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Net Energy Savings from Solid Waste Management Options

A Summary

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NET ENERGY SAVINGS FROM SOLID WASTE MANAGEMENT OPTIONS SUMMARY

A Study prepared for the
SOLID WASTE MANAGEMENT BRANCH
ENVIRONMENT CANADA

by Peter Love

edited by Anthony Taylor

MIDDLETON ASSOCIATES
6 Crescent Road, Suite 2b
Toronto, Canada M4W 1T3
(416) 961-5136

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An essential difference between solid waste management systems lies in their treatment of the large paper component. The study reveals that in the majority of cases considered for southern Ontario, net energy savings are attributable to recycling waste paper rather than utilizing it as a source of energy. It was also found that recycling waste paper could result in a net decrease in air and water pollution. The energy savings attributable to reduction at source options were assessed separately.

PREFACE

This paper is a summary edition of a larger report on a study undertaken by Middleton Associates in early 1976. The study identified the energy implications of different solid waste management options, and was sponsored by the Solid Waste Management Branch of Environment Canada. The principal investigator was Peter Love. Special thanks are due to Ted Rattray of the sponsoring agency for his support and contribution throughout the project.

A number of other individuals participated directly in the design, research and production of the study and the report and merit special mention: Terry Burrell, George Hathaway, Peter Middleton, Grant Slinn, Judy Smith, Anthony Taylor and David Wood, all of Middleton Associates; Roy Emery of Roy W. Emery Limited; William Franklin and Bob Hunt of Franklin Associates Limited.

By its nature, the study required substantial assistance from experts in resource recovery, in the pulp and paper industry, as well as various government agencies. A list of these individuals, all of whom are to be thanked for their time and advice, is included in the larger edition of the report.

RÉSUMÉ

Le mode de traitement convenant aux rebuts de papier, qui forment une portion importante des déchets solides, marque une différence essentielle avec les méthodes de gestion généralement appliquées à ceux-ci. La présente étude, effectuée dans le sud de l'Ontario, révèle que, dans la plupart des cas examinés, on obtient une épargne nette d'énergie en recyclant le papier de rebut plutôt que de le transformer en combustible. En outre, cette option se traduit par une diminution nette de la pollution de l'air et de l'eau. L'épargne d'énergie due à la réduction des rebuts à la source fait l'objet d'une évaluation disticte.

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THE OBJECTIVE OF THE STUDY

Over the past few years, an increasing concern about Canada's energy supply has led to an interest in energy conservation. The use of energy in traditionally accepted resource conversion processes and styles of life is being questioned. Changes in the amount of waste we generate and in our methods of handling waste are pointed to as one source of energy savings.

The subject of this study is solid waste. Its intent is to examine possibilities for saving energy through different solid waste management options in the more densely populated areas of Canada.

There are basically three approaches which can, it is argued, produce energy savings when compared to the traditional practice of discarding and landfilling solid waste:

(a) Energy Recovery - The recovery of energy from solid waste has been demonstrated to be feasible and to yield substantial energy benefits in the context of larger urban areas, and elsewhere. Typically, energy is recovered as heat through burning the paper, plastic and organic material in solid waste. Alternatively, combustible gases and liquids may be recovered for use as a fuel through the gasification of organic waste.

(b) Reclamation - The reclamation (that is, removal) of certain constituents of solid waste for recycling into new products has also demonstrated energy savings, and many systems are in operation today which regularly reclaim such materials. The use of reclaimed metals in production, for example, can save up to 95% (in the case of aluminum) of the energy required to process virgin ore.

(c) Reduction at Source - The most controversial option is reducing the amount of waste that is generated in the first place, through, for example, requiring less packaging, expanding the use of reusable container systems, and manufacturing products which last longer. The full implications, energy and otherwise, of reduction are not known.

Under certain conditions, these options all promise to yield net energy savings in comparison with current Canadian practices of waste generation and disposal through landfill. And to a large extent, they are compatible with one another: a reduced volume of waste may still be expected to contain valuable materials for reclamation and, once these are removed, energy may be recovered from the remaining waste. An attempt to put these options into practice would raise at least the following two questions:

- What materials should be reclaimed for recycling and what should be used as an energy source? Alternatively, for a material which is combustible, under what conditions should it be recycled instead?

