact, the estimates reported in this study are consistent with customary practices in the recycling industry. For example, recycled glass or compost made from yard or food wastes have lower energy savings and are typically used near the community from which they are recycled. But recycled paper, plastics, and aluminum cans have higher energy savings and often are shipped great distances to manufacturers of recycled-content products.

Methodological Issues and Simplifying Assumptions

In order to compare net energy consumed by manufacturing with recycled MSW materials against net energy consumed by manufacturing with virgin materials and disposing of recyclable MSW materials via EFW incineration, several crucial methodological issues are confronted. This section outlines these issues, beginning with the most difficult - drawing equivalent analytical boundaries around the virgin and recycled materials manufacturing systems.

1. Treatment of Direct Vs. Indirect Energy Requirements

The energy crunch during the 1970s produced many studies on ways to conserve energy, a number of which focused on using recycled waste materials as substitutes for virgin materials in manufacturing commonly used products, such as newsprint, aluminum cans, or glass food and beverage containers. These studies often had very different approaches to deciding what system boundaries would be used to define the energy consumption required to manufacture recycled- versus virgin-content products.

For example, an electric power utility might focus just on electricity purchased by a manufacturer using virgin material inputs, and compare that with the electricity purchased to produce the same product with recycled (secondary) materials.[2] A more comprehensive manufacturing energy calculation would include the full heat, light and power requirements of the production process, regardless of whether the energy source is electricity generated off-site or steam generated on-site by burning conventional fuels such as oil and coal. Energy consumed extracting, processing and transporting material inputs, whether virgin or secondary, might or might not be included in a study attempting to compute total energy required to manufacture a product.

In addition to energy used to obtain direct material inputs and energy used in the production process itself, energy is needed to make production machinery and buildings, feed humans involved in the various stages of production, make the machine tools used to make machines, make the machines used to make intermediate goods, manufacture the gloves used by a worker who made a machine tool used to make a machine ... *ad infinitum*. One needs vast amounts of data and complex calculations to reach across the industrial structure and back in time to sum up energy consumed in producing the cascade of direct and indirect inputs (including capital goods such as plant and equipment) used to manufacture a product.

Estimates reported in this paper include energy used to extract, process and transport major virgin or secondary materials used in manufacturing a product, as well as production process heat, light and power requirements, regardless of the source of that energy. Energy used to produce input materials that are only consumed in minor amounts in manufacturing a product typically is not counted. Indirect energy inputs, for example, energy used to make machines and buildings, or energy required to support the lifestyles of humans providing labor inputs, also are ignored.[3]

2. Treatment of Process Energy Derived from Raw Material Inputs

A second methodological problem is that some raw material inputs themselves have substantial intrinsic heat value and can be used to generate on-site power for the production process, rather than being incorporated entirely into the product itself. For example, chemically based wood pulping results in substantial wood residues and byproducts that can be used to generate steam power.[4] Thus, some virgin-content paper products use less externally purchased energy than their recycled-content counterparts, because much of the process energy is generated by burning residues from the chemical pulping of trees.[5]

Energy from these tree residues should be counted as part of total energy requirements for virgin-content paper products. This study, thus, counts all the intrinsic energy value of wood in trees used for virgin-content paper making as energy saved when manufacturing paper from recycled paper rather than trees.

3. Adjustment for Lower Electrical Generation Efficiency of EFW

Perfectly efficient generation of electricity would yield one kilowatt hour (kWh) for each 3596 kilojoules (kJ) of heating value in the input fuel. However, due to heat loss and mechanical inefficiencies in converting fuel energy to electricity, 10,807 kJ are typically required to produce a kWh from conventional fuels such as petroleum or coal.[6] This is an average efficiency of just 33% (= 3596/10807).

Converting MSW into electricity is even less efficient than converting conventional fuels into electrical energy. Electricity from MSW typically is generated by injecting seasonally changing, heterogeneous, and often wet mixed solid waste materials into a mass burn furnace.

The result is that only about 507 kWh of electricity are produced for each metric ton of garbage burned.

This electrical energy output is based on solid waste having an input heating value of about 12,100 kJ per kilogram (kg).[7] Thus, (12,100 kJ/kg x 1000 kg/metric ton =) 12.1 million kJ input heating value is required to produce (507 kWh/metric ton x 3596 kJ/kWh =) 1.8 million kJ output electrical energy per metric ton of waste. This is an input/output efficiency of just 15%.[8] In other words, almost 2 kilograms of waste, 23,820 kJ of input heating value from MSW, is necessary to generate one kWh.

To take into account the inefficiencies in burning solid waste to generate electricity versus burning a conventional fuel to generate electricity for a production process, heating values of waste stream materials are adjusted down by the ratio 10807/23820 = 45%. This yields heating values for EFW incineration of MSW materials that are comparable to heating values for energy inputs in manufacturing processes.

