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Plastic incineration versus recycling: a comparison of energy and landfill cost savings☆

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Abstract

Recycling of municipal solid waste has been offered as an attractive alternative to traditional forms of waste disposal such as landfilling. In recent years, attention has also been focused upon recycling as an effective method of energy recovery. The focus of this article is to address these assumptions and to determine the degree of energy saving achieved through recycling, particularly in comparison to waste-to-energy conversion. The theoretical cost saving arising from the recycling or reuse of raw materials found in municipal solid waste is presented along with the theoretical energy value of converting plastic to energy by combustion. An energy cost saving from recycling is proven for many recyclable products, excluding plastics. Given current recycling technology, maximization of energy recovery from plastic recycling can only be accomplished through waste-to-energy conversion, which may have other undesirable results.

Keywords: Recycling; Waste-to-energy (WTE); Incineration; Municipal solid waste (MSW); Energy; Energy recovery

1. Introduction

Energy savings result from waste recycling if the energy used in collecting, separating, and treating reclaimed wastes, along with subsequent processing, is less than the energy used in originating and processing primary materials and disposing of wastes [1]. The Environmental Protection Agency (EPA) has made estimates of the content and quantity of municipal solid wastes in the United States [2–4]. Other studies have been conducted to ascertain the energy savings per unit weight for each component of

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municipal solid waste (MSW) [1, 5]. Based upon these previous studies, the theoretical cost saving can be calculated for the recycling or reuse of raw materials found in municipal solid waste, both in energy units and in dollars. Furthermore, the cost saving of recycling can be compared to the recovery of energy from plastic incineration.

2. Background

The energy cost savings evaluated in this study arise from two different recovery operations. First, the recycling of certain products requires much less energy than producing the product from raw materials. This type of energy cost saving is called avoided energy cost. Aluminum and steel are excellent examples of MSW components that have high avoided energy cost values because they require much less energy to recycle than to produce from virgin material. Table 1 gives the energy cost avoided by recycling aluminum [1]. The recycling costs include all costs except sorting of the post-consumer MSW. It is assumed that the sorting is conducted by the consumer; however, the evaluation does include the cost of transporting sorted material. A rank ordering of all the MSW components by energy cost saving is given in Table 2.

Table 1
Comparison of unit energies for primary and secondary processing of aluminum [1]

Type of process	Primary processing (GJ/t)	Secondary processing (GJ/t)
Refining	193.0	5.5
Processing (benefication)	41.5	5.4
Procurement and transport	0.5	2.1
Total	235.0	13.0

Table 2
Energy cost saving of selected MSW components [1]

MSW Component	Energy savings (GJ/t)
Aluminum[a]	222.0
Incinerated plastics[a]	32.6
Nonincinerated plastics[a]	0.0
Recyclable steel[b]	12.6
Paper and paperboard[a]	7.0
Glass[a]	6.0
Yard waste	0.0
All other	0.0

[a] See Ref. [1].
[b] Steel Can Recycling Institute, 28 March 1990.

The second type of energy cost saving evaluated is energy recovery from the use of MSW as fuel in waste-to-energy (WTE) processes, which converts the material to energy instead of being reused or recycled. Plastic was the only MSW component considered for waste-to-energy conversion and then only under certain conditions. In most cases, WTE conversion of plastic is the only economical alternative for recycling large quantities of post-consumer plastic at this time. The term *energy cost savings from recycling* refers to both avoided cost saving, if any, and WTE saving. Adequate information is presented in each case for the reader to differentiate the source of the energy cost saving.

3. Methodology of energy cost saving analysis

Several different scenarios must be evaluated to correctly analyze the effectiveness of recycling for energy recovery. Complete analyses have been presented elsewhere; however, a summary of the four most important scenarios will demonstrate the energy saved through recycling and WTE [1, 5].

Case 1, the reference case, assumes all MSW material that can be recycled will be recycled without regard to relative economic cost or benefit. This scenario serves as a reference case from which other scenarios can be calculated. Case 2 is the most likely case based upon current trends in MSW management and recycling. A recycling rate of 25% across-the-board recycling is assumed along with total exclusion of yard wastes from landfills. In Case 3, it is assumed that all material is recycled, but plastic is converted to energy in the WTE process. Case 4 is similar to Case 2 but with plastic conversion by WTE.

An example (Case 1) of the format of the results is presented in Table 3. Column 1 of the table lists the materials considered in this report. Materials other than those

Table 3
Case 1: Energy saving analysis from 100% recycling and no WTE conversion [5]

Material	Percent of material recycled	Per capita energy savings per annum[b] (MJ)	Per capita energy savings 1991–2000 (MJ)	Per capita energy savings per annum[b] (discounted $)	Per capita energy savings 1992–2000 (discounted $)
Paper and paperboard	100.0	1816	19148	$4.92	$48.29
Glass	100.0	291	2810	$0.79	$7.10
Aluminum	100.0	1126	13530	$3.05	$34.02
Recyclable steel	100.0	122	1081	$0.33	$2.74
Plastics[a]	100.0	0	0	$0.00	$0.00
Yard wastes[a]	100.0	0	0	$0.00	$0.00
All other	0.0	0	0	$0.00	$0.00
Total		3355	36569	$9.09	$92.15

