

THE SIMILARITY OF ENVIRONMENTAL IMPACTS FROM ALL METHODS OF MANAGING SOLID WASTES*

JOSEPH R. VISALLI

Program Manager

Municipal Waste and Environmental Research

New York State Energy Research and Development Authority

ABSTRACT

There are four principal methods of managing solid wastes—recycling, composting, incineration, and landfilling. The public's knowledge about the environmental impacts of each method comes from a wide variety of sources. The media, environmental groups, universities, consultants, government, and competing equipment vendors have provided a vast amount of information that is often incomplete, conflicting, and biased. Consequently, it is difficult to know how well the public understands the environmental aspects of managing waste. However, in distilled form, the publicized popular perspective can probably be summed up as a negative view of incinerators and landfills, and a perception that recycling and composting tend to be environmentally benign. This disparity has created social tensions and political problems in many communities, and has made integrated waste management systems (i.e., a system comprised of all four methods of managing wastes) difficult, if not impossible, to implement. The intent of this article is to reduce current levels of rhetoric and conflict by describing the many environmental impact similarities that exist among the different methods of managing wastes. In addition, the difficulties in comparing these impacts are outlined, and the complexities in comparing impacts from primary and recycled materials processing are discussed. A clear understanding of these similarities and comparative difficulties is a necessary prerequisite to planning integrated systems, and would help to ensure that one type of adverse environmental impact is not merely replaced with another. In this article, the term "environmental impact" is used to mean the concentration or generation rates of various pollutants that are emitted during waste processing operations.

* The concepts, suggestions, and opinions expressed in this article represent the views of the author, and do not necessarily represent or reflect the policies or programs of the New York State Energy Research and Development Authority or of the State of New York.

WHY THE SIMILARITY?

The common methods of managing solid wastes typically involve some type of thermal, chemical, or biological process. A few, such as crushing glass for use as an aggregate, involve strictly physical processes. Incineration is a thermal process. Recycling can be a thermal process (metals and glass) or a chemical process (paper). Composting and landfilling are principally biological processes. All methods involve the handling and sorting of wastes, which are physical processes.

Regardless of the type of process, pollutants will appear in facility emissions, effluents, and ash or sludge residues. Also, with certain processes, pollutants can appear in useable end products as well. In general, the sources of contaminants which cause these pollution problems are due to chemicals in consumer products, chemicals added to the waste stream to facilitate processing, and chemical compounds created during waste processing [1]. The similarities in pollutant characteristics from waste processing operations exist because of three primary reasons:

1. All waste management processes separate out and concentrate metals that are not involved in primary reactions of interest or are not targets for materials recovery;
2. All waste management processes emit a variety of chlorine and sulfur compounds due to their ubiquitous presence in waste or in fuels that are used in the process, or because they are added to the process; and
3. No waste management process can be controlled perfectly, and a variety of unwanted organic and metallic compounds can be created unintentionally and/or emitted during the process.

In essence, the key to understanding the similarities of environmental impacts lies in recognizing the variety of chemicals used to make consumer goods and to facilitate waste processing, and in remembering that the conservation of mass principle must always be satisfied and that no process can be 100 percent efficient.

HEAVY METALS

Heavy metals, such as lead, cadmium, and mercury, appear in a wide variety of consumer products. They are intentionally used in large and small amounts in many consumer products made from metals, paper, plastic, rubber, and leather. Also, trace quantities of heavy metals can be found in many products as a result of unintentional contamination or natural causes.

When heavy metals represent a significant fraction of the weight of a consumer product, they can be recovered through recycling. Examples where heavy metals are used in gross recoverable quantities are: cadmium in nickel-cadmium batteries, lead from lead-acid batteries, and mercury from mercuric oxide batteries and thermometers.

Heavy metals are used intentionally in small quantities in many consumer products. For example, cadmium is used in metal coatings and plating for white goods, electronics and fasteners, and in many types of color pigments for plastics, paints, and printing inks. Lead is used in paints for rustproofing, for electrical stability in PVC (polyvinyl chloride) insulation for wire and cable, in bottle caps, and in the contact base of incandescent light bulbs. Mercury is used in fluorescent lights, in zinc-carbon and alkaline batteries, in power control switches for lights and thermostats, and in mildew-proofing paints. Typically, because of the small quantity used in this type of product, these heavy metals are not recovered for economic reasons.