4. Treatment of Collection and Processing Energy for MSW and Recycling

Energy used to collect and haul MSW for incineration; to collect, haul and process MSW materials for recycling; and to transport processed recyclables to a manufacturing end user is accounted for separately from energy used to haul virgin materials to the manufacturing plant. For example, energy required to harvest trees and transport them to a pulping mill is accounted for in the net recycled versus virgin production energy calculation. But energy required to collect and process recycled paper and then transport it to a recycled paper mill is not included in the calculation of production energy conserved by recycling.

Rather, incremental energy necessary to collect recycled materials on a different truck than is used to collect garbage, energy used processing recyclables into commodities that can be used as manufacturing inputs, and energy required to transport recycled materials to manufacturers are used to determine how far recycled materials could be shipped before the energy savings from using recycled instead of virgin materials in manufacturing would be used up transporting them to market. Thus, transportation and processing energy usage are all taken into account for both recycling and incineration options; they just have been divided into two categories - manufacturing system and solid waste management system energy consumption. The hauling of recycled materials from waste generator to market and the processing of recycled materials are included in the latter category, and used to compute breakeven distance to market.

5. Calculation of Average Energy from Incineration Vs. Recycling

As indicated above, just over 500 kWh are generated by incinerating a metric ton of garbage at an EFW facility - a conventional fuel equivalent heating value of less than 5,500 kJ per kilogram (kg) of garbage. In Table 1 in Part 2 of this article in the March *UnEconomist*, the composition mix of Ontario's residential garbage is shown to yield over 6,100 kJ of conventional fuel equivalent heating value per kilogram. This is slightly higher than the heating value of waste typically received at incineration facilities, perhaps due to a different waste composition or, more likely, to the fact that heating values for individual waste materials were not adjusted to include the typical moisture content of mixed garbage. However, the difference is not critical to the results demonstrated by this study. In fact, adjusting these heating values down would just increase the amount by which recycling beats EFW in terms of energy efficiency.

What is important is to estimate average energy conserved by recycling and compare that estimate to the 5,500 or 6,100 kJ/kg of energy captured from garbage incinerated at an EFW facility. This study estimates this comparative figure by calculating the weighted average for energy conserved by manufacturing with recycled waste rather than virgin materials, where the weights are the relative proportions of waste materials in Ontario's residential waste stream.[9] Based on this calculation (which is explicitly reported in Table 1 in the March *UnEconomist*), recycling MSW materials on average conserves three to five times more energy than an EFW incinerator generates.

Finally, it is important to understand that comparing the weighted average for energy conserved by recycling with average energy generated by incineration does not imply that MSW must either be 100% recycled or 100% incinerated. The comparison is only meant to summarize the fact that for virtually every major waste material in MSW, recycling conserves more energy than is generated by incinerating that material in mixed garbage. However, the fact that twenty-four of twenty-five materials save more energy when recycled than they generate when burned does imply that, *ceteris paribus*, MSW materials should be recycled rather than incinerated whenever a choice is to be made between these two methods for managing MSW materials.[10]

About The Monthly UnEconomist

This monthly online newsletter available at www.SoundResource.com intends to provide insight and analysis on the everyday economics of recycling and the unpriced or underpriced environmental benefits of reducing waste disposal and replacing virgin-content products with products manufactured from recycled materials. Reader feedback is encouraged via email to info@ZeroWaste.com, and substantive comments will be published whenever they add to our understanding of recycling.

The *UnEconomist* also analyzes northwestern and northeastern U.S recycling market prices for nine recycled materials (mixed paper, ONP, OCC, glass containers, tin cans, UBC, PET bottles, HDPE natural bottles, and HDPE colored bottles) tracked by graphs available online at www.SoundResource.com. These graphs are updated at least quarterly. *The UnEconomist* will from time to time report on the accuracy of the annually updated five-year recycling price forecasts that are also provided online for each of the nine materials.

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[1] This study has also been summarized in two articles published elsewhere, Morris and Canzoneri, "Comparative lifecycle energy analysis: theory and practice," *Resource Recycling*, November 1992, Volume XI/Number 11; and Morris, "Recycling versus incineration: an energy conservation analysis," Journal of Hazardous Materials, Vol. 47 (1996), pp. 277-293.

[2] For example, Temanex Consulting (North Vancouver, B.C.) in a report prepared for Ontario Hydro, *The Ontario Newsprint Industry to the Year 2005 - Impact of Deinked Newsprint Trends*, estimated savings from using secondary fiber to manufacture newsprint to be between 3600 and 3960 kJ/kg of finished newsprint versus virgin stone groundwood production of newsprint, and 6840 kJ/kg versus virgin thermomechanical pulp (TMP) production. These energy savings estimates are based on usage of purchased electricity by pulp and newsprint manufacturers. Energy used in harvesting and transporting trees to the pulp mill, energy used to collect and process recycled newspapers, non-electrical energy inputs to the pulping and newsprint manufacturing process, and energy generated by burning tree residues during the pulping process are all ignored in these estimates.