[a] Energy savings only as WTE conversion value.
[b] 1991 value.

detailed are combined in the category of *All Other* wastes. Column 2 defines the percentage of materials to be recovered from recycling; in this case 100% for all components (yard waste excluded from landfill, not recycled). Column 3, *Per capita energy savings per annum (MJ)*, gives the per person energy cost avoided by recycling. The units of expression are millions of Joules (MJ) and the 3355 MJ represents the calculated value for the year 1991. Annual energy savings are projected to change along with variations in per capita volume and composition of MSW for the years 1992–2000. Column 4, *Per capita energy savings 1991–2000*, shows the cumulative energy cost savings for the ten-year period (36 569 MJ). It should be noted that the energy cost savings considers all material recycled whether retrieved by an individual at home or by a municipality at the waste management facility. Furthermore, the energy cost savings include all energy costs (mining, refining, smelting, separation, preparation, transportation, effluent treatment, etc.) except waste sorting. Since some raw materials originate from outside the United States, some energy cost savings will be external to this country.

The energy cost savings in MJ's were converted into dollars based upon the United States Energy Information Agency's (EIA) most likely projections of oil prices [6]. For 1991, the EIA projects oil prices were $16.10 per barrel, which was equivalent to 0.003135 per MJ. After calculating the dollar equivalent of the energy savings, the revenue was discounted to midyear 1991 dollars. An 8% discount rate was chosen to cover the average cost of the public funds used to finance the necessary capital investments in recycling facilities. The value of $9.09 in column 5 represents the energy cost savings derived from recycling 100% of the recyclable MSW discarded by one person in one year (current dollars). Similarly, the column 6 represents the value of the energy saved for ten years ($92.15), also expressed in current dollars.

4. Energy saving results

Case 2, the most likely case, assumes 25% of all recyclable materials are recycled and 100% of yard wastes are excluded from landfills. Recycling operations generally require a significant degree of materials sorting, either at curbside or at another point before disposal. Assuming a goal of 25% reduction in the volume of MSW to be deposited in landfills, it is reasonable to assume the most effective presorting procedure could capture all recyclable components in proportions equal to their pro rata share of the gross MSW. Table 4 is a presentation of the Case 2 results. The projected ten-year cost savings clearly shows that paper ($12.07) and aluminum ($8.50) make up most of the total value. In this case, there is no net energy cost savings from plastic recycling.

Case 3 (Table 5), reference case with WTE permitted, is identical to Case 1 with the exception that an energy cost savings is added for plastic. This is useful as a reference case in calculating the value of other cases where plastic conversion by WTE is allowed. Note the increase in cost savings from $92.15 to $132.32 between the two cases, all as a result of the energy value associated with plastic WTE allowed.

Table 4
Case 2: Energy saving analysis from 25% recycling and no WTE conversion [5]

Material	Percent of material recycled	Per capita energy savings per annum[b] (MJ)	Per capita energy savings 1991–2000 (MJ)	Per capita energy savings per annum[b] (discounted $)	Per capita energy savings 1992–2000 (discounted $)
Paper and paperboard	25.0	454	4787	$1.23	$12.07
Glass	25.0	73	702	$0.20	$1.78
Aluminum	25.0	282	3383	$0.76	$8.50
Recyclable steel	25.0	30	270	$0.08	$0.69
Plastics[a]	25.0	0	0	$0.00	$0.00
Yard wastes[a]	100.0	0	0	$0.00	$0.00
All other	0.0	0	0	$0.00	$0.00
Total		839	9142	$2.27	$23.04

[a] Energy savings only as WTE conversion value.
[b] 1991 value.

Table 5
Case 3: Energy saving analysis from 100% recycling with WTE conversion [5]

Material	Percent of material recycled	Per capita energy savings per annum[b] (MJ)	Per capita energy savings 1991–2000 (MJ)	Per capita energy savings per annum[b] (discounted $)	Per capita energy savings 1992–2000 (discounted $)
Paper and paperboard	100.0	1816	19148	$4.92	$48.29
Glass	100.0	291	2810	$0.79	$7.10
Aluminum	100.0	1126	13530	$3.05	$34.02
Recyclable steel	100.0	122	1081	$0.33	$2.74
Plastics[a]	100.0	1447	15942	$3.92	$40.17
Yard wastes[a]	100.0	0	0	$0.00	$0.00
All other	0.0	0	0	$0.00	$0.00
Total		4802	52511	$13.02	$132.32

[a] Energy savings only as WTE conversion value.
[b] 1991 value.

Case 4 (Table 6), the most likely case with WTE permitted, is identical to Case 2 with the exception that an energy cost savings is added for plastic. Note the increased cost savings from $23.04 to $33.08 as a result of the energy value associated with plastic WTE conversion.