- In light of better waste handling practices (reclamation and energy recovery), how attractive is reduction of waste at source?

The intent of this study is to examine certain aspects of these two questions. For the first question, the comparison of reclamation and energy recovery, the study looks only at the paper content of solid waste. Paper is chosen because it is a significant proportion of residential solid waste (35% by weight) and because it is for the paper component that a real choice between reclamation and energy recovery arises. Most other reclaimable materials are not combustible. For the second question, the study looks only at the impact of waste reduction on the amount of energy required to perform a certain function or deliver a given product.

For both questions, the primary focus of the analysis is energy use. In a more complete policy analysis, designed to assist decision makers in the choice of waste management systems, it would be important to examine a number of dimensions. A change in waste management practices will have many impacts.

Natural resource utilization:

a) Energy
b) Forests (as a productive fibre source)
c) Land
d) Air (pollution)
e) Water (pollution)
f) Raw materials

Use of other resources:

g) Labour
h) Capital
i) Technology

Other factors:

j) Product quality
k) Social and economic costs and benefits

This study focusses primarily on energy impacts, although attention is also paid to air and water pollution to identify instances where waste management options might differ in their impact on the environment.

The first part of this volume, comprising ten sections, reports on the study of the first question, the choice between recycling waste paper and recovering its energy value. The analysis is a detailed one, involving the presentation of new data. The second part deals with energy savings from waste reduction and is more cursory, based on existing data and previous studies.

SHOULD WASTE PAPER BE RECOVERED FOR ITS FIBRE OR FUEL VALUE?

1. The Approach

The first and principal choice examined in the study is between recovering the paper fibre in solid waste for its fibre or fuel value, from the point of view of energy use. The two options are not, however, mutually exclusive. The reclamation of a portion of the paper component can, for example, be followed by the burning of the rest of the paper with the remaining solid waste to produce energy. The essential problem then is to determine, from the point of view of energy use, how much, if any, of the paper in waste should be recycled, and under what conditions.

By definition, the recycling of waste paper involves its use as an input to a production process. Throughout this study, the assumption is made that the choice of whether to recover waste paper as a source of fibre or fuel does not affect the total output of the production system. In other words, the total quantity of products available will be the same regardless of whether a given portion of waste paper is put to use as a material input in a production process. This implies that if waste paper is recycled, it will replace another input (virgin fibre from wood) in an amount such that the total output of the production process in question remains the same. It is assumed that the change in input does not produce a functionally different product, although product quality may conceivably change. The change in input may manifest itself in one of two ways: through replacement of some virgin fibre by waste paper in a particular plant's process, or through a decrease in output of a plant using virgin fibre and a corresponding increase in the output of a plant using secondary fibre.

In order to compare the two solid waste management processes, then, it is necessary to examine energy use in the paper production process as well, because different mixes of raw material inputs require different amounts of energy. The following analysis answers the question: Will energy be saved by using a given ton of waste paper as an input in the production of a particular paper product rather than disposing of that ton through energy recovery or landfill?

The answer, yes or no, is found to depend on the following six variables:

Variables Affecting the Energy Savings from Recycling

1. Energy Cost of Reclamation - Energy will be required to collect, reclaim, and prepare the waste paper to be an acceptable input for paper production.

2. Energy Cost of Wood Harvesting - On the other hand, the energy required to harvest the wood that is displaced by the waste paper will be saved.

3. Energy Costs of Transportation - Energy required to transport the wood to the mill will also be saved, but the energy will be required to transport the waste paper to the mill. Moreover, the waste paper may go to a different mill (a recycling rather than a virgin mill) so that the energy required for product distribution may also be different.

4. Energy Costs of Production - Energy may be saved in production because reclaimed fibre generally requires less energy to process into paper than does virgin fibre.

5. Energy Value of Wood - The wood that is displaced from paper production by the reclaimed waste paper becomes potentially available for use as a fuel. The energy value of this opportunity depends on how much of this wood will actually be harvested for fuel.

6. Energy Value of Waste Paper - On the other hand, the waste paper being recycled is not available for use as a fuel. The energy value of this lost opportunity depends on how much of the paper would have been used as a source of energy and how much would have been landfilled.