There are a number of examples where heavy metals contaminate consumer products unintentionally or through natural causes. For example, lead based inks for newspapers are no longer used by most companies. But lead can appear as a trace contaminant in these inks in concentrations up to 600 ppm and still be classified as a non-lead based ink [2, 3]. As a consequence, there is some lead in newspaper ink. A good example of contamination by natural causes is lead and cadmium in paper and wood products. Since these metals are frequently found in soils in concentrations up to 200 ppm for lead and 7 ppm for cadmium [4, 5], they are taken up by trees as they grow.

The significance of heavy metals in consumer products is that *regardless* of how these wastes are managed (i.e., recycled, incinerated, composted, or landfilled), some or all of the heavy metals will become part of the process emissions or effluent, and part of the residue ash or sludge. In the case of recycling, most or some of the heavy metals will be in the end product as well.

Take waste paper for example. If paper containing ink with trace amounts of lead is burned in an incinerator, lead will appear in captured ash and in stack emissions in amounts equal to that originally in the paper. If the paper is deinked and recycled, the lead will appear in "captured" sludge and in the process effluent in amounts equal to that in the incinerator emissions and ash, less the amount remaining in the pulp. The paper sludge must be landspread, composted, landfilled, or incinerated. If the paper sludge (or original waste paper) is landfilled, the lead will eventually appear in leachate as the paper biodegrades. If the paper sludge is landspread or composted, or if waste paper is composted, the lead will be "tied-up" in the soil or compost (humus) until the sludge or compost ultimately biodegrades [6]. At that point lead will remain in a form that is analogous to ash, and can leach or erode into surface or ground water. If the paper sludge is incinerated, lead will appear in captured fly ash and in stack emissions. As a consequence, the amount of lead introduced into the environment as a result of managing waste paper by any of these methods is the same.

In cases where insulated copper or aluminum wire or aluminum cans are burned in an incinerator or smelted at recycling plants, lead, cadmium, and other

heavy metals that originally were in paint pigments or insulation will appear in captured ash and in stack emissions. Since these heavy metals are in captured ash, they also will be in ash disposal landfills for the incinerator or secondary metal smelters. If an alkaline battery or fluorescent light is incinerated, mercury will be emitted as an air pollutant. If these products are landfilled, the mercury will eventually escape either in leachate as an organo-metallic or salt compound or along with biogas.

When steel white goods are landfilled, lead, cadmium, and mercury that originally were in paints, platings, solder, and switches may appear in leachate as the appliances corrode. If the white goods are smelted at a recycling plant, the heavy metals will appear in plant emissions and captured ash, and may appear in leachate from landfilled ash. Again, the amounts of lead, cadmium, and mercury introduced into the environment as a result of managing these wastes by any of these methods is the same. A similar argument can be made for any waste product that contains a small amount of heavy metal that is not worth recovering. Even in instances where heavy metals are used in consumer products in large, recoverable quantities, limitations in process control and in the efficiency of pollution control devices result in some of the heavy metals being discharged into the environment in emissions or effluent and in captured ash or sludge.

A number of examples of heavy metal impacts from a variety of waste management methods are shown in Table 1. No attempt is made here to cover all methods or all pollutants, or to compare or rank order the impacts from the processes. The intent of Table 1 is merely to show that there are heavy metal impacts from all methods of managing solid wastes.

These impacts can also be found at facilities such as material recycling facilities (MRF) where handling, sorting, and preprocessing methods such as paper baling and glass crushing occur. The results of some testing at two MRF's are shown in Table 2. The uncontrolled emissions testing was conducted in a forced air ventilation duct at a facility where paper sorting and baling, glass sorting and crushing, and metals sorting and baling is conducted. This plant processes about twelve tons of waste per eight-hour day. As can be seen, while emission rates in terms of pounds per hour are very small, the concentrations of heavy metals can be quite high. These concentrations are also probably indicative of settled dust that will accumulate in MRF's, and will need to be swept up and disposed of on a periodic basis. In terms of heavy metal concentrations, this dust is comparable to ash from an incinerator. Table 2 also shows the heavy metal content of various residues and discards from a second MRF, where paper sorting and baling, and glass sorting and crushing takes place. As can be seen from this limited testing, heavy metals can be found in a wide variety of consumer products, and hence will be found in waste processing residues. EPTOX tests were not conducted in either study to determine whether processing dusts and residues would be considered toxic by definition.

