The Monthly UnEconomist

Evaluating Externalized Costs in the Management of Discards

by
Jeffrey Morris*

The January 2001 *UnEconomist* discussed economic concepts that are useful for managing discards as resources rather than wastes, and for bringing sustainability concepts into discussions about solid waste management choices. Environmental externalities are one of the key sustainability concepts outlined in that issue of this newsletter.

In order to add sustainability considerations to traditional internalized-cost-based analyses of solid waste management choices, it is necessary to assign costs to externalities so as to make it possible to consider the costs of those externalities along side the traditional internalized costs of waste management options. One can then make choices that trade off decreases in external costs against increases in internal costs. Such choices would seem irrational in an analysis that only considered internal costs.

The first step in developing estimates of external costs is to identify what environmental impacts one wants to measure – e.g., impacts on human health from releases of pollutants to the air or water. Next, one must measure those impacts – e.g., harm to human health when pollutants are released. Lastly, one needs to estimate costs associated with those impacts – e.g., increased private and public expenditures to cure or treat diseases in humans exposed to pollution.

There has been work performed in numerous important solid waste management and energy resource management studies to quantify the cost of specific environmental impacts. For example, a number of studies have estimated the cost to public health from releases of pollutants to air or water. This paper reviews data and findings in several of these studies, and reports external cost estimates from these studies. The May and June issues of the *UnEconomist* report on a Washington state case study that used these cost estimates in order to consider some external environmental costs in an analysis of internal versus external costs for curbside recycling versus disposal of residential solid waste.

Specific Studies of Pollutant Releases and Estimates of the Externalized Costs of Pollutants

Studies that Measure Emissions to Air and Water

Industry and governmental agencies have been tracking emissions of certain pollutants to the air and water for a number of years now. In the past decade researchers have used these data along with other information to prepare life-cycle inventory (LCI) studies on solid waste management systems that handle the materials generated as residuals from production and consumption activities.[1] These LCI studies examine the life cycle of a product, from raw materials acquisition all the way through to management of residuals at the end of the product's life, so as to determine material and energy inputs and waste outputs and environmental releases associated with production, use and end-of-life management of that product.

Those parts of the LCI study that focus on resources, energy and environmental releases associated with raw materials acquisition and

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* Jeffrey Morris is a University of California-Berkeley Ph.D. economist at Sound Resource Management in Bellingham, WA. Preparation of this paper was supported in part through the Washington State Department of Ecology's study on sustainability in solid waste management. The author is grateful for the thoughtful comments of a number of reviewers. Analyses and conclusions in this paper remain the responsibility of the author.

[1] A ***life-cycle inventory*** of air and waterborne pollutant releases is often one of the first steps in a life-cycle assessment and economic valuation of the environmental impacts of a product. The life-cycle inventory attempts to measure all significant inputs and outputs for a product throughout its life cycle, from raw material acquisition and use of natural resources through management of residuals at the end of the product's life. The ***life-cycle assessment*** then attempts to account for the environmental effects of those inputs and outputs; and the ***economic valuation*** attempts to place a dollar cost or benefit on each effect caused by each input or output.

product manufacturing are often referred to as the "upstream" (from the MSW management system) component of the LCI. This upstream component is important for comparing resources, energy and environmental releases from production of recycled-content products against resources, energy and environmental releases from production of the same products using virgin raw materials. Upstream LCI data show that manufacture of recycled-content products often yields substantial reductions in resource use, energy use, and environmental releases, as compared with manufacture of virgin-content products.

Combining the upstream LCI data with LCI data for the various waste management methods themselves yields a complete solid waste system LCI for a product, from raw materials acquisition through disposal or recycling of residuals. The upstream data for recycled-content products are combined with LCI data for recycling collection, processing and transportation of processed recyclables to markets. Virgin-content product LCI data are combined with LCI data for garbage collection, transfer, haul and disposal. This yields two sets of LCI data that compare the management of discards via recycling versus disposal.[2]

Upstream LCI data can also be used in combination with LCI data on specific waste prevention or source reduction methods to determine resource, energy and environmental releases associated with these "top of the hierarchy" waste management methods.

Table 1, LCI Emissions Data Used in Waste Management System Environmental Impact Studies, lists atmospheric and waterborne emissions covered in LCI data reported in five different studies on the economic and environmental impacts of waste management methods. Some emissions listed in Table 1 are grouped according to prioritization categories developed in the US or internationally for regulating or classifying environmental releases.

