Municipal Solid Waste Recycling Issues

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Abstract

Municipal solid waste (MSW) recycling targets have been set nationally and in many states. Unfortunately, the definitions of recycling, rates of recycling and the appropriate components of MSW vary. MSW recycling has been found to be costly for most municipalities compared to landfill disposal. MSW recycling policy should be determined by the net cost to the community and to society more generally. In particular, recycling is a good policy only if environmental impacts and the resources used to collect, sort and recycle a material are less than the environmental impacts and resources needed to provide equivalent virgin material plus the resources needed to dispose of the post-consumer material safely. From a review of the existing economic experience with recycling and an analysis of the environmental benefits (including estimation of external social costs), we find that, for most communities, curbside recycling is only justifiable for some post-consumer waste, such as aluminum and other metals. We argue that alternatives to curbside recycling collection should be explored, including product take back for products with toxic content (such as batteries) or product re-design to permit more effective product re-manufacture.

1. Introduction

The USA is a "throw away" society whose total and per capita waste has been increasing for more than forty years. The average American produces about 4.4 pounds of municipal solid-waste (MSW) each day, resulting in roughly 210 million tons per year for the nation [Census98]. Most MSW goes to landfills. From examination of landfill wastes, Rathje [92] found that the composition of landfill mass deposited in the 1980s was roughly 40% paper, 8% organics, 8% plastic, 11% metal, 6% glass, 12% construction/demolition waste and 15% additional, unclassified waste.

Some people dislike landfills because they are a nuisance. Others have been alarmed by the closing of landfills, the threat of running out of space in landfills, and the waste of resources when MSW is sent to landfills. The almost universal aversion to landfills comes from the history of city dumps that smelled, looked terrible, were infested with rats and other pests, and posed risks to health.

Sanitary engineers responded by designing modern landfills that pose few of these problems. Modern landfills have a minimum odor nuisance, do not have pests, and pose few problems after they are closed. With rules mandating daily cover, clay and rubber liners, clay caps, and leachate collection systems, modern landfills are a tribute to sanitary engineering.

Even with these improvements, landfills are still unpopular. The traffic and other nuisances of even a modern landfill are a bother to nearby residents. Methane emissions from landfills can pose a safety hazard to nearby buildings and contribute to urban ozone problems and global warming. In most communities, groups attempt to close current landfills and have made it extremely difficult to site new ones. Dislike of landfills has led to a popular revolt in states like Pennsylvania and Virginia against taking MSW from other states, although interstate transfers of waste are the cheapest way of handling MSW in particular situations [Louis96].

In the popular press, the closing of many landfills in the last decade and the opposition to opening new ones has led to concern that we are running out of landfills. The number of landfills has declined significantly because of new regulatory requirements for improved design and management. However, the decline in tipping fees in recent years is evidence that landfill space meeting the new regulatory requirements is readily available [Biocycle98].

Another objection, that landfills waste precious resources, has led to two actions: energy recovery units and recycling. MSW contains a great deal of energy that potentially could be recovered. It also contains a great deal of valuable raw materials. While energy recovery reduces the landfill problem (it reduces the volume by 2/3) and extracts some of the raw materials value in the MSW, it recovers only a tiny fraction of the potential value in the materials.

Many states and cities have responded by requiring households to recycle; some have specific goals, such as requiring 50% recycling of MSW [Goldstein97]. However, little analysis underlies the recycling targets [Garrick98]. There has been some analysis of whether MSW recycling is beneficial, particularly recycling with curbside collection of recyclables [Denison96, Tierney96].

This paper considers the life cycle economic and environmental impacts of MSW recycling. We seek to identify cost-effective policies to achieve environmental and sustainability goals for MSW. Similar to [Haith98], we emphasize that some recycling improves environmental quality and sustainability while other recycling has the opposite effect. For example, recovering aluminum beverage containers in an urban area generally benefits the environment and lowers the use of energy and other resources; in contrast, the minuscule amount of aluminum in consumer packages is likely to require more energy and other resources separate and recycle than it saves.