Table 1. Heavy Metal Impacts in Waste Management Processes

<i>Process</i>	<i>Impact</i>	<i>Reference</i>
Secondary Brass and bronze	Baghouse Dust 1-12% Lead Content	[7], p. 4-36
Recycled paper Deink	Sludge 3-294 mg/kg Lead Dry Weight with Organic Content of 50%	[4], Appendix E, p. E2
Secondary lead	Particulate Emissions Estimated NSPS with Baghouse/Venturi Scrubber .05 lb Lead/Ton Processed	[8], p. 6-5
Recycled paper Deink Other	Influent to Pollution Control 1-320 mg/l Lead 2-900 mg/l Lead	[9], Table V-31
Recycled paper Deink Other	Process Effluent 1-30 mg/l Lead 2-190 mg/l Lead	[9], Table V-31
Recycled iron and steel	Leached Baghouse Dust .6 mg/1-130 mg/l Lead Eptox Test	[10]
Recycled steel	Raw Waste Discharge from Wet Scrubbers 1.2-33 mg/l Lead .06-3.3 mg/l Cadmium	[11], p. 415-420
Sludge—MSW Compost	Dry Basis, 50% Organic 430 ppm Lead 55 ppm Cadmium	[4], Appendix D, p. D-3
MSW landfill	Leachate N.D.—14.2 mg/l Lead	[12], Subpart 2-36
MSW incinerator Ash	Collected Fly Ash 220-26600 ppm Lead 5-2210 ppm Cadmium	[13], p. 74
MSW incinerator Ash	Collected Bottom Ash 110-5000 ppm Lead 1.1-46 ppm Cadmium	[13], p. 75

Table 2. Heavy Metal Impacts from Material Recycling Facilities (MRF)

<i>Uncontrolled Air Emissions^a</i>	<i>Maximum</i>		<i>Minimum</i>	
	<i>PPM</i>	<i>10⁻³ lbs/hr</i>	<i>PPM</i>	<i>10⁻³ lbs/hr</i>
Cadmium	452	.019	141	.0048
Lead	3570	.150	178	.0096
Mercury	330	.014	18	.0012
Chromium	928	.048	93	.0096
Nickel	7647	.260	333	.0140
Total particulate		105.		34.

<i>Residues and Discarded Materials^b</i>	<i>Heavy Metals (MG/KG)</i>				
	<i>Cd</i>	<i>Cr</i>	<i>Pb</i>	<i>Hg</i>	<i>Ni</i>
Rubber	8.6	35.	83.	< .04	< 5.
Yarn (red)	< .6	3.5	10.	.08	3.1
Assorted metals	28.	510.	540.	.05	< 60.
Bottle caps	25.	800.	260.	< .3	150.
Glass	1.0	260.	38.	< .04	55.
Hard plastic	< .2	< 2.	< 2.	< .04	< 5.
Soft plastic	12.	53.	190.	.11	.94
Black/white paper	.31	2.5	11.	.04	4.2
Colored paper	< .2	8.0	17.	.14	< 2.
Cardboard/wood	< .3	2.6	7.6	.07	1.9

^a [14], Appendix D—based on six samples taken during different types of plant activities.

^b [15], based on one set of samples from one day of processing.

The potentially wide variation in heavy metal impacts indicated by the data shown in Tables 1 and 2 is due to four major factors:

- The heavy metal concentration in the waste being processed;
- The type of technology used in the process (e.g., the impacts from using an electric arc furnace, a basic oxygen furnace, or an open hearth furnace for iron and steel recycling are different);

- The type of product being made (e.g., the impacts of deinking newspaper to make recycled newspaper are different than using non-deinked newspaper to make paperboard or builders paper; and
- The type of pollution control equipment that is used (e.g., use of a baghouse will capture a higher percentage of small, more readily leachable metallic particles than a wet scrubber or electrostatic precipitator.