The abbreviations and citations for studies inventoried in Table 1 are as follows:

- EPA MSW 2001 - Research Triangle Institute, Franklin Associates, Roy F. Weston, North Carolina State University, and University of Wisconsin-Madison, *A Decision Support Tool for Assessing the Cost and Environmental Burdens of Integrated Municipal Solid Waste Management Strategies*, US EPA National Risk Management Research Laboratory, forthcoming 2001.
- AUS RCY 2001 - Nolan-ITU, SKM Economics, and ENVIROS/RIS, *Independent Assessment of Kerbside Recycling in Australia*, Australian National Packaging Covenant Council, January 2001. (go to Home page from http://www.packcoun.com.au)
- MN MSW 2000 - R.W. Beck and Ecobalance, *Assessment of the effect of MSW management on resource conservation and greenhouse gas emissions*, Minnesota Office of Environmental Assistance (OEA), September 1999. Summary included in Appendix A to MN OEA, *Solid Waste Policy Report, Waste management in Minnesota: A transition to the 21st century*, January 2000. (http://www.moea.state.mn.us/policy/index.cfm)
- KAB RCY 1994 - Franklin Associates, *The Role of Recycling in Integrated Solid Waste Management to the Year 2000*, Keep America Beautiful, September 1994.
- CSG PKG 1992 - Tellus Institute, *CSG/Tellus Packaging Study: Assessing the impacts of production and disposal of packaging and public policy measures to alter its mix*, The Council of State Governments, US EPA, and New Jersey Department of Environmental Protection and Energy, May 1992.

EPA's Decision Support Tool

The five studies differ substantially in their coverage of specific solid waste management methods and types of residuals. Within each study there are also differences in the extent to which the complete life cycle is covered for each

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[2] The reader should note that LCI data on the use stage of a product's life cycle do not need to be gathered for a solid waste management system life cycle analysis, because it is typically the case that impacts during a product's use will be the same whether the product is manufactured from virgin or recycled materials.

particular type of residual for each particular waste management method, as well as differences in availability of data measuring discharges throughout a product's complete life cycle for each particular pollutant.

For example, EPA's decision support tool (DST) study reports emissions for 27 pollutants[3] for both upstream and end-of-life recycling or disposal components in the life cycle for seventeen particular residuals. The 27 pollutants are indicated by a "yes" in the EPA MSW 2001 column of Table 1. The seventeen discards are:

1. corrugated boxes,
2. newspapers,
3. office paper,
4. magazines,
5. third class mail,
6. telephone books,
7. text books,
8. glass containers, clear,
9. brown,
10. and green,
11. aluminum cans,
12. PET bottles,
13. HDPE bottles, translucent and,
14. colored,
15. LDPE film and,
16. steel cans and,
17. steel scrap.

For another group of 40 pollutants[4], the EPA DST study reports only upstream emissions for the seventeen residuals listed above. These pollutants are indicated by an "up" in the EPA MSW 2001 column of Table 1.

Where there was a gap in the data on emissions of a particular pollutant for a particular recycling or disposal management method included in the EPA DST study, EPA decided not to report data on emissions from any waste management method for that pollutant to avoid any implications of bias in the study. For example, atmospheric or waterborne dioxin/furan emissions data were not available for all MSW management methods. As a result, the EPA DST study does not report dioxin/furan emissions for any waste management method, even though those emissions are available in other studies for specific management methods such as disposal through waste-to-energy incineration.

The other pollutants listed in Table 1 that have neither a "yes" nor an "up" in the EPA MSW 2001 column are pollutants whose emissions are not reported in the EPA DST study. However, the absence of emissions data in the EPA study should not be interpreted as an indication that the seventeen residuals listed above, or other types of residuals for that matter, are associated with zero emissions of these pollutants. In fact, at least one of the other four studies referenced in Table 1 provides emissions data from the life cycle of some residual type for each of these other pollutants.

Additionally, up to this point in time researchers on product life cycles have conducted LCI's that are applicable to the residual categories defined in the DST study only for virgin- and recycled-content manufacturing of commodities (e.g., newsprint or aluminum ingot) that are made into products (e.g., newspapers or aluminum beverage containers, respectively) whose end-of-life residuals are among the seventeen enumerated above (e.g., old newspapers and empty aluminum beverage cans, respectively). Thus, the DST does not include upstream impacts for the other 22 residual types among the 39 waste components evaluated by the DST model.

