Using Life-Cycle Management to Evaluate Integrated Municipal Solid Waste Management Strategies

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Introduction

Communities throughout the United States are struggling to develop efficient and cost-effective plans for managing their MSW. In the past, these plans primarily consisted of waste collection and disposal at a local landfill. Today's MSW management plans often include integrated systems that address all types of solid waste materials, solid waste sources, and waste management options [1].

Developing more efficient integrated MSW management plans necessarily involves complex decisions where tradeoffs between environment performance and cost and must be carefully analyzed. For instance, how does the cost and environmental performance of a MSW management system change if we include or exclude a specific material (e.g., glass, paper, plastic, metal) from our recycling program? And should we recycle newsprint if we are interested in waste-to-energy combustion? To better evaluate the tradeoffs involved with these types of questions, the entire life cycle of MSW must be considered. As shown in Figure 1, the life cycle of MSW starts with the production of products from virgin and/or recycled materials. Eventually, these products are discarded to the MSW stream and may be managed through a variety of options such as recycling, combustion, composting, and landfilling. Materials that are recovered and recycled are incorporated into new products and will eventually reenter the MSW stream. By taking a life-cycle perspective, it is possible to capture tradeoffs and transfers of environmental burdens from one waste management operation to another, or from one life-cycle stage to another, and analyze multiple system design issues concurrently [2,3,4].

The Research Triangle Institute (RTI) is continuing work under a multi-year cooperative agreement with the U.S. Environmental Protection Agency (EPA), through funding from EPA and the U.S. Department of Energy (DOE), to conduct a life-cycle study of integrated MSW management. The final outputs of this research include a database containing life-cycle inventory (LCI) and cost data and a computer-based decision support tool to help solid waste planners evaluate the environmental burdens and costs associated with integrated MSW management systems. RTI's research team currently includes life-cycle assessment and MSW experts from North Carolina State University, University of Wisconsin-Madison, and Franklin Associates, Ltd. Groups of internal EPA and DOE advisors and external stakeholders are also active participants in this unique forum which brings together experts from industry, federal government agencies, local governments, academia, and environmental advocacy organizations.

Overview of Key System Considerations

Figure 1 highlights the major components of our defined system. The system definition also includes specifications for the types of waste components, waste management upstream processing units, and waste generating sources. Because the waste management stage is the primary focus of this research, it is defined in greatest detail.

In general, all unit operations that have a bearing on the LCI are being evaluated. In cases where some portion of the MSW is recycled, the energy and resources expended and emissions generated in separating, transporting, and converting the recyclables to a new product are considered. These are then compared and netted out from the energy, resources, and emissions for manufacturing the same product from virgin materials. For example, the total amount of energy required to recover the recyclable from the waste stream and convert it to a new product is included in the LCI and termed Er. Similarly, the amount of energy required to produce a corresponding amount of the same product from virgin material is calculated and termed Ev. The net amount of energy (En) saved (or expended) to recycle a material is then calculated as the difference between Er and Ev (En = Er - Ev). Similar calculations are performed for all LCI parameters involved in the recycling and remanufacturing processes.

In operations where energy is recovered (e.g., combustion of MSW or Refuse-Derived Fuel (RDF), combustion of landfill gas), an energy offset is calculated. The methodology used for energy recovery is the same as that described above for remanufacturing. However, an assumption is made that any net energy "saved" offsets electricity generated from fossil fuel (coal, oil, or natural gas) and not from alternative sources (e.g., hydro, nuclear, and geothermal). The rationale for this assumption is that, because the alternative sources are "cleaner," they will be operating at capacity and any energy "saved" will reduce the reliance on electricity generation from "dirtier" sources.

Numerous pieces of capital equipment from refuse collection vehicles, through balers, to major equipment at paper mills are also important parts of the system. In theory, resources associated with the fabrication of capital equipment, as well as the construction of a new facility, should be considered as part of the LCI [2, 4]. This may be particularly relevant in evaluation of MSW management strategies which suggest the construction of a new facility, such as a material recovery facility (MRF), or the purchase of new refuse collection vehicles. Although theoretically correct, the inclusion of these resources introduces additional complexity which may not be necessary. Thus, the amortized purchase price of a facility or a piece of equipment is being used as a screen to evaluate the importance of its inclusion in the LCI. Where the amortized capital cost of a piece of equipment is low relative to the non-labor cost to operate it, an assumption is made that the resources involved in fabrication of the equipment are insignificant.