Depending on these factors, a very wide variation in heavy metal impacts should be expected.

CHLORINE AND SULFUR

Chlorine and sulfur are intentionally used to make a number of consumer products. Examples include: chlorine in PVC plastics and insulation, bleached paper products and textiles, and sulfur in tires, cutting oils, and battery acid. Chlorine is also used to facilitate a number of recycling processes. These include using bleach for brightening recycled paper, and salts as fluxes in recycled metal smelting. Chlorine is in table salt, and hence appears in food wastes. Because chlorine and sulfur are ubiquitous in nature, they appear in wood products, yard wastes, and food due to plant uptake from soils. Sulfur and traces of chlorine also can be found in fuels such as oil and coal, which provide the energy needed to process recycled wastes and some types of compostable wastes. Chlorine and sulfur are not directly recovered in any waste management process.

As a result of these many intentional and unintentional uses of chlorine and sulfur, they appear in the emissions, effluents, and residues of all waste management methods. Hydrogen chloride and sulfur oxides are typically found in the emissions of thermal waste management processes such as incineration, and metals and glass recycling. Some examples of the emission rates of these compounds are shown in Table 3. Examples of the concentration of chlorides (metal salts and hydrogen chloride) and sulfur oxides found in the flue gases of municipal waste incinerators and of several thermal recycling processes can be found in [16], pp. 5-27 to 30.

The effluent from paper recycling processes, especially those that contain a bleaching step, contains a wide variety of chlorine based compounds [9]. These tend to be chlorinated organics such as chlorophenols, chloroform, chloroethylene, and chlorobenzene, but also include organic chlorides such as methylene chloride and carbon tetrachloride. Summarizing this information is beyond the scope and intention of this article. In addition, the sludge from controlling organics in the wastewater from paper recycling processes also contains chlorine compounds. If this sludge is dewatered and incinerated, hydrogen chloride will be generated. If this sludge is landfilled, chlorine compounds will be included in leachate and in biogas that is formed during anaerobic decomposition. Data on the type and amount of chlorine compound gases emitted from paper mill sludge landfills are not available.

Table 3. Chlorine and Sulfur Compounds Generated during Thermal Waste Management Processes

<i>Process</i>	<i>Uncontrolled Pollutant Generation Rate</i>	<i>Reference</i>
Incineration	3.9 lbs HCL/hr/tphr	[17], p. 10
Incineration	3.4 lbs SO ₂ /hr/tphr	[17], p. 10
Secondary aluminum	1.7 lbs HCL/hr/tphr	[18]
Secondary aluminum	1.8 lbs SO ₂ /hr/tphr	[18]
Secondary lead	72 lbs SO ₂ /hr/tphr	[8], p. 6-17

Chlorine and sulfur compounds have been found in the biogas produced at municipal solid waste landfills [19]. These compounds include sulfur dioxide, hydrogen sulfide, vinyl chloride, chloroethane, chloroethene, perchloroethylene, and carbon tetrachloride, and are thought to be produced by both chemical and biological metabolic processes occurring in the landfill. Biogases from paper sludge landfills may contain similar compounds, since much of the waste in municipal landfills is paper.

As can be seen, a variety of chlorine and sulfur compounds are emitted by all waste management methods. In many cases, the types of compounds are identical. Typically, thermal processes emit acid gases, while chemical and biological processes emit a wide variety of similar sulfur and chlorinated organic compounds.

ORGANIC AND CHLORINATED ORGANIC COMPOUNDS

Much like the case of heavy metals, organic and chlorinated organic compounds can be found in many consumer products due to intentional use in large and small amounts. Also, trace quantities can be found in consumer products as a result of unintentional contamination from unwanted chemical reactions during the manufacturing process.

When used in large amounts and not mixed with other materials, organic and chlorinated organic compounds can be recovered through recycling. Well known examples of recoverable materials include paper and plastics. When mixed with other materials to make a product, these compounds often cannot be recovered. Examples include waxed and coated paper and polyvinyl chloride plastic insulation for cable and wire.