Sections 3 to 8 of this chapter examine these variables in turn. Variables 1 and 6 represent energy spent to recycle waste paper, whereas Variables 2,4 and 5 represent energy savings from recycling. Variable 3 may favour either option. Section 9 totals up the energies and shows that under most conditions, the recycling of waste paper produces net energy savings in comparison to burning that same amount of waste paper. However, some conditions are identified under which the variables assume values which in sum do not favour recycling from a net energy perspective,

2. Terms and Scope of the Analysis

To lay the ground for the examination of the six variables, this section discusses the scope and context of the analysis.

(a) Data Sources and References

A number of studies have dealt with aspects of the questions addressed here. One particularly useful study by the Ontario Research Foundation was available just prior to the completion of this project and reference is made to it (1). Other studies in this area have been listed in the references (2 - 10).

In light of the experience gained through these efforts, it was decided to base this investigation on primary data, gathered from existing systems and facilities wherever possible. There are certain arguments that can be made in favour of an engineering approach, one which would estimate the energy required by each of the separate processes involved in a pulp and paper mill, energy recovery plant, and so on. However, it was judged important at this time to ground the research in actual operating data in order to assess in a more realistic fashion the energy conservation potential.

Consequently, primary data were collected from a small number of carefully selected pulp and paper mills, from various types of energy recovery systems, from waste paper reclamation systems, transportation facilities, etc. These are reported below in the appropriate sections. Canadian operating data were used wherever available, but in some cases the analysis had to rely on previously published U.S. data.

The calculations of the energy consumed and the pollution produced by the systems analysed were made using the Resource and Environmental Profile Analysis (REPA) program pioneered by William Franklin and Robert Hunt, formerly of the Midwest Research Institute in Kansas City. It has been used extensively by policy makers in industry and government over the last five years in the United States.

(b) Geographic Perspective

Because the study is based on primary data where possible, there are geographic limitations which depend on the choice of data sources. Generally speaking, the data represent the relatively densely populated "Quebec-Windsor" corridor. In particular, the pulp and paper mills chosen were those currently serving or designed hypothetically to serve the Southern Ontario market. It was assumed that Toronto was the final destination for the finished products. The energy requirements for solid waste collection are applicable to large urban areas only, and are based on Metropolitan Toronto data. Similarly, reclamation and landfilling requirements are based on large scale operations with continuous flow of materials. However, the assumption made throughout the study is that all associated energy effects, regardless of where they occur, should be included. Thus, although the geographic context of the analysis can be thought of as the area from which the waste paper is drawn, energy expenditures or savings in all regions are included.

(c) Measurement of Energy

All energy figures used in this study are measured in terms of the calorific value or enthalpy associated with the particular fuel used or generated. The units are 10^6 BTU and GJ (gigajoule). A discussion of the differences between enthalpy and free energy may be found in other studies (1, 11).

The energy values attached to the use of a fuel in this study include the secondary or pre-combustion energy associated with the extraction, processing and transportation, as well as the inherent energy, of the various fuels used by the different processes. In addition, the environmental disruption associated with the production and use of a fuel is considered.

Electricity is not a fuel and is treated in a different manner. Electrical energy use or savings are considered only in terms of thermal generation of electricity from coal. This assumption has been based on the Ontario situation where a mix of hydroelectric, nuclear and thermal generators are used as "base load" units, but thermal generators alone supply the additional "peak" power needs. Thus, any marginal increase or decrease in electrical energy requirements is taken up by the thermal generating stations. A further discussion of this assumption can be found in the Ontario Research Foundation study (1).

The heat rate for thermal stations in Ontario was estimated to be 10,500 BTU/kwh, including transformer and transmission losses. This is a more relevant figure than the theoretical conversion factor of 3413 BTU/kwh. The estimated energy associated with the extraction and transportation of the coal used to generate the electricity has been included in this figure.

Some of the pulp mills examined in this study generate their own electricity. For those that operate thermal electricity generators, a heat rate calculation was unnecessary because the heating values of the fossil fuels and wood wastes used to fuel the boilers was known. For self generation of hydro-electricity, the same heat rate as for thermal stations has been applied because this hydro-electricity could theoretically have been added to the Ontario Hydro grid as part of its base load.