In the waste treatment and disposal end of the system, the energy associated with the treatment of liquid and solid wastes is also considered. For example, if biological oxygen demand (BOD) is treated in an aerobic biological wastewater treatment facility, then energy is consumed to supply adequate oxygen for waste treatment. Similarly, if a solid waste is produced which requires burial, energy will be consumed in the transport of that waste to a landfill and its burial in the landfill. These and similar parameters are included in the study.

It is important to recognize that the system boundary for cost analysis differs from that used for the LCI. The cost analysis focuses only on the cost of MSW management as experienced by the public sector. Thus, the cost analysis includes the cost of waste collection, transfer stations, MRFs, composting facilities, combustion, RDF plants, and landfills. In addition, where a waste is produced as part of a waste management facility, the cost of waste treatment is included in the cost analysis of that facility. For example, we include the cost of leachate treatment in our cost analysis of landfills. Costs associated with remanufacturing are not included because they are assumed to be reflected in the price paid to a community for recyclables or electricity (as generated through combustion of MSW or landfill gas).

Overview of Allocation Procedures

A major challenge in this research is allocating LCI data to the individual components of MSW. Existing allocation schemes are based on simplistic mass- or volume-based schemes. For this research, we are investigating and developing more accurate allocation procedures. A summary of the key assumptions, allocation procedures, key issues, and improvement needs related to the allocation of LCI data for each major unit operation are presented in Table 1.

Conclusions

The issues presented in this paper convey a sense of the complex relationships of environmental burdens and costs between different waste management operations. As data for upstream raw materials acquisition and manufacturing for MSW components are obtained and added, this complexity will be extended throughout the entire life cycle. However, such a life-cycle perspective is critical for making accurate and efficient decisions about the environmental burdens and costs of integrated MSW management systems.

The value of life-cycle thinking and more formal life-cycle assessment for evaluating integrated MSW management systems has also been recognized by many other countries, including Canada, France, Germany, the Netherlands, Sweden, and the United Kingdom, all of whom have studies underway in this area. We are continuing research in the context of this international initiative to advance the application of life-cycle concepts to integrated MSW management in the United States.

Finally, it should recognized that environmental LCI and cost data only present two components of a very complex system design problem and they must be combined with additional decision making factors to formulate a solution. Additional factors facing solid waste planners might include political pressures, social pressures, aesthetics, and level of available technology. Striking a balance between environmental, cost, and these additional decision making factors is crucial to the development of successful integrated MSW management strategies.

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Table 1. Summary of Existing and Proposed LCI Allocation Procedures

Major Operations	Key Assumptions	Key Design Characteristics	Existing Allocation	Proposed Allocation
Upstream	Closed-loop recycling, and products made from virgin versus recycled material are identical.	Energy grid structure can be specified by user. A typical process design will be used to estimate LCI data.	Mass	None. Primarily dependent on the allocation method used by developer of data.
Collection	Data on population, generation and, capture rate, etc. are input by the user.	Given data for a site, fuel used, and associated emissions are calculated.	Mass	Allocation procedures for collected materials are being evaluated on a volume basis.
MRF	Data on facility cost, labor cost, and productivity are input by the user.	MRF design depends on the collection type and the recyclables mix.	Mass	Allocation procedures are based on the specific equipment (e.g., baler) that is used to process recyclables.
Composting	Data on site conditions are input by the user to derive retention time, cost, and emissions.	Aerated windrow composting design is assumed.	Mass	Allocation procedures are currently being developed through laboratory testing and factorial analysis.
Combustion	Combustion with generation of electricity is assumed from a new facility that meets recent regulations.	Generic cost and design data are used, no detailed design is available.	Mass	Allocation of metal emissions is based on specific components of waste, allocation of other air emissions is based on ultimate analysis of waste components.
Landfill	Data specified by the user are used in designing the landfill.	Landfill designs with or without gas control and leachate collection can be considered.	Mass (organics only)	Allocation procedures are being developed based on analyses of waste components and leachate quality.

Figure 1. Life Cycle of Integrated Solid Waste Management