A wide variety of consumer products contain small amounts of organic and chlorinated organic compounds. Examples include toluene in inks, formaldehyde in particle board and glues, chlorobenzene in cleaners, methylene chloride in

spray propellents, and numerous other compounds used in making paints, solvents, etc. The small amounts and wide variety of these compounds make them nonrecoverable, even if collected separately as household hazardous wastes.

Trace quantities of organic and chlorinated organic compounds are produced unintentionally during the manufacturing of some consumer products and incorporated into the product. The most notable examples in this category include dioxin in paper products and in wood products treated with chlorophenols.

The significance of organic and chlorinated organics in consumer products is that *regardless* of how these wastes are managed, these compounds will become part of the process emissions or effluent, and part of the residue ash or sludge, or they will react during the process to form new compounds.

Paper products are a good example. These products contain small quantities of dioxin [20] that is probably produced during pulp bleaching operations. The dioxin is in the pulp product, and in the process effluent and sludge [21]. If the sludge is incinerated, some dioxin may not be destroyed or more can be formed. The same is true if the paper product is burned in a municipal waste incinerator once it becomes waste. If the waste is recycled, dioxin in the product can be emitted in the process effluent either in solution or adsorbed on suspended and settleable (paper) solids. Or, additional dioxin might be produced if the recycled paper is bleached. The very limited testing conducted thus far indicates that dioxin concentrations in recycled paper sludge and effluents are in the 10-37 ppt range [21]. These very low concentrations represent only the 2, 3, 7, 8 isomer of dioxin (not total dioxin). In addition, standardized dilution factors are not yet used in reporting these concentrations, making comparisons between plants and between different methods of managing waste very difficult.

Dioxin can also be formed during many thermal processes for managing wastes. Some examples are shown in Table 4, where data are based on results from the USEPA Tier 4 Dioxin Study. Since data from secondary aluminum smelters are not available, the potential for dioxin to form is not clear. Oils, grease plastics, and paints are burned off during decoating operations, but only small amounts of chlorine are present to facilitate dioxin formation. Hydrogen chloride is present in large amounts during subsequent smelting operations, but little organic material is present, particularly if electrical induction furnaces (rather than fossil fueled furnaces) are used in the smelting step.

Based upon available data, dioxin can be formed unintentionally and emitted by a number of different waste management methods. Dioxin is formed by chance chemical or thermo-chemical reaction, because no process can be controlled perfectly to ensure that only desirable reactions occur. Likewise, it is emitted because no pollution control device is 100 percent efficient, and formation reactions can take place in these devices as well.

A variety of other organic and chlorinated organic compounds are formed and released during waste management processing. While data are not cited here because of the difficulty in comparing the information (many different types of

Table 4. Dioxin Produced during Thermal Waste Management Processes

<i>Process</i>	<i>Total Dioxin Concentration^a ng/dscm @ 7% O₂</i>
Steel Drum Reclamation with Afterburner for APC ^b	
Inlet to APC —	155 - 737
Outlet from APC —	2.4 - 6.3
Scrap Insulated Copper and Aluminum Wire Reclamation with Afterburner for APC	
Outlet from APC —	27 - 1421
Copper and Other Metals Recovery from Scrap Telephone and Circuit Boards with Afterburner and Baghouse for APC	
Outlet from APC —	7610 - 12100
Municipal Solid Waste Mass Burn Incinerators with ESP for APC	
Inlet to APC —	12 - 374
Outlet from APC —	1.1 - 284

^a Source: [22].

^b Air Pollution Control.

Note: See [16] for additional discussion of this data along with information on dioxin concentrations in process ash. Total Dioxin refers to the sum of the tetra through octa homologues. Concentrations of the 2, 3, 7, 8 isomer of dioxin are typically in the range of .01-1 ng/dscm @ 7% O₂ (10-1000 ppt) at the inlet to APC.

compounds, different sampling and analytical methods, lack of common dilution factors, etc.), a few references are available: landfills [19, 23], paper recycling facilities [9], iron and steel recycling [11], source separated MSW composting [14], incineration [16, 24], and materials recycling facilities [14]. In addition, there are a number of other special waste management processes, such as PCB contamination of residues from automobile and white goods shredding, where the problem is well known but not well quantified.