[3] This assumption probably biases the analysis against recycling. For example, Peter Love in "Energy Savings from Solid Waste Management Options," *Resources Policy*, March 1978, P. 57, states, "...capital-related energy consumed by ... newsprint ... operations is less than 5% of the total energy consumed in the production of a ton of paper, and ... capital-related energy consumption for energy recovery systems is about 1% of the fossil fuel equivalent energy produced. This order of magnitude has no substantial effect on the outcome of the comparison, especially since a large part of the capital for the two options is the same...

To the extent that the exclusion of capital-related energy does impart a bias to the analysis, the bias will be against reclamation and recycling. Energy recovery is more capital intensive than reclamation, and the harvesting and pulping of wood is more capital intensive than the preparation of waste paper for recycling."

[4] Ince, P., and Klungness, J., "Economics of Increasing the Use of Recycled Fiber in Linerboard," *Tappi Journal*, Vol. 67, No. 8, August 1984, p. 62, estimate that in virgin kraft paperboard manufacturing the virgin kraft (sulfate) chemical pulping process yields only about 50% of input wood chips as output pulp product. Similarly, a recent report from International Paper by Wilfred Cote', *Life-Cycle Assessment: Proceed with Caution*, estimated that 56 percent of the energy requirements in the average paper mill are met by wood residues and byproducts.

[5] As an example of the impacts of this system boundary issue on calculations of energy and CO_2 emissions, in a study by the Institute for Energy and Environment (IFEU) in Heidelberg completed for the European Commission,

energy used for planting, tending and harvesting timber, as well as CO_2 absorbed by growing trees, was excluded from the analysis of recycling versus incineration. "This made the combustion options appear more environmentally 'friendly'. If the system boundary had been moved back down the production cycle, proper account could have been taken of the fact that growing trees absorb CO_2, compensating for that released when paper is burned." (Quote from an article by one of the study team, Mike Flood, "Life Cycle Assessment: Understanding the Limits," *Warmer Bulletin*, No. 42, Aug 94, pp. 5-6, published by The World Resource Foundation, Kent, UK.)

[6]Electrical generation factor from US Energy Information Administration, as reported in 1990 *Statistical Abstract of the United States, p. 559*. See also, US Energy Information Administration, National Energy Information Center, *Energy Interrelationships, A Handbook of Tables and Conversion Factors for Combining and Comparing International Energy Data*, Jun 77.

[7]This estimate for average heating value of MSW is from Camp, Dresser & McKee, *Town of Oyster Bay Draft Environmental Impact Statement for a Proposed Resource Recovery Facility*, March 1988, p. 4-125. Amir Shalaby, Ontario Hydro System Planning Division, in his paper "Role of Alternative Generation Sources in Ontario," presented at IEEE Power Engineering Society 1986 winter meeting in New York City, estimates that heating value of waste in urban areas is about 11,000 kJ/kg.

Pai, V., Ontario Hydro Mechanical and Equipment Engineering Department, "Energy From Municipal Solid Waste Issues," December 1989, p. 4, states, "The higher heating value of MSW, as received with typically 25 percent moisture is approximately 10,500 kJ/kg." Table 1 shows the composition of residential MSW for a typical residential waste stream, in this case residential waste in the Canadian province of Ontario. Based on this composition, Ontario's residential waste has an estimated average heating value of about 13,500 kJ/kg. However, the estimates of heating value for individual waste materials shown in Table 1 do not adjust for the 25% moisture content of mixed garbage.

[8]Camp, Dresser & McKee, *op. cit.*, p. 4-125, projected net electricity generation for sale per metric ton of incinerable solid waste to be 507 kWh. Oyster Bay's incinerable waste was projected to have a heating value of 12, 095 kJ/kg, or 12.1 million kJ per metric ton. Thus, a 15% efficiency factor is specified in the engineering design of this particular EFW facility. A United States Environmental Protection Agency publication, "Reusable News," reported that EFW generates only about 475 kWh per metric ton (EPA/530-SW-91-022, Fall 1991, p. 5). The higher figure of 507 kWh per metric ton is used in this paper to calculate energy benefits for EFW incineration of MSW.

[9]Ontario's residential waste stream is used because a portion of the study on which this paper is based was funded by Ontario Hydro as part of the adjudicatory hearings for Ontario's 25-year electrical power demand and supply plan. See Morris, Jeffrey, and, Canzoneri, Diana, *Recycling Versus Incineration: An Energy Conservation Analysis*, prepared for Pollution Probe (Toronto, Ontario) and Work on Waste USA (Canton, NY) by Sound Resource Management (Seattle, WA), Sep 92.

[10]Lea, Reid, and Tittlebaum, Marty, "Energy Costs Savings Associated with Municipal Solid Waste Recycling, *Journal of Environmental Engineering*, Vol. 119, No. 6, Nov/Dec 93, came to the same conclusion, except that the authors assumed that no there were no economically viable production energy savings from recycling plastics. This led to the conclusion that plastics should be incinerated and other materials recycled to get the most energy benefit from MSW. However, there is a difficulty with recovering thermal energy only from plastics. MSW would need to be thoroughly sorted to burn just plastics and not burn any other materials. This sorting probably would add the economic viability to plastics recycling that Lea and Tittlebaum claim is absent.