Before recycling can occur, the materials must be collected from consumers, a reversal of the logistics system that distributed products to consumers. People familiar with the complexity of the current distribution system should not be surprised at the difficulty of designing and operating a "reverse logistics" system that is universal, cheap, and reliable. Curbside pickup is one of several reverse logistics systems with its peculiar advantages and drawbacks. Other reverse logistics systems include consumers taking recyclables to a central collection point or returning them to the retailer as part of a deposit-refund system. The alternative systems have radically different implications for the amount of work that consumers must perform, the cost of collection and sorting, and the overall efficiency of the system.

2. What Should We Do with Products at the End of Their Lives?

Despite efforts of the Environmental Protection Agency [EPA99] and the legislation and regulations mandating recycling programs, there is no consensus on what constitutes MSW recycling, either on which post-consumer waste is included in MSW or on how to measure the fraction of material that is recovered for re-use.

When a consumer no longer wants to keep a product, any of the following options may be possible. The product might be

reused (as with old furniture),
re-manufactured (as with copier machines or automobile alternators),
re-cycled into the same use in a "closed loop" (as with asphalt pavements),
re-cycled into a lower valued use (as with re-cycled plastic molded into park benches),
incinerated (as with burning paper to recover energy),
landfilled (as with most MSW), or
discarded directly to the environment (as with littering).

Individuals and organizations differ on how many of these categories should be included within the definition of "recycling," although most people would include categories (1) - (4). If incineration productively recovered most of the energy in MSW (5), there would be a good case for including it as recycling. Storing the waste in a landfill until it is recovered might even be considered recycling.[5] EPA has been working to standardize definitions and methods of calculating the

[5] The transformation from raw materials to products doesn't increase or reduce the amount of iron, aluminum, carbon, or hydrogen on the Earth. Similarly, use and disposal of a product does not change the number of atoms of each element, although both production and disposal processes change the chemical form and location of the product and both consume large amounts of energy,

proportion recycled.

The definition of recycling distracts society from the real issues: environmental quality and sustainability. The definition matters only because recycling goals have been specified. We repeat that the goal is not to increase recycling, it is to improve environmental quality and sustainability. Recycling, whatever the definition, is one possible way to accomplish these goals.

Some laws declare that, for example, 50% of MSW must be recycled without defining what is included in MSW. A strict definition might include only the waste collected at curbside from residences. However, this definition excludes important consumer products such as batteries and automobiles, as well as waste from residential construction and demolition. We prefer a broader definition that includes all post-consumer waste that ordinarily is sent to a landfill. However, since little of the demolition waste is a candidate for recycling, an arbitrary requirement for recycling doesn't make sense.

A final issue is the controversy about measuring what is recycled. Roughly 95% of automotive lead-acid batteries are returned for recycling. Does this mean that 95% of automotive batteries are recycled? Typically, the materials other than lead in the battery are discarded. Thus, 40% of the battery weight is discarded. Of the lead in these batteries, 95% is retrieved in the secondary smelter recovery process. Thus, of all lead-acid batteries taken from cars, 54% (0.95x0.6x0.95) of discarded automobile battery material is recycled, and 90% (0.95x0.95) of the lead in these batteries is recycled. In our judgment, the best measure of recycling is the proportion of discarded products that are returned to a productive use, or 54% in the case of lead-acid starting/lighting/ignition batteries.

3. What should be the objectives of MSW recycling?

Perhaps the most widespread goal for MSW recycling is to increase recycling. Many people feel guilty about our profligate life style and feel that steps need to be taken to improve environmental quality and sustainability. Recycling seems to be an obvious response. We agree with the concern

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primarily from petroleum, coal, and natural gas. In a sense, a landfill can be thought of as a giant storage bin of materials.