Table 2, LCI Data Availability in EPA’s DST Model, summarizes the availability of LCI data in the DST model for these 39 waste categories. Notable among the 22 residual types lacking upstream LCI data are the organic waste stream components defined in the EPA study - grass, leaves, branches and food waste. As yet, researchers have not evaluated the reduction in emissions related to reduced use in agriculture of

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[3] This number counts the emission of the same chemical substance, e.g., lead, to both air and water as two pollutants.

[4] This number counts includes the emission of the same chemical substance, e.g., manganese, to both air and water as two pollutants.

fertilizers, fungicides, herbicides and insecticides that appear to be a beneficial result of using compost as a soil amendment.

Finally, the EPA DST study provides LCI data for the upstream benefits of waste prevention and reduction for the seventeen residuals listed above, but no LCI data on specific methods, such as double-sided copying or glass container reuse, that might be used to prevent or reduce waste.

As a result of these lacks in upstream and waste management method LCI data, the DST provides a comprehensive comparison of emissions from recycling versus disposal options for just the seventeen residuals enumerated above and for just those emissions indicated by a "yes" in the EPA MSW 2001 column of Table 1. This fact is noted not to disparage the EPA model - for, in fact, the DST contains the most well-researched, peer-reviewed MSW life cycle information ever assembled for the US. Rather it is to point out the complexity of life-cycle analysis and the huge amount of work that remains to be done to develop a complete LCI for all discards for all waste management methods for all types of atmospheric and waterborne emissions.

Four Other Studies on Life Cycle Atmospheric and Waterborne Emissions from MSW Choices

In comparison with the broad range of disposal options covered by the EPA study, the Australian study inventoried in Table 1 focused on residential curbside recycling versus landfilling of typical recyclables. The Australian study did cover a variety of curbside collection and processing systems for mixed paper, newspaper, glass containers, aluminum cans, steel cans, PET bottles, HDPE bottles and paperboard drink cartons. As shown by the "x" marks in the AUS RCY 2001 column of Table 1, the Australian study provides LCI data on a broader range of toxic releases over the life cycle of these eight discards than does the EPA study.

At the same time, it was not possible within the scope of this review to determine whether the Australian study had any data gaps of the kind that are indicated by the "up" as opposed to "yes" entries for the EPA DST study in Table 1. Thus, coverage of pollutant emissions in the Australian study, as well as the other three studies referenced in the table, is indicated by just an "x" in each study's column of Table 1.

The study conducted for the Minnesota Office of Environmental Assistance (OEA) focused on resource conservation associated with Minnesota waste management, where resource conservation was defined as the avoided use of natural resources, avoided pollution and avoided waste generation. For waste reduction the study examined five materials - office paper, wooden pallets and containers, corrugated cardboard, glass containers and plastic containers. For recycling, the study included newspaper, corrugated cardboard, glass containers, aluminum cans, steel cans, PET bottles and HDPE bottles.

The study also partially examined the life cycle impacts of composting, and the life cycle impacts of recycling used oil and scrap tires. The OEA study covered a subset of those emissions included in the EPA study. The exception is for waterborne releases of nitrates, phosphates and hydrocarbons for which comprehensive solid waste method LCI data are not included in the EPA model.

The Keep America Beautiful study focused on three management methods - recycling, incineration and landfill - for residential residuals of newspapers, glass containers, aluminum cans, steel cans, PET bottle, and HDPE bottles and containers, and on three management methods - composting, incineration, and landfill - for residential yard trimmings.

Finally, the Council of State Governments study conducted by Tellus Institute focused on developing an LCI for material and energy use along with air and water emissions associated with disposal of a list of particular packaging materials - aluminum, glass, steel, five types of paper (bleached Kraft paperboard, unbleached coated folding boxboard, linerboard, corrugating medium, and unbleached Kraft paper), and six types of plastic (PET, HDPE, PVC, LDPE, PP, and PS). This pioneering study first revealed the fact that emissions from upstream virgin raw materials acquisition and virgin-content product manufacturing tend to dwarf emissions from MSW management methods, at least under the assumption of perpetual maintenance of state of the art air emissions and leachate control at disposal facilities.

Economic Valuation of Atmospheric and Waterborne Emissions

Once LCI data are available for a solid waste system, one can analyze impacts on pollutant releases from changes that could be made to current methods of handling discards. Some options may increase certain emissions while reducing others. In this case deciding which option might be most desirable involves making trade offs between types of pollution. One method for evaluating these trade offs is to convert physical quantities for pollutant releases to dollar costs.