COMPARING IMPACTS

Comparing the environmental impacts of the four major waste management methods is a complex task due to three major factors [1]. First, different methods result in process emissions that are released into different mediums. For example, incinerating paper causes air pollution, recycling paper causes surface water pollution, and landfilling paper causes ground water pollution.

Second, different methods do not affect the same populations and ecosystems due to different locations for processing plant and residue disposal sites. For example, a mass burn incinerator or (local) landfill will generally affect the population in the locale where the waste originated. If several paper, metals, and glass recycling plants process the same waste stream, the major impacts (other than those from MRF's) will occur in communities where the recycling plants are located—not where the waste originated.

Third, while different methods can generate similar pollutants, they can also generate different pollutants that have different toxicities and risks. For example, vinyl chloride has been found in air emissions from landfills, but not in emissions from incinerators or secondary metal smelters, or in the effluents from paper recycling processes.

Theoretically, risk assessments can be conducted to compare the environmental impacts of different waste management methods on a “common denominator” basis. A preliminary generic risk assessment that compares incineration to landfilling has been developed [25], but similar assessments need to be conducted for recycling and composting. Even then, using this information will be difficult. Recycling impacts will not generally occur in the locale where the wastes are generated, and local governments may not be able to compare these impacts objectively with more local impacts from composting, incineration, and landfilling in environmental impact statements.

SHOULD IMPACTS FROM RECYCLING BE “DISCOUNTED”?

Generally speaking, the impacts due to recycling processes preclude the impacts due to raw materials processing. While the impacts from both need to be considered in the legal sense, the preclusion argument can influence public opinion and political decision making, depending on how the impacts are compared.

In the early 1970s, several attempts were made to compare the pollution resulting from primary and recycled materials production. These comparisons were based on gross pollution measures such as particulate and suspended solids concentration, and did not consider specific hazardous pollutants such as lead. These reports (e.g., [26, pp. 5-9]) conclude that, in general and with a few exceptions, the recycling of waste materials would result in less pollution than that generated as a result of virgin materials processing. These conclusions,

Table 5. Pulp, Paper, and Paperboard Wastes from Virgin and Recycling Processes

Process	Untreated or Raw Waste Loads			
	AVE ^a COD ^e mg/l	AVE ^b BOD ^e kg/kkg ^c	AVE ^b TSS ^e kg/kkg ^c	AVE ^b Flow kg/kkg ^c
Virgin Materials				
Kraft based	869	37	75	150
Unbleached kraft	1259	16	19	41
Sulfite based	3576	103	92	178
Ground wood based	625	15	47	64
Recycled Wastes				
Deink	1958	38	202	71
Non-deink	4037 ^d	9	36	26

^a [9, Table V-32, p. 229].

^b [9, Table VIII-38, p. 464].

^c Kilogram or kiloliter per thousand kilograms of product.

^d 2232 without counting builders paper and roofing felt as products.

^e Chemical Oxygen Demand, Biological Oxygen Demand, Total Suspended Solids.

however, were based on a very broad view of the comparison problem, and did not attempt to take into account different technologies that might be used to process a given material, the quality of input feedstock (i.e., ore versus "prompt" scrap, post-consumer scrap, etc.), or the type and quality of the product being manufactured. If these factors are considered, a different, more complex comparison can result.

Perhaps the best example of this complexity is detailed in a water pollution report on the pulp, paper, and paperboard industry conducted for USEPA [9]. Plants producing a variety of paper-based products were grouped into integrated mills where pulp or paper products are produced from virgin timber, and secondary fiber mills where a variety of paper products are produced from various grades of waste paper. A summary of the average raw waste loadings (i.e., going into pollution control systems) of several water pollution measures for different processes is shown in Table 5. As can be seen, no clear pattern emerges as to whether virgin or recycling processes produce more pollution. In addition, 128 toxic pollutants were measured at all plants, and twenty-five were found to be "of concern" (see Table VI-5 in [9]). Of these twenty-five toxic pollutants, five were found in virgin materials processes only, and eight were found in recycling processes only. Of the remaining twelve toxic pollutants found in both

virgin and recycled materials processes, eleven showed higher levels in the recycling processes, and one was the same for both types of processes. Lead, for example, is clearly more of a problem in deinking process effluents [9] and sludges [4], than in virgin paper manufacturing or in non-deinked paper recycling.