Can these landfilled materials ever be recycled? In developing countries, scavenging at dumpsites is still common [Huysman94]. If the price of MSW materials increases sufficiently or if effective landfill "mining" technologies are developed, then the materials in landfills will be recovered and recycled. For example, one can imagine small robots burrowing through closed landfills to retrieve valuable objects such as nickel-cadmium batteries or trace gold. Efforts to mine landfills in the future might be aided by some separation by type of material in the present, e.g. construction and demolition debris might be separated from discarded consumer appliances. This idea of "monofills" could increase the portion of valuable materials such as metals in particular zones of a landfill, thereby making future landfill mining more likely.

for the environment and sustainability but do not regard recycling itself as a goal. Instead, we see four primary goals of MSW recycling:

1. We want to save landfill space.
2. We want to save money from handling MSW. Governments face fiscal difficulties and constant criticism for being inefficient in providing public services.
3. We want to increase environmental quality, by lowering discharges of pollutants. In particular, the goal is to eliminate dissipative emissions of hazardous and toxic materials to the environment, including greenhouse gases and toxic materials sent to MSW landfills.
4. We want to increase the sustainability of the economy. This implies minimizing the use of depletable resources such as ores or petroleum and reducing the use of renewable resources, such as lumber, to sustainable levels.

Low cost recycling is important for environmental as well as fiscal reasons. For example, petroleum to run collection trucks is just as much a use of this resource as petroleum to make consumer products; future generations will not have a barrel of petroleum used for either purpose. The resources going to recycling are an important determinant of which MSW alternative is best at achieving the goals of environmental quality and sustainability. Sound policy requires examining the full range of alternatives to compare the resources, energy, and labor needed for the entire life cycle of each alternative [OTA89]. The comparison between recycling and making new products must be an even-handed examination of the total use of energy and nonrenewable resources and dissipative emissions.

We can state our conclusion as the "economic-environmental criterion:" Recycling is good policy only if environmental discharges and the resources used to collect, sort, and recycle a material are less than the environmental discharges and resources needed to provide an equivalent virgin material plus the resources needed to dispose of the material safely.

For example, glass is made of sand and potash, neither of which is in short supply. Glass is non-toxic: discharging it to the environment poses no risk, save from cuts. For recycling glass to be a sensible environmental policy, the energy, equipment, and labor associated with collection, separation, and recycling glass should be smaller than the energy, equipment, and labor associated with producing the sand and potash, including the energy, equipment, and labor required to collect and landfill the glass. If the resources associated with collecting, separating, and recycling glass are larger than the resources associated with securing the potash and sand and with landfilling the glass, recycling does not help either environmental quality or sustainability.

A more general form of the economic-environmental criterion applies to reuse, remanufacturing, and other programs for dealing with MSW such as resource reduction: A program is beneficial to the environment and sustainability only if it actually reduces energy, resource use and pollution, taking account of the full life cycles of the program compared to its alternatives.

A limitation to this statement of the economic-environmental criterion is that it neglects the fact that current products were not designed to be recycled. As a consequence, many cannot be recycled easily. For example, Lave [98] shows that nylon carpet could be redesigned to improve the implications of recycling for environmental quality and resource use.

4. Is MSW recycling profitable?

At one time, advocates claimed that recycling MSW would be profitable for municipalities. Recycling programs were expected to more than pay for themselves. A few categories of post-consumer wastes can be recycled or re-used profitably; aluminum cans and automobiles are common examples. For most categories of MSW, the costs of collection are likely to exceed the revenue from sales. Based on national data, Ackerman [96] estimated that curbside recycling cost $142 per ton even after a credit for avoided tipping fees (Table 1). Revenues from the sale of some, but not all, recyclables might offset this cost. Revenue for a typical bundle of MSW recyclables (including metals, paper, and glass) was estimated as $140 per ton in 1995 but only $45 per ton in 1997 [Berenyi97]. Combining the cost of $ 142 per ton and the 1997 revenue of $ 45 would result in a revenue loss of $ 97 per ton for municipalities. The composition of recyclables is also important, with aluminum cans commanding revenue more than ten times that of recycled paper. However, at current price levels, curbside collection programs for most recyclable materials cost more than landfilling and must be justified on environmental grounds.

