The Monthly UnEconomist

Recycling versus Incineration: an Energy Conservation Analysis

Part 3

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.

February, March and April 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).[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.

February covered the study's methodology and general conclusions. March reported the tabular data and covered incremental energy usage in collection, processing and shipping needed to recycle MSW materials. This issue covers the recycling versus incineration analysis for each separate waste material.

****

A review of energy conserved by recycling each major category of materials in MSW reveals the superiority in general of recycling to EFW in terms of energy savings.[2]

1. Paper

The energy saved when used paper or paperboard products are recycled into new paper or paperboard products ranges between 14,000 and 39,000 kJ/kg, where the high estimate is for manufacturing tissue and toweling papers. These energy savings estimates are from secondary sources listed in footnotes to Table 1 in the March *UnEconomist*, except that estimates were adjusted upward to include the energy value of trees not used when paper or paperboard products are made from recycled paper rather than trees.

For example, according to one source raw material transport and manufacturing energy savings alone would total 5800 kJ/kg of recycled-content newsprint, assuming that no incremental energy is expended to harvest trees for newsprint because the wood chips for pulping come from sawmill residues. To these energy savings is added the energy equivalent of the 2.13 kg of trees not used when a kilogram of recycled-content newsprint is produced, after adjusting for an estimated 85% yield in transforming ONP into newsprint.[3] This gives the high-end energy savings estimate for recycled-content newsprint manufacture. The secondary source for the low-end estimate for newsprint manufacture already included the energy value of trees.

As a second example of the energy savings from recycling paper and paperboard materials, metal/plastic/wax coated paper materials such as polycoated paperboard milk cartons are being recycled in more communities as time passes. To account for the possibility of recycling polycoated papers into tissue, the 38,600 kJ/kg savings for recycled content tissue papers is listed in Table 1 for the metallic, plastic or wax coated paper waste material category.

2. Plastics

The energy saved when used plastic packaging or other plastic materials are recycled into new plastic products ranges between 42,000 and 111,000 kJ/kg. As indicated in footnotes to Table 1, these energy savings estimates are primarily from the US Congress Office of Technology Assessment (OTA). OTA based their estimates for energy savings from recycling the major commodity thermoplastics on the HDPE/PET reclamation process developed by the Center for Plastics Recycling Research at Rutgers University, and on the Extruder Technology 1 for manufacturing mixed post-consumer plastics into extruded plastic products. Because neither technology has as yet been widely applied in the US to the diverse range of plastics listed in Table 1, the energy savings estimates in Table 1 should be considered preliminary.

3. Glass

Energy saved when container glass is remanufactured into new containers is estimated to be between 900 and 5500 kJ per kilogram of recycled-content glass containers. Because most glass is manufactured using some recycled cullet, and because glass is seldom manufactured using only recycled cullet, these energy savings estimates do not compare 100% virgin glass versus 100% secondary glass containers.

Glass waste materials (e.g., ceramics and window glass) other than glass containers can be used in road surfacing (glasphalt) and roadbed materials. These glass wastes also are used, along with mixed color container glass, as a substitute for construction aggregate. Based on estimated energy needed to produce sand, all types of glass yield energy savings of about 600 kJ/kg when recycled as a construction aggregate.

4. Metals

The energy saved when used metal packaging or other metal products are remelted into new metals ranges from a low of about 7,000 kJ/kg for recycling tin-plated steel cans to 200,000 to 360,000 kJ/kg for aluminum beverage containers and other aluminum scrap.

Aluminum is extremely energy intensive when smelted from raw bauxite. However, aluminum cans and aluminum scrap metal are rather easily resmelted into, respectively, new aluminum sheet for cans and secondary ingot for use in other aluminum products. Energy savings are huge -- between 201,562 and 360,900 kJ/kg recycled. Although aluminum cans are somewhat more combustible than heavier aluminum products, they still yield less than 750 kJ/kg when burned as part of MSW.

Tin-plated steel cans have traditionally been recycled at de-tinning plants where their tin coating is separated from their steel body content. More recently, the ability of electric arc furnaces and steel-making technology to manage contaminants such as tin has improved, and the amount of tin coating applied to steel cans has decreased. Now tin cans are sometimes recycled directly into new steel.

Energy savings are estimated to be between 7,094 and 37,100 kJ/kg. As with glassmaking, in practice most steel contains recycled material so that comparing 100% virgin to 100% recycled steel is essentially impossible. Nevertheless, energy savings from increasing average recycled content in steel are still quite large because ferrous metals are virtually non-combustible.

Non-ferrous metals other than aluminum are also readily recycled via resmelting and manufacturing into the same types of products in which virgin ores appear. Copper is used as a surrogate for the vast array of non-ferrous metals. Energy savings from recycling copper are estimated to be between 110,148 and 122,429 kJ/kg. Energy produced from incinerating non-ferrous metals is insignificant.

5. Organics

The organic fraction of solid waste can be broken down biologically and transformed into compost. *Aerobic* composting involves biological transformation in the presence of oxygen. *Anaerobic* decomposition (also called "digestion" or "biogasification") involves biological transformation of organic wastes in the absence of oxygen. Though a newer technology, anaerobic digestion of solid waste offers potential net energy advantages over aerobic composting, since anaerobic systems produce methane (natural) gas in addition to producing a compost-like soil amendment.