When wood or solid waste is used as a fuel in this study, the energy produced is expressed in terms of fossil fuel savings. It is assumed that the wood and solid waste are being used to generate steam. A "solid waste to fossil fuel equivalent" multiplier has been defined as the ratio of the energy efficiencies of steam conversion from solid waste and from fossil fuel. Based on a survey of twelve energy recovery systems, an average multiplier value of 0.7 was calculated. That is to say, in this study it is assumed that each BTU of energy in solid waste used to produce steam will save 0.7 BTU of coal that would have been necessary to produce that same amount of steam. A similar approach was used in the ORF study (1). The multiplier was used to calculate fossil fuel savings when either waste paper or wood was used as a source of energy.

(d) Capital Related Energies

Estimates for energy associated with the capital equipment involved in transportation has been incorporated into the analysis. However, the energy required to build new plants (pulp and paper mills, resource recovery facilities) has not been included for several reasons.

In the first place, the study is intended to compare the energy impacts of two waste paper management options - recycling and energy recovery - for one ton of waste paper under general urban conditions in Canada today. The choice of option for small amounts of waste paper has a significant per ton energy impact, but no discernable impact on capital needs nor, therefore, on capital-related energy. But there may well be a measurable impact on transportation capital (an extra truck or rail car required) even for small amounts of waste paper. To include plant capital, however, would confound the study's object of isolating the current per ton energy impact of waste paper use.

In certain instances, of course, the implementation of one of the waste management options may require the construction of a plant while the capital requirements for the other option may already exist. To consider these instances and make capital-related energy estimates would involve tying the analysis to a host of specific assumptions which would destroy its generality: for example, it would be necessary to make particular assumptions about the region, about the quantity of paper under consideration (a small amount would differ in per ton capital requirement from a large amount), about optimal plant size, about lifetime and total output of equipment, about vintage of and the historical and replacement costs of existing equipment, and the energies related to these costs.

The question arises whether the study's reluctance to tie itself to specific assumptions and to consider capital-related energy has jeopardized its utility. This would be likely if capital-related energy were a significant portion of the total energy associated with the options. Calculations made in other studies, however, suggest that this is not so. Recent data for Ontario (1) indicate that capital-related energy consumed by pulp and paper (newsprint) operations is less than 5% of the total energy consumed in the production of a ton of paper, and that capital-related energy consumption for energy recovery systems is about 1% of the fossil fuel equivalent energy produced. This order of magnitude has no substantive effect on the outcome of the comparison, especially since a large part of the capital for the two options is the same (e.g. paper-making equipment).

It should also be noted that to the extent that this study's exclusion of capital-related energy does impart a bias to the analysis, the bias will be against reclamation and recycling: energy recovery is more capital intensive than reclamation, and the harvesting and pulping of wood is more capital intensive than the preparation of waste paper for recycling.

3. Energy Costs of Reclamation

The following six sections examine the six variables which determine the energy saved by recycling waste paper rather than recovering energy from it. The first variable is the energy required to collect, reclaim and prepare the waste paper in question in order to make it available to the paper mills for recycling. A number of different reclamation systems and techniques are available. A critical feature is the grade of fibre they produce, for grade determines what types of paper mills and processes can use the fibre. Higher grades of waste paper are more uniform and relatively free from contaminants; because they are readily substitutable for virgin fibre in many paper processes, they are in high demand and already enjoy a high rate of recycling. On the other hand, lower grades of waste paper have fewer uses in paper production and frequently are disposed of as solid waste.

The study identifies reclamation energy for three grades of waste paper: deinking, corrugated, and news. The last two are considered lower grades. Any significant increase in paper recycling, and correspondingly any significant reduction in solid waste must involve the reclamation of lower grades. Mixed waste paper, which is the lowest grade, is of value to only very few mills, primarily those producing building materials and boxboard. For the most part those mills already use as much reclaimed fibre as production permits, so that with current production technology, there is little possibility of recycling significantly increased quantities of mixed waste paper. Consequently, it has not been included in this analysis.