Assigning dollar costs to each type of emission shown in Table 1 is most often done in one of two ways:

- By estimating costs of damages caused by emissions (Damage Costing).
- By estimating costs incurred to control releases of the pollutant (Control Costing).

Several methods or techniques are available to develop each type of cost estimate, each with particular strengths and weaknesses.[5] However, there are substantial technical difficulties involved in getting complete and accurate estimates of externalized costs using any of these standard methods for estimating damage or control costs. This has led to protracted debate among proponents of one or another method for estimating externalized costs, and to wide variations in the actual estimates as well. As a result of the high range of uncertainty associated with each of the scientific approaches to valuing externalities, some experts have suggested that economic valuations should be established as part of a political process.[6]

While keeping this advisory in mind, it is nevertheless instructive to review some estimates of costs for pollutant releases. Table 3, Economic Valuation of Atmospheric and Waterborne Emissions ($ per pound), exhibits estimates of economic cost for many of the atmospheric and waterborne emissions listed in Table 1.

Two of the five studies referenced in Table 1 included the step of assigning costs to pollutant loadings - The Australian National Packaging Covenant Council[7] and the US Council of State Government[8] studies. Pollutant cost estimates from those studies are shown in Table 3.

The three other columns of cost estimates shown in Table 3 are:

- MN PUC 1995 - Under direction from the Minnesota legislature, the Minnesota Public Utilities Commission quantified the environmental costs of electricity, and in the process developed estimates for the externalized costs of criteria air pollutants. These estimates were challenged in court and after

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[5] Researchers use three main methods to carry out damage costing - market valuation, hedonic valuation and contingent valuation. Two methods are used for control costing - control cost valuation and mitigation cost valuation. A 1994 study by the Office of Technology Assessment, *Background Paper: Studies of the Environmental Costs of Electricity*, provides a short description and review assessment of each of these five valuation methods.

[6] International Expert Group for Life Cycle Assessment and Waste Management Meeting No 5 (May 2000), Head office of the Environment Agency of England and Wales, Bristol England. Cited in the National Packaging Covenant Council's curbside recycling study, Appendix A, "Environmental Assessment Methodology, p. A-3

[7] Australian dollars were converted to US dollars at the exchange rate used in the Australian study, one Australian dollar = US$0.60.

[8] Pollutant externalized costs used for the *1992 Packaging Study* are given in Appendix A, pp. 3A-1 to 3A-3 of Report #3, "The Marginal Cost of Handling Packaging Materials in the New Jersey Solid Waste System." The costs shown in Table 2 are from the 1994 update of the *Packaging Study*'s impact assessment method, as reported in Tellus Institute, *Evaluation of the Environmental Impact of Packaging Production for Mexico*, Appendix A, pp.30-31. The methodology used to cost pollutants in the *Packaging Study* did not distinguish between atmospheric and waterborne emissions of each particular pollutant.

four years of litigation were affirmed by the Minnesota Court of Appeals. Minnesota's Supreme Court denied a requested review of that affirmation in 1998. (Documents available at http://www.me3.org/projects/costs)

- OTA Review 1994 - Office of Technology Assessment, Congress of the US, *Background Paper: Studies of the Environmental Costs of Electricity*, September 1994. (Document available at the Office of Technology Assessment Archive at http://www.ota.nap.edu)
- MKT TRADES 2000/01 - Recent emission allowance or emission reduction credit trading prices. (Price data on sulfur dioxide emission allowances trading are at http://www.epa.gov/airmarkets/trading/so2market; on emission reduction credits for nitrogen oxides and carbon dioxide at http://www.cantor.com/ebs/marketp.htm

Examination of Table 3 reveals the diversity of estimates available for assigning an environmental cost to pollutant releases. At the same time, the estimates given in the table offer a good deal of guidance on evaluating trade offs between types of pollution. For example, atmospheric emissions of chlorinated/aromatic hydrocarbons are more troublesome than waterborne emissions, while the opposite is the case with mercury. On the other hand, on a pound for pound basis, both of these pollutants are much more damaging than atmospheric emissions of sulfur or nitrogen oxides, or of particulates.

However, to choose among waste management methods, the researcher needs to tie environmental costs per pound for pollutants to the quantity of each pollutant's releases associated with managing a ton of each waste discard under each management method. Only then can one make the final call on relative environmental costs for managing wastes using available prevention, recycling and disposal methods.