A similar comparison of primary and secondary aluminum and steel production (e.g., [11, 27]) reveal a pattern that is less striking but similar to that shown in Table 5. That is, depending on the technology that is used, the chemical qualities of input feedstock and fuels, the type of product produced, and the types of pollution control that are used, primary materials processing can result in more or less pollution than that which results from recycling.

The mining of ores and the harvesting of trees add to the gross pollution burden that results from primary materials production, but there can be benefits, as well as costs, associated with this aspect. For example, harvesting of pulp trees can lead to increased biodiversity and bioproductivity in forests. On the other hand, less energy is used in processing most recycled materials especially metals, and this reduces environmental impacts due to energy generation. The energy requirements of collecting and transporting virgin and recycled materials is not as clear. All told, while there are clear materials and potential energy conservation benefits to recycling, the picture regarding environmental benefits and risks is complex, especially when specific hazardous pollutants are taken into account. The problems in comparing these risks are similar to those noted previously for comparing impacts from different waste management methods.

SUMMARY

It should be clear that all methods of processing solid waste result in process emissions and effluents, and in ash or sludge residues, that have potentially hazardous compounds. In many cases, the compounds are quite similar. There are, of course, potential dissimilarities. The homologues of organic compounds like dioxin and specific metallic anions may differ for the different processes, and some processes may emit unique pollutants. This will mean that the volatility, solubility, and toxicity of chemical compounds emitted from different processes may be different. Nonetheless, all the processes have the potential to impact public health and the environment adversely.

The lack of this knowledge, and the inability to compare the risks associated with the various methods of managing solid wastes, is a serious problem. Local decisions regarding integrated waste management systems are being hindered or influenced by a biased perception of the environmental impacts from the four major methods of managing solid wastes. By focusing on the environmental impact of incinerators and landfills, regulatory agency actions provide fodder for the NIMBY syndrome ("not in my backyard"), and can act to heighten peoples' fears because the impact risk becomes official and self-fulfilling [28].

While the hierarchy of waste management represents a sound basis for planning integrated waste management systems, current levels of rhetoric and fear regarding the environmental impacts of incineration and landfilling make it very difficult, if not impossible, to implement such systems. More detailed information on the environmental impacts of the four major methods of managing solid wastes and a comparative risk assessment is needed [1, 29]. Familiarity with such information should reduce current levels of rhetoric and fear, and may enable integrated waste management systems to be planned and implemented in a more objective manner.

REFERENCES

1. J. R. Visalli, Environmental Impact Considerations in Recycling Solid Wastes, *Journal of Resource Management and Technology*, 14:4, December 1985.
2. J. S. Lavelle and J. M. Fetsko, *Lead in the Consumer Environment: A Literature Survey*, 2nd Edition, National Printing Ink Research Institute, Lehigh University, Bethlehem, Pennsylvania, May 1977.
3. P. Volpe, Private Communication, Natural Association of Printing Ink Manufacturers, Inc., Harrison, New York, January 14, 1988.
4. *Pulp and Papermill Sludges in Maine: A Characterization Study*, E. C. Jordan and Co., Maine Department of Environmental Protection, National Council of Paper Industry for Air and Stream Improvement, National Resources Council of Maine, Paper Industry Information Office, University of Maine, September 1984.
5. J. B. Forste, Complying with Land Application Regulations, *Biocycle*, 28:9, October 1987.
6. P. Linkens, Private Communication, Biology Department, Clarkson University, Potsdam, New York, November 5, 1987.
7. *A Review of Standards of Performance for New Stationary Sources—Secondary Brass and Bronze Plants*, USEPA, OAQPS, EPA-450/3-79-011, June 1979.
8. *A Review of Standards of Performances for New Stationary Sources—Secondary Lead Smelters*, USEPA, OAQPS, EPA-450-3-79-015, March 1979.
9. *Development Document for Effluent Limitations Guidelines and Standards for the Pulp, Paper, and Paperboard Industry*, EPA, EGD, EPA 440/1-82/025, October 1982.
10. D. E. Oman, Hazardous Waste Minimization: Part VI Waste Minimization in the Foundry Industry, *Journal of Air Pollution Control Association*, 38:7, July 1988.
11. *Development Document for Effluent Limitations Guidelines and Standards for the Iron and Steel Manufacturing Industry*, USEPA, EGD, EPA 440/1-82/024, May 1982.
12. *Draft EIS for Revisions to 6 NYCRR Part 360—Solid Waste Management Facilities*, New York State Department of Environmental Conservation, Albany, New York, April 1988.