Table 1: Average Annual Curbside Recycling Costs in the US

(1)	(2) Per Household ($)	(3) Per ton ($)
Avoided MSW Disposal Cost (Savings)	(7)	(31)
Recycling Collection	27	123
Avoided MSW Collection	0	0
Recycling Processing	11	50
Total Cost (Sum of Four Categories)	31	142
Revenue from Sale of Recylables (1997)	10	45
Net Cost after Sale of Recyclables	21	97

Source: [Ackerman 96] for costs, [Berenyi97] for revenue.

Separate collection of recyclables is particularly expensive since each residence is visited twice [Lave94]. Collection trucks that can carry regular MSW and recyclables are preferable, since each residence gets a single pickup. However, trash pickup is likely to get much more expensive since the truck will be delayed by any sorting and the truck must visit both the landfill and the recycling facility. Since the trucks will be collecting trash and recyclables in different compartments, one compartment will fill first requiring the truck to go to the recycling site and landfill even though the other compartment(s) is partially empty. Having recycling compartments that are too big or too small will increase collection costs sharply. Drop-off points can reduce municipal costs, but may incur substantial private costs if they require additional driving.

5. Does MSW recycling help the environment?

Denison [96] reviewed several studies of overall environmental impact of recycling MSW, concluding that recycling saved energy and resource inputs. Denison evaluated the bundle of household recyclables rather than each component; he implicitly has the high value components subsidize the low value components. Pearce [95] found that the net benefit of recycling is not always positive. Our analysis suggests that recycling some of the components, e.g., aluminum, has a much higher potential for recycling than do other materials, e.g., glass. An analysis of environmental externalities for curbside recycling in Milton Keynes, England also found significant differences in benefits for different components of MSW [Craighill96].

Table 2 gives a direct indication of the environmental benefits of avoided production due to recycling of different commodities. This table summarizes electricity use, fuel use, energy (including electricity and fuels), industrial water intake, some conventional pollutant emissions, global warming potential, toxic air releases and hazardous waste generation for 1,000 metric tons of different commodity productions. These environmental effects are calculated by tracing all of the economy-wide supply chain requirements for the various commodities using the 500 sector 1992 economic input-output model developed by the US Department of Commerce coupled with ancillary environmental impact calculations [Hendrickson 98, Horvath97]. For example, toxic air emissions are computed by multiplying the level of activity in each of the 500 commodity sectors by the average level of toxic air emissions per dollar of output. These calculations show the savings from recycling by avoiding this primary production.

A final row in the table represents a rough estimate of the external environmental costs of this production. It is based upon estimates of the social costs from air emissions of conventional pollutants [Matthews99, Hendrickson98b]. Chung [97] and Craighill [96] also made estimates of such external costs, but for Hong Kong and the United Kingdom, respectively. Included in these costs are the estimated health effects related to ozone, particulate and other conventional or "criteria pollutants." The estimates are reported in thousands of social cost dollars, so a metric ton of primary aluminum is estimated to have an external environmental cost due to air emissions of $ 220 (Table 2). Comparing this number to the estimated cost of collection ($142 per ton), aluminum appears to be a good candidate for recycling, even without counting the economic costs of producing a ton of aluminum.

Our calculations find that avoiding primary aluminum production has the greatest environmental benefit. Recycling aluminum is generally profitable because of the high price for this scrap. Ferrous metals and logging have intermediate benefits. Avoiding additional glass production has relatively small environmental benefits for the various categories of environmental emissions we analyzed, especially since the numbers for glass are over-estimates because they include the final container processes which would also be incurred for recycled glass.

Table 2: Environmental Effects of 1,000 Metric Tons of Production for Different Commodities – Savings Available from Recycling

Category	Primary Aluminum	Blast Furnaces and Steel Mills	Glass Containers	Logging
Electricity (million kW-hrs)	21	1	0.1	0.06

Fuel Use (metric tons)	1700	850	470	800
Total Energy Use (terajoules)	58	25	2	4
Water Intake (million gallons)	29	23	0.4	0.6
SO2 Emissions (metric tons)	46	27	1	0.9
Particulate Emissions <10micron (metric tons)	1	1.2	0.09	0.02
Global Warming Potential (metric tons CO2 equivalent)	4500	2200	120	230
Hazardous Waste Generated – RCRA (metric tons)	110	26	3	7
Toxic Air Emissions – TRI (metric tons)	2	0.2	0.1	0.5
External Cost due to Criteria Air Emissions (000's $)	220	11	0.7	8