Use of Natural Resources

Studies on the economic and environmental costs and benefits of solid waste management systems sometimes include an analysis of land use and resource conservation impacts associated with various waste management methods. For example, the Australian Packaging Covenant Council's study of curbside recycling concluded that 75% of the overall environmental benefit of curbside recycling came from reductions in air and water pollutant emissions associated with reduced use of virgin raw materials to manufacture products.

That study also concluded that land use benefits from reduced mining and harvesting of mineral and forestry resources accounted for 21% of the benefits from recycling. Global warming credits accounted for 4%, while benefits of reduced land use for landfills accounted for another 2%. These environmental benefits of recycling were offset by environmental costs from increased truck traffic. Environmental costs from truck traffic offset 2% of total benefits.

The estimate that 21% of environmental benefits from recycling came from reduced use of mineral and forestry resources excluded the benefits associated with reduced emissions of pollutants and greenhouse gases to avoid double counting these benefits of emissions reduction. Included in the 21% were impacts related to land use and sustainability of resource access for bauxite, coal, crude oil, iron ore, lignite, limestone, natural gas and sand. The Australian study combined an estimate of the costs for rehabilitating land used for coal mining with an estimate of resource depletion costs for coal to obtain US$26 per ton as the land use and resource depletion cost for coal.

It is worth noting here that establishing a resource depletion value for coal or any other natural resource is not simple. In the case of coal it involves in some inevitable degree a prediction about tastes and needs of future generations, future coal stocks, and future technology. Even estimating the stock of coal in the earth today is a tricky business, involving as it does geologic data on locations of known and likely coal stocks, and technological data on how deep one can dig for coal and how free the vein of coal has to be from other minerals and rock for it to be recoverable.

Thus, the figure chosen to measure the extra value (its resource depletion value) coal would have, were future generations able to bid in today's markets, must sum up predictions and estimates about today's coal stocks, future stocks versus the rate of depletion of today's stocks, future technological capabilities to recover stocks inaccessible with today's technology, and future needs for coal resources.[9]

Similar difficulties would be encountered in estimating the land use and resource depletion value from reduced use of other natural resources as well. As an alternative, to determine a value for these other natural resources the Australian study used an international scale based on biodiversity and primary biomass productivity impacts to rank coal against the other mineral resources in terms of land use. The study also compared global production with global resource stocks for each mineral versus coal's estimated 666 years of remaining resource life.

Combining these land use and resource depletion rankings for the other mineral resources against coal with coal's estimated $26 per ton externalized cost, the Australian Packaging Covenant Council's study derived environmental valuations that ranged from a low of under $6 per ton for sand to a high of almost $61 for bauxite. Interestingly, limestone and iron ore fell toward the top of this range - at $50 and $44 per ton, respectively - while natural gas and crude oil were just above sand at the bottom with valuations of about $20. This result is most likely related in part to the smaller impact on land surface ecosystems associated with oil and natural gas drilling compared with surface and strip mining for iron ore and limestone.

Finally, the Australian study used “hypothetical non-wood charges” for forest resources to develop a land and natural resource use environmental cost for trees from native, regrowth and plantation forests. The estimates reported in the study are $20 per ton for timber cut from native forests, $7 for regrowth, and $3.50 per ton for plantation timber.

Minnesota OEA’s evaluation also included natural resource conservation of coal, natural gas, crude oil, iron ore and limestone in its comparison of waste management methods, but did not attempt to calculate a monetary value for natural resources conserved.

The EPA DST model, the Keep America Beautiful study, and the Council of State Governments study cover natural resource conservation only indirectly through calculations of energy use for solid waste management methods.

Energy Use

Numerous studies have examined the energy conservation and consumption impacts of solid waste management. Three of the five studies inventoried in Table 1 - EPA's DST, Keep America Beautiful and The Council of State Governments, developed energy profiles for the various management methods. Richard Dension of the then named Environmental Defense Fund published a review of the Keep America Beautiful and Council of State Government studies, as well as a review of two other studies - A US Department of Energy study by Stanford Research Institute and a Toronto Pollution Probe study by Sound Resource Management Group.[10] Denison's summary of the energy impacts of recycling, incineration and landfill reflects the conclusions of these four studies as well as others

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[9] For an economist's analysis of this problem see P. S. Dasgupta and G. M. Heal, *Economic Theory and Exhaustible Resources*, Cambridge Economic Handbooks, Cambridge: Cambridge University Press, 1979.