Summary results of the energy saving evaluation are given in Table 7. Whether judged on a theoretical (reference case) or a most likely case basis, the results indicate

Table 6
Case 4: Energy saving analysis from 25% recycling with WTE conversion [5]

Material	Percent of material recycled	Per capita energy savings per annum[b] (MJ)	Per capita energy savings 1991–2000 (MJ)	Per capita energy savings per annum[b] (discounted $)	Per capita energy savings 1992–2000 (discounted $)
Paper and paper board	25.0	454	4787	$1.23	$12.07
Glass	25.0	73	702	$0.20	$1.78
Aluminum	25.0	282	3383	$0.76	$8.50
Recyclable steel	25.0	30	270	$0.08	$0.69
Plastics[a]	25.0	362	3985	$0.98	$10.04
Yard wastes[a]	100.0	0	0	$0.00	$0.00
All other	0.0	0	0	$0.00	$0.00
Total		1201	13 128	$3.25	$33.08

[a] Energy savings only as WTE conversion value.
[b] 1991 value.

Table 7
Energy cost saving – summary results [5]

	Per capita energy savings per annum (MJ)	Per capita energy savings 1991–2000 (MJ)	Per capita energy savings per annum[b] (Disc. $)	Per capita energy savings 1992–2000 (Disc. $)
References cases				
Case 1[b]	3355	36 569	$9.09	$2.15
Case 3	4802	52 511	$13.02	$132.32
Most likely cases				
Case 2[b]	839	9 142	$2.27	$23.04
Case 4	1201	13 128	$3.25	$33.08

[a] Calculated value for year 1991.
[b] No WTE conversion.

that maximization of energy recovery can occur only when WTE conversion of plastic is included. If WTE conversion is not considered, there is little or no net energy cost savings from recycling of plastic for two reasons: (a) plastic must be very homogeneous to recycle (i.e., only high density polyethylene (HDPE) or only polyethylene (PET)) thereby requiring significant presorting expense; (b) near break-even energy cost for recycling as compared to current feedstock (oil) prices. Given a change in technology or higher oil prices or increased demand for recycled plastics, the economics could become more attractive in the future.

While there is essentially no energy cost savings from the recycling of plastic, it has the largest recoverable energy content on a per unit weight basis of any MSW component. Feedstocks for plastic are long-chain hydrocarbons that may not be economically recycled at this time; however, WTE conversion is an option that results in both significant energy recovery and substantial volume reduction. While this report does not attempt to determine whether WTE conversion of any type is a desirable solution, an understanding of the fundamentally different nature of plastic waste is important.

Paper WTE conversion was considered but ultimately rejected because of the existing incentives for recycling. Paper is similar to plastic in that the raw feedstocks of both have energy value. For paper, some energy cost savings arise from recycling, although not to the same degree as aluminum or steel. Unlike these MSW components, paper can be recycled only a finite number of times before its fibers become too short for further beneficial use. Therefore it can be shown that paper recycling only delays the date of ultimate disposal. Recycling will reduce the rate of disposal but disposal will eventually occur nonetheless. Given the enormous amount of paper consumed in the Unites States, large quantities of recycled paper can be tolerated. Consequently, it will be many years before significant quantities of nonrecyclable paper will be discarded and, therefore, paper WTE conversion has not been considered as an option.

5. Conclusions and limitations

MSW recycling programs may be designed to maximize energy cost savings or to minimize landfill volumes. Unfortunately, these multiple objectives cannot be accomplished with the same design criteria due to the compositional nature of MSW. Conclusive evidence exists that significant energy cost saving can be attained from aluminum recycling. Also, studies have shown that the reuse of glass bottles can also achieve significant energy savings. Plastics, however, are fundamentally different from other recyclable/reusable components of MSW. Plastic has a high inherent energy content while the energy cost saving from recycling is negligible, especially when sorting costs are considered. While it may be shown that plastic recycling saves energy when compared to the single use of a plastic product followed by landfill disposal, this is true only because of the inherent energy content and not due to any process energy savings. When the true energy consumption and savings are analyzed for comparable cases, clearly energy use is minimized (or energy recovery maximized depending on the perspective adopted) only if WTE conversion is allowed. Furthermore, post-consumer plastic is the fastest growing but least dense component of MSW. The low specific weight of plastic means that waste minimization efforts, which are generally intended to reduce dependence on landfills, will specifically target this component for recycling. If maximization of energy cost saving is coupled with waste minimization, both very laudable goals, it nevertheless becomes impossible to simultaneously optimize both objective functions unless WTE is allowed.

Assumptions regarding the recyclability of materials are also affected by environmental conditions such as frequency of pickups, moisture content of MSW and sorting technology, to list a few. All projections of energy recovery are on average and do not include the cost of sorting but do include transportation of the recyclable material to recycling centers. Energy pricing projections are notoriously susceptible to change, although the US Energy Information Agency's most likely case scenario prices were used for this report.

A final note on paper and plastic is that the feedstocks for these represent a significant energy source above and beyond the energy costs of manufacturing. Steel and aluminum have no residual energy value. Understanding this fundamental distinction is important in the analysis of any large, long-term recycling program.

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