13. E. W. Repa and J. V. L. Kiser, Disposing Ash, *Waste Alternatives—Landfill of the 90's*, December 1988.
14. B. Commoner, et al., Draft Final Report, *Development and Pilot Test of an Intensive MSW Recycling System for the Town of East Hampton, New York*, New York State Energy Research and Development Authority Contract No. 982-ERER-MW-87, NYSERDA, Albany, New York, November 1, 1988.
15. Galson Technical Services Laboratory Report, *Broome County Recycling Demonstration*, New York State Energy Research and Development Authority Contract No. 1013-ERER-MW-88, July 5, 1985.
16. *National Dioxin Study: Tier 4—Combustion Sources, Engineering Analysis Report*, USEPA, OAQPS, EPA-450/4-84-014h, September 1987.
17. A. J. Teller and J. Y. Hsieh, Emission Control for MSW Incineration, *Resource Recovery*, January/February 1988.
18. *New York State Department of Environmental Conservation Stack Test Data from a Secondary Aluminum Smelter*, provided by R. Young, July 1988, and Private Communication with Facility Engineer, D. Lagoe, December 1988.
19. J. A. Wood and M. L. Porter, Hazardous Pollutants in Class II Landfills, *Journal of Air Pollution Control Association*, 37:5, May 1987.
20. Traces of Dioxin Found in Range of Paper Goods, *New York Times*, p. 1, September 24, 1987.
21. J. Barney, *Summary of Dioxin Data for Paper Mill Sludges*, USEPA, Region 5, Chicago, Illinois, September 25, 1987.
22. W. Kelley, Measurement of Dioxin and Furan in Combustion Flue Gases: Results and Problems, *Proceedings of the International Municipal Waste Incineration Workshop*, Environment Canada, Montreal, Quebec, October 1-2, 1988.
23. R. E. Zimmerman, et al., *Landfill Methane Recovery Part III: Data Analysis and Instrumentation Needs—Final Report*, Gas Research Institute, Chicago, Illinois, December 1983.
24. *Results of the Combustion and Emissions Research Project at the Vicon Incinerator in Pittsfield, Massachusetts*, New York State Energy Research and Development Authority, Albany, New York, Report 87-16, June 1987.
25. *Managing MSW: A Comparative Risk Analysis of Landfill and Resource Recovery Facilities*, CONEG Policy Research Center Report, Energy Systems Research Group, Inc., Boston, Massachusetts, ESRG Report 87-102.
26. *First Report to Congress: Resource Recovery and Source Reaction*, USEPA, SW-118, 3rd Edition, 1974.
27. R. C. Ziegler, et al., *Environmental Impacts of Virgin and Recycled Steel and Aluminum—Tables 35 and 51*, EPA/530/SW-117c, February 1974.
28. D. Hanson, Low Risks a Problem in Chemical Regulation, *Chemical and Engineering News*, January 5, 1987.
29. Environmental Effects, Transport, and Fate Committee, EPA Science Advisory Group, *Evaluation of Scientific Issues Related to Municipal Waste Combustion*, USEPA, Science Advisory Board, SAB-EETFC-88-25, p. 18, April 1988.

Direct reprint requests to:

Joseph R. Visalli
Program Manager
Municipal Waste and Environmental Research
New York State Energy Research and Development Agency
2 Rockefeller Plaza
Albany, NY 12223