[10] Denison, Richard A., "Environmental Life-Cycle Comparisons of Recycling, Landfilling, and Incineration: A Review of Recent Studies", *Annual Review of Energy and the Environment*, Vol. 21, 1996, pp. 191-237. The SRMG study "Recycling versus incineration: an energy conservation analysis" is available via the peer-reviewed *Journal of Hazardous Materials*, Vol. 47 (1996), pp.277-293, or as serialized in *The Monthly UnEconomist* Vol.2, Nos. 2 through 4, Feb. - Apr. 2000. (go to the no charge Subscribers Access section at <http://www.zerowaste.com>)

that have been conducted on energy usage in solid waste.

"From a system-wide view, recycled production plus recycling uses the least energy, considerably less than virgin production plus incineration, whereas virgin production plus landfilling uses the most. This difference is due to the substantial reduction in energy use associated with manufacturing processes that use recycled materials relative to those that use virgin materials.

"This rank ordering holds despite the fact that, because of higher fuel use, collection and processing for recycling uses the most energy of the three options, whereas collection and processing for landfilling uses the least. Energy use within the waste management system is low, however, compared to the amount of energy generated by incineration or the reduction in energy used in manufacturing using recycled materials.

"Transportation energy required to ship processed recycled materials to market (i.e., points of remanufacture) is quite modest, amounting to at most a few percent of manufacturing energy."[11]

Because many of the emissions of pollutants associated with waste management methods arise from energy use related to those methods, overall energy usage is sometimes a useful surrogate for the environmental impact of a solid waste system. It is relatively easy to measure energy use based on market purchases of energy resources throughout a product's life cycle, while it is much more difficult to measure emissions of numerous pollutants. At the same time, it is important to remember that environmental benefits from reduced use of energy are reflected in emissions reductions and reduced use of mineral resources, and that energy use itself is not an externality.

It is also important to note that some energy resources likely are underpriced due to subsidies or externalities in energy markets. For example, the impacts on salmon from hydroelectric power generation have not historically been included in prices paid by consumers of hydropower. Similarly, most, if not all, of the costs for long term management of radioactive wastes and for security needs related to fissionable materials are not included in prices paid by consumers of electricity. On this basis a study on the sustainability of solid waste systems should include the effects on costs for waste management methods that would result were energy prices to reflect the removal of subsidies and internalization of these currently externalized costs. Presumably the higher energy usage methods would find their costs rising relative to less energy intensive waste management methods.

About The Monthly UnEconomist

This monthly online newsletter available at www.ZeroWaste.com (or 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. In addition to *The Monthly UnEconomist*, Sound Resource Management's website ZeroWaste.com also offers recycling markets price history graphs, reports on a variety of topics including the economic and environmental benefits of recycling, and GarboMetrics - elegant, yet not mysterious tools and spreadsheet models for solid waste and recycling.

These materials are all available for no charge at www.ZeroWaste.com. User feedback is encouraged via info@ZeroWaste.com, and substantive comments will be published in our newsletter whenever they add to our understanding of recycling.

As an example of newsletter content, some issues of the *UnEconomist* analyze 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

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[11] *Ibid*, p. 232.

bottles). These prices are tracked by online graphs updated quarterly.

In addition, some issues of the *UnEconomist* are devoted to GarboMetrics, economic models for managing and analyzing solid waste and recycling. These newsletter issues explain the structure and use of GarboMetric models provided at ZeroWaste.com for such purposes as designing garbage customer rate structures and correctly comparing garbage rates in different communities. GarboMetric models and corresponding issues of *The Monthly UnEconomist* can be downloaded at no charge from www.ZeroWaste.com.

Table 1
LCI Emissions Data Used in Waste Management System Environmental Impact Studies