Estimates for energy generated from composting organic wastes given in Table 1 are based on methane produced by anaerobic digestion being used as fuel for steam-electric power generation. The compost residue from anaerobic digestion is assumed to substitute for peat in use as a soil amendment.[4] In an assessment of anaerobic digestion, Robert Legrand and his associates calculated that anaerobic decomposition of MSW generates a net 5,150 kJ/kg of material processed. When the humus-like residue from the digester is dewatered, screened and cured to produce a compost-like material, then substituted for peat, the anaerobically produced soil amendment increases the energy conserved by composting MSW to an estimated 5,550 kJ/kg of MSW.[5]

Anaerobic digestion of yard waste produces a net estimated 3,150 kJ/kg of waste digested. Substituting anaerobically digested yard waste for peat would increase energy savings to about 3,550 kJ/kg of yard waste.[6]

Estimated energy savings from anaerobically digesting food waste assume that preprocessing food waste prior to anaerobic conversion requires only about 75 percent of the energy needed to preprocess MSW for anaerobic digestion, but that energy used at later stages of the process would be the same. The estimate also assumes that approximately 30 percent of food waste is dry and free of ash, and that 80 percent of the dry, ash free solids in food waste are converted into methane. Given these assumptions, anaerobic digestion of food waste produces a net 3,800 kJ/kg of waste digested. Substituting the residue for peat could be expected to increase energy savings to 4,200 kJ/kg of food waste.

6. Wood

Using recycled wood in place of virgin wood in the manufacture of particleboard saves about 6,400 kJ/kg of waste.[7]

7. Rubber

Retreading is the process by which tires can be recycled. It is really a combination of reuse and recycling in that the old tire's casing becomes the base for new tread material made from virgin rubber. Energy savings for retreading are estimated to be between 16,200 and 48,800 kJ/kg. The increasing popularity of radial tires, however, has complicated the retreading process for passenger car and light truck tires and made retreading less common than in previous decades. Competition from low-priced tires imported into the US has also negatively impacted tire retreading.

Stuart Natof, a Program Manager with the US Department of Energy, notes that the use of surface-treated rubber particles in polymer composites yields the greatest energy savings potential of all scrap tire uses. According to Natof, substituting surface treated rubber for a portion of the virgin polymers in composite materials yields savings of between 67,000 and 229,000 kJ/kg of material substituted. Taking the midrange of this estimate yields high-end energy savings of 148,000 kJ/kg.

Rubber products other than tires can be recycled at an estimated energy savings of 25,700 kJ/kg.

8. Textiles/Diapers

One use for old cotton textiles is in manufacturing writing papers. Estimated energy savings in that use is 42,100 kJ/kg. The average energy consumed in manufacturing synthetic textiles is estimated at about 58,300 kJ/kg, based on polyester, nylon, acrylic modacrylic and olefin production. It is assumed that all this production energy would be saved if synthetics are re-used as rags.

The low-end estimate of energy conservation from recycling disposable diapers considers only energy savings associated with the reclaimed pulp. This estimate ignores potential savings associated with reclaimed plastic and absorbent gel material, since only the pulp is currently marketable. Under these assumptions, recycling diapers instead of using virgin materials to produce kraft pulp saves about 62,600 kJ/kg of dry pulp, or 6,800 kJ/kg of diapers recycled.

In recent work by Lehrburger and two associates, data was gathered on energy used during each step of the manufacturing process for both single-use and reusable diapers, as well as energy consumption during the laundering of reusables.[8] In the Lehrburger study it was assumed that 15 percent of the MSW waste stream, including single-use diapers, is burned for energy. This gave single-use diapers an incineration energy credit. To develop the high-end estimate reported in Table 1 for energy saved by recycling/reusing diapers, Lehrburger's figures were adjusted by deleting the incineration energy credit.

The manufacture and use of disposable diapers consumes 75 percent more energy than the manufacture and use of reusables. Reusables save 15,100 kJ/kg of diaper waste. To this figure is added 28 kJ, the energy savings that accrue if reusable diapers are recycled into cotton rags for paper production after their last use as diapers. With reusable diapers recycled into cotton rags at the end of their lives, substituting reusable for disposable diapers saves 15,100 kJ/kg of single use diaper waste.

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.

---

[1] 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. 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 further details on energy conservation estimates for particular materials, see Morris and Canzoneri, *Recycling Versus Incineration, op. cit.*

[3] See footnote (b) to Table 1 (In the March 2000 *UnEconomist*).

[4] For further detail on the energy conservation estimates for composting see Morris and Canzoneri, , *Recycling Versus Incineration, op. cit.*

[5] Robert Legrand, *et al*, "A Systems Analysis of the Biological Gassification of MSW and an Assessment of Proven Technologies. Estimates updated via phone conversations with Legrand in January and July of 1992.

[6] Based on conversations with Robert Legrand and David Chynoweth in January and July of 1992, and yard waste composting process energy consumption at Cedar Grove Compost Facility, King County, WA.

[7] "Highlights from Wood for Structural and Architectural Purposes," *Forest Products Journal*, Feb 1977, by Conor W. Boyd, Peter Koch, *et al.*, Table 5; and telephone conversation with Conor Boyd (January, 1992). Extraction and transport of raw materials and preparation of particleboard finish in the form of planer shavings, plywood trim, and sawdust is reported to consume approximately 4.617 million Btu's per oven dry (OD) ton of particleboard, or 2,308 Btu's per oven dry pound of particleboard. Heating (i.e., drying) virgin wood requires 5.598 million Btu's per OD ton or 2,799 Btu's per OD pound of particleboard. (Conversion factor for Btu to kJ, one Btu = 1.054 kJ.) When comparing the use of virgin to recycled wood, it is assumed that it takes an average of 1.24 pounds of recycled wood to produce 1 pound of oven dry particleboard.

[8] Carl Lehrburger, Jocelyn Mullen, and C.V. Jones, January 1991, "Diapers: Environmental Impacts and Lifecycle Analysis," Report to The National Association of Diaper Services in Philadelphia, Pennsylvania. This report assumes 87 percent of reusable diapers are home laundered and 13 percent are washed by commercial diaper services.