Notes:

1. Economic effects are calculated throughout the US economy using the US Department of Commerce's 500x500 commodity 1992 input/output model.
2. Prices for the various commodities typically vary considerably over time and space. Assumed prices for these calculations are: blast furnace and steel mills $ 135/ton; aluminum $ 1,500/ton; glass $ 50/ton; logs $ 300/ton (or $ 500/thousand-board-feet)

A full analysis of the environmental effects would also include the environmental effects associated with collection, sorting and processing of recycled materials. These processes require capital equipment (especially trucks) and energy use (for truck operation and sorting).

7. A Policy Test for Recycling

Should materials be recycled or put in a landfill? The question can be answered with the economic-environmental criterion.

One form of the economic-environmental criterion is that faced by companies. What should be done with the waste generated by a manufacturing plant, service center, or office? The company would like to reduce its costs and so calculates whether recycling is less costly than disposal. Consider, for example, a stamping plant that turns out steel parts for automobiles, generating large quantities of steel scrap. This "prompt scrap" is of high quality and commands a relatively high price. Automobile companies would laugh at the idea of paying to landfill this scrap steel, since they get paid handsomely to recycle it. Similarly, many companies find that recyclers will pay high prices for their scrap office paper.

A well-run company will recycle waste if it costs them less than disposing of it; they should separate and collect the valuable materials for recycling and dispose of other materials. This means that the market prices of scrap, landfill costs, and separating and transport costs determine whether "waste" is recycled or landfilled. Thus, the first form of the economic-environmental criterion is recycle only if the cost of collection and separation is less than the cost of collection and disposal. An environmentally conscious company might decide to do more recycling than is implied by the economic-environmental criterion. However, as markets get more competitive, companies are forced to cut "unnecessary" expenses, but it needs to be careful that the additional unit recycled actually reduces environmental discharges and materials use. For a municipality, this form of the economic-environmental criterion is modified slightly: The city seeks not only to minimize its costs, it also seeks to avoid local environmental nuisances. This means that a city might choose an alternative that is somewhat more expensive, if this avoided a nuisance.

This "private" form of the economic-environmental criterion squarely faces the realities of companies. They are driven by costs. They will recycle materials where the costs of collection plus the tipping fee is greater than the cost of collecting and sorting the recyclables less the revenue from selling the recycled material. While many companies would like to do good, they are severely limited by competition or current budgets. Cities face tight budgets as well.

Recycling only materials that satisfy this first form of the economic-environmental criterion is not fully satisfactory in protecting the environment or working toward a sustainable future. If there are externalities associated with extracting resources, landfilling, or sorting recyclables, or myopia in managing resources, the private costs faced by companies or cities neglect important dimensions of the MSW decision. For example, the regulations governing landfills might be inadequate, leading to future environmental degradation. If so, the price of landfills will be "too low" and landfilling will damage environmental quality. The obvious remedy is to change the landfill regulations so that environmental quality will not suffer. Similarly, society may give too little weight to the needs of future generations for raw materials. If so, raw materials will be priced too low and companies will choose to do too little recycling. An obvious remedy is to impose a tax to increase the prices of raw materials so that more will be saved for future generations.

Another example might be inadequate environmental regulations associated with mining coal, which is then used in producing aluminum and steel. If so, the cost of producing steel and aluminum would be too low, discouraging recycling of these materials. An obvious remedy is to improve environmental regulations concerning coal mining. Mandating steel and aluminum recycling does decrease the amount of coal that is mined, but the coal is still mined in a way that damages the environment.