Atmospheric & Waterborne Emissions Included in LCI Study	EPA* MSW 2001	AUS RCY 2001	MN MSW 2000	KAB RCY 1994	CSG PKG 1992
EPA Criteria Air Pollutants					
1. Ozone (O_3)					
2. Carbon Monoxide (CO)	yes	x	x	x	x
3. Nitrogen Oxides (NO_x)	yes	x	x	x	x
4. Sulfur Oxides (SOx)	yes	x	x	x	x
5. Particulates less than or equal to 10 micrometers (PM_{10})					x
6. Particulates less than or equal to 25 micrometers (PM_{25})					
Particulates (Total)	yes	x	x	x	x
7. Lead (Pb)	yes	x			x
Greenhouse Gases Targeted by the Kyoto Protocol					
1. Carbon Dioxide (CO_2)	yes	x	x	x	
2. Methane (CH_4)	yes	x	x	x	x
3. Nitrous Oxide (N_2O)		x			
4. Hydrofluorocarbons (HFCs)					
5. Perfluorocarbons (PFCs)					
6. Sulphur Hexafluoride (SF_6)					
Additional Greenhouse Gases					
7. Chlorofluorocarbons (CFCs)					
8. Ozone (O_3)					
9. Water Vapor (H_2O)					
Other Atmospheric Emissions					
1. Hydrocarbons (non CH_4)	yes	x	x	x	x
2. Ammonia (NH_3)	yes	x		x	x
3. Hydrochloric Acid (HCL)	yes	x		x	x
4. Mercury (Hg)		x			x
5. Aldehydes (including Formaldehyde)	up			x	x
6. Hydrogen Fluoride (HF)	up	x		x	x
7. Chlorine	up			x	x
8. Kerosene	up				
9. Antimony	up				
10. Arsenic (As)	up	x			
11. Beryllium	up				
12. Cadmium (Cd)	up	x			
13. Chromium (Cr)	up	x			
14. Cobalt	up				
15. Manganese	up				
16. Nickel (NI)	up	x			
17. Selenium	up				
18. Acreolin	up				
19. Benzene	up	x			x
20. Perchlorethylene	up				
21. Trichlorethylene	up				
22. Methylene Chloride	up				
23. Carbon Tetrachloride	up				x
24. Phenols	up				x
25. Naphthalene	up				x
26. n-Nitrosodimethlate	up				
27. Radionuclides	up				
28. Dioxins/Furans		x			
29. Copper (Cu)		x			
30. Zinc (Zn)		x			
31. Hydrogen Sulfide (H_2S)		x			x
32. Chlorinated/Aromatic Hydrocarbons		x			x
33. Metals			x	x	
34. Other organics				x	

Table 1 (continued)
LCI Emissions Data Used in Waste Management System Environmental Impact Studies

Atmospheric & Waterborne Emissions Included in LCI Study	EPA* MSW 2001	AUS RCY 2001	MN MSW 2000	KAB RCY 1994	CSG PKG 1992
Waterborne Releases					
1. Dissolved Solids	yes			x	
2. Suspended Solids	yes	x	x	x	x
3. BOD	yes	x	x	x	x
4. COD	yes	x	x	x	x
5. Oil	yes			x	x
6. Sulfuric Acid	yes			x	
7. Iron	yes	x		x	
8. Ammonia	yes	x	x	x	x
9. Copper	yes	x			x
10. Cadmium	yes	x			x
11. Arsenic	yes	x			x
12. Mercury	yes	x			x
13. Phosphate	yes				
14. Selenium	yes				x
15. Chromium	yes	x			x
16. Lead	yes	x			x
17. Zinc	yes	x			x
18. Acid	up			x	
19. Metal Ion	up			x	
20. Phenol	up	x		x	x
21. Sulfides	up	x			x
22. Cyanide	up			x	x
23. Nickel	up	x			x
24. Chloride	up	x			x
25. Sodium	up				
26. Calcium	up				
27. Sulfates	up				
28. Manganese	up				
29. Fluorides	up	x		x	x
30. Nitrates	up	x	x		
31. Phosphates	up		x		
32. Boron	up				
33. Chromates	up				
34. Chlorinated/Aromatic Hydrocarbons		x			x
35. Dioxins/Furans		x			x
36. AOX (adsorbable organic halides)		x			
37. Total Organic Compounds		x			x
38. Hydrocarbons			x		x
WA Dept. of Ecology Persistent Bioaccumulative Toxics (PBT)					
1. Aldrin/Dieldrin					x
2. Chlordane					
3. DDT (DDD & DDE)					x
4. Toxaphene					
5. Benzo(a)pyrene		x			x
6. Dioxins and Furans	up	x			x
7. Hexachlorobenzene		x			
8. Mercury		x			x
9. PCBs		x			

*In the EPA MSW 2001 column "yes" means that the EPA study provides emissions data for virgin raw materials acquisition and refining plus virgin- vs. recycled-content product manufacturing, as well as emissions for solid waste methods. An "up" means that the EPA study provides emissions data for only the upstream part (raw materials acquisition plus product manufacturing) of a waste component's life cycle.