Still another example might be the profligate use of fossil fuels leading to greenhouse gas emissions. If recycling is more energy efficient, low recycling rates lead to "too much" greenhouse gas emissions. The externality could be internalized either by a fee on greenhouse gas emissions (making production of virgin materials more expensive) or a cap on the total emission of greenhouse gases, which would mean the production of virgin materials was "inadequate" for the needs of the economy, thereby increasing the price of recycled materials. More generally, the externalities can be accounted for by having regulatory agencies give direct orders to firms and consumers that internalize the externalities. However, in an economy as large and complicated as that of the United States, regulatory agencies do not have the knowledge or personnel to figure out what actions will internalize the externalities. An alternative is to use the market system by imposing taxes to account for the externality. The use of market incentives has greatly reduced the cost of achieving such environmental objectives as reducing the emissions of sulfur dioxide to prevent acid rain and the emissions of chlorofluorocarbons to prevent the destruction of stratospheric ozone [Schmallensee98]. This approach is called "full cost" pricing, meaning that the social as well as private costs are included in prices.

The second form of the economic-environmental criterion, the "public" formulation, is to internalize all important externalities in prices or regulations so that prices and practice reflect the full environmental costs associated with each action, including the availability of resources for future generations. Once this is done, the private form of the recycling policy prescription becomes an accurate social formulation of the right decisions. Once the important externalities have been controlled or internalized, materials should be recycled only if the cost of collection and separation, less the revenue from selling the recycled material, is less than the cost of collection plus the tipping fee. The private version of the economic-environmental criterion helps to understand current recycling behavior. The social version of the economic-environmental criterion helps to guide us toward the best social policy.

Does this social version of the economic-environmental criterion help sustainability? It requires society to examine the need of future generations for resources and to satisfy this need either by explicitly preserving some resources for future generations or by raising the prices of raw materials through a "sustainability" tax. Such a tax may not be needed for metals and other durable resources. Since landfills simply store these materials, they are available whenever society decides to "mine" them.

For fossil fuels and other depletable resources, there is little alternative to explicitly examining the needs of future generations. This analysis is difficult since technology changes and the tastes of future generations are likely to change. For example, planting oak trees in the past to enable the current generations to have masts for sailing ships has not proven to be much of a boon. The technology for energy production has been changing rapidly. It is hard to know what future generations will desire and hard to know how much energy they will need to provide a life style that they will find at least as good as the current generation finds its life style.

8. Conclusion and Future Research: Is MSW recycling the best policy?

The goal of MSW recycling programs should not be to increase MSW recycling. The goal should be to increase environmental quality and the sustainability of the economy. Our hopes concerning MSW recycling must be tempered by the economic-environmental criterion: Recycling will benefit the environment and sustainability only if the energy, resources, and environmental discharges associated with recovering the material are less than those associated with producing virgin material. Curbside recycling of post-consumer metals can save money and improve environmental quality if the collection, sorting, and recovery processes are efficient. Curbside collection of glass and paper is unlikely to help the environment and sustainability save in special circumstances.

Some alternative policies also deserve consideration as MSW recycling options. Deposit/refund schemes offer an important option. In these systems, products earmarked for recycling would require a consumer (or producer) deposit, with a refund to the consumer when they are returned. For example, each return of a nickel-cadmium battery would receive a refund sufficient to make it attractive to undertake the return. Aluminum cans and metal scrap are sufficiently valuable that "trash pickers" routinely search for these post-consumer wastes even without deposit/refund schemes. An advantage of these deposit/refund schemes is that products and materials can be individually targeted for removal from the MSW stream. Palmer [97] concludes that deposit/refund schemes can be more efficient at waste reduction than recycling subsidies. While deposit/refund systems can recover the vast majority of the product, the energy and resources required could be large. For example, if consumers make a special trip to return the recoverable materials, the energy required is likely to exceed the energy saved by recovery.

Another policy that can be beneficial is product take-back by manufacturers, especially when remanufacturing and re-use is available [Klausner 98]. This option attempts to preserve the value of the original goods. In contrast, recycling seeks to recover only the value of the raw materials. Product take-back for small appliances, such as hand tools, might have significant benefits. In particular, the raw material value of most complicated products such as computers is only a small fraction of the product value. Also, manufacturers would have incentives to alter designs to make re-manufacture and use more effective.

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