Table 2
LCI Data Availability in EPA's DST Model

Residential Waste Component	Upstream LCI Data	Solid Waste Methods LCI Data
Yard Waste		
1. grass	no	yes
2. leaves	no	yes
3. branches	no	yes
4. food waste	no	yes
Ferrous Metal		
5. cans	yes	yes
6. other ferrous metal	yes	yes
7. non-recyclables	no	yes
Aluminum		
8. cans	yes	yes
9 - 10. other aluminum	no	yes
11. non-recyclables	no	yes
Glass		
12. clear	yes	yes
13. brown	yes	yes
14. green	yes	yes
15. non-recyclable, non-container glass	no	yes
Plastic		
16. translucent HDPE	yes	yes
17. pigmented HDPE bottles	yes	yes
18. PET beverage bottles	yes	yes
19. LDPE film/bags	yes	
20 - 24. other plastic	no	yes
25. non-recyclable plastic	no	yes
Paper		
26. newspaper	yes	yes
27. office paper	yes	yes
28. corrugated containers	yes	yes
29. phone books	yes	yes
30. books	yes	yes
31. magazines	yes	yes
32. third class mail	yes	yes
33 - 37. other paper	no	yes
38. non-recyclable paper	no	yes
39. miscellaneous	no	yes

Table 3
Economic Valuation of Atmospheric and Waterborne Emissions ($ per pound)

Atmospheric & Waterborne Emissions	AUS RCY 2001	CSG PKG 1992/94	MN PUC 1995	OTA REVIEW 1994	MKT TRADES 2000/01
Atmospheric Emissions					
Carbon Monoxide (CO)	$0.007	$0.48		$0.43 - 0.45	
- urban			$0.0008		
- suburban			0.0005		
- rural			0.0002		
Nitrogen Oxides (NO$_x$)	1.04	4.53		0.82 - 3.70	$0.41
- urban			0.34		
- suburban			0.11		
- rural			0.03		
Sulfur Oxides (SO$_x$)	0.12	2.23		0.75 - 0.79	
Sulfur Dioxide (SO$_2$)				0.88 - 2.13	0.07
- urban			0.08		
- suburban			0.04		
- rural			0.01		
Particulates (Total)	2.56	1.30		1.19 - 1.25	
Particulates (PM10)					
- urban			2.72		
- suburban			1.22		
- rural			0.35		
Lead (Pb)	0.19	528.00			
- urban			1.75		
- suburban			0.91		
- rural			0.21		
Carbon Dioxide (CO$_2$)	0			.0068 - .012	0.0002
- urban			0.0009		
- suburban			0.0009		
- rural			0.0009		
Methane (CH$_4$)	0.26	0.01		0.11 - 0.38	
Nitrous Oxide (N$_2$O)	0			1.98 - 2.08	
Hydrocarbons (non CH$_4$)	0.26				
Ammonia (NH$_3$)	12.47	0.76			
Hydrochloric Acid (HCL)	2.49				
Mercury (Hg)	3,915.90	2,464.00			
Hydrogen Fluoride (HF)	2.49				
Arsenic (As)	2,317.88	7,477.29			
Cadmium (Cd)	966.62	1.606.34			
Chromium - trivalent	0.24	0.74			
- hexavalent	22,831.08				
Nickel (Ni)	231.77	137.89			
Dioxins/Furans	153,177.31				
- 2378-TCDD		42,646,153.85			
Copper (Cu)	28.55	19.90			
Hydrogen Sulfide (H$_2$ S)	11.99	11.46			
Chlorinated/Aromatic Hydrocarbons	1,598.48				

Table 3 (continued)
Economic Valuation of Atmospheric and Waterborne Emissions ($ per pound)

Atmospheric & Waterborne Emissions	AUS RCY 2001	CSG PKG 1992/94	MN PUC 1995	OTA REVIEW 1994	MKT TRADES 2000/01
Waterborne Releases					
Suspended Solids	$6.23				
BOD	0.08				
COD	0				
Iron	0				
Ammonia	1.84	$0.76			
Copper	9.59	19.90			
Cadmium	215.78	1,606.34			
Arsenic	11.99	7,477.29			
Mercury	6,233.72	2,464.00			
Chromium	335.66				
Lead	61.54	528.00			
Zinc	0.56	3.70			
Phenols	87.91	1.23			
Nickel	0.04	137.89			
Chloride	199.81				
Sulfates	0.12				
Fluorides	199.81	12.32			
Nitrates	0.12				
Chlorinated/Aromatic Hydrocarbons	303.69				
Dioxins/Furans	74,325.11				
- 2378-TCDD		42,646,153.85			
AOX (adsorbable organic halides)	0.005				
Total Organic Compounds	0				