There are three basic types of waste paper reclamation techniques:

- mechanical systems which shred mixed solid waste at a central facility specifically to reclaim paper
- separate collection systems for waste paper that has been kept segregated from the rest of solid waste by the consumer
- hand picking bundled newspapers or cardboard from a conveyor belt in a resource recovery plant

Each of these can be applied separately or in various combinations.

a) Mechanical Systems

Mechanical systems are designed to maximize the recovery of paper fibres from solid waste; most of them produce a low grade of mixed fibre and are not of great interest to this study. One system, which does not shred the mixed waste, is capable of separating out reclaimed fibres containing a high percentage of corrugated containers. This is the Sorain/Cecchini System currently used in three large recycling plants operating in Rome and Perugia, Italy. The system burns the unreclaimed portion of the paper with the rest of the waste to produce energy. Complete energy data were available on the Sorain/ Cecchini System from Reed Paper Ltd. of Toronto who have the Canadian rights to this process. For the purpose of this study, a direct energy requirement of 1.7×10^6 BTU for reclaiming one ton of corrugated cartons using the Cecchini system is assumed (12).

Additional information on this and other mechanical systems is available in previous studies (15, 16). Where mechanical systems are applied in the analysis, the energy required per ton to collect solid waste must be added to the reclamation energy to get the total energy cost of producing the reclaimed fibre. Collection energy has been estimated to be 0.17×10^6 BTU/ton based on solid waste collection in a densely populated urban centre (1).

b) Separate Collection

Three opportunities exist for the separate collection of the three grades of waste paper considered in this study: newspaper from households, corrugated from stores and industries, and deinking grades from offices.

A number of different techniques have been used to collect waste newspapers from homes, both as part of and separate from regular garbage collection. For example, a separate truck has been used in Toronto for this purpose for more than three years. The manpower and equipment required were made available by schedule changes. Figures received from officials there indicate that an average of about 60 tons of newspapers were collected weekly in the city of Toronto in 1975 (15) representing a rather low recovery rate of 9%. For purposes of this study a recovery rate of 30%, well within that believed possible by other studies (16, 17), has been assumed with a proportionate decrease in the per ton collection energy required.

It has been assumed that the only energy required for separate collection of corrugated containers from stores and industry and discarded fine paper (deinking grades) from offices is the energy to transport the material to the nearest waste paper dealer and from there to the user mill. (See Section 5, Energy Costs of Transportation)

c) Hand Picking

Hand picking of waste paper has been included in the plans for the Ontario Resource Recovery Centre and has been mentioned in various studies of waste paper recycling (18). There appears to be limited North American experience with this technique but the energy expenditure can be expected to be very small. Although viable, this reclamation approach has not been included in the analysis.

The waste paper reclaimed by any of the above systems can be either sold to a paper dealer who will then sell it to a paper mill, or can be sold directly to a paper mill. In either case, the paper is often baled. Based on information supplied by a baler manufacturer, about 0.09×10^6 BTU are required to bale one ton of waste paper using a mill-size baler (19). This energy has been added to the energy requirements of the reclamation system previously calculated in this section. The only other major operations performed by most waste paper dealers are contaminant removal and sorting/upgrading, which are, at present, almost entirely manual and thus require very little mechanical energy. No energy associated with these operations has been included in this study.

These figures have been used as the basis of this analysis but were revised to include the capital-related indirect energy required for each system. This indirect energy would include the energy required in equipment manufacture, repair and maintenance as well as construction of terminals. A recent study estimated that the ratio of the total energy (including both direct and indirect energy) to direct energy was 1.7 for freight by rail and 2.0 for passenger cars (27).

These results are in contrast to the manufacturing sector of society, where the indirect energy required to build and operate the capital equipment for a newsprint mill was estimated to be less than 5% of the total energy (see Section 2); this represents a total/direct energy ratio of 1.05. Because the previously mentioned study did not estimate the total/direct energy ratio for trucks, a value of 1.4 was estimated for use in this study. The total energy figures used in this study are shown below.

Table 1

ENERGY COSTS FOR TRANSPORTATION

	Direct Energy (10^6 BTU/ ton-mile)	Total/Direct	Total Energy (10^6 BTU/ ton-mile)
Truck	2.50×10^{-3}	1.4	3.50×10^{-3}
Rail	5.60×10^{-4}	1.7	9.52×10^{-4}

Because these figures are national averages, they take into account the fact that sometimes the truck or freight car is not loaded to full capacity and may even be empty on a back-haul trip. On the other hand, they do not reflect any special features (such as unit trains, special heavy duty trucks, travel over lumbering roads, different average payloads) which could result in the energy figures applicable to transportation in the pulp and paper industry being different from national average figures.

Air and water pollution resulting from the combustion of fuel to propel these two modes of transport is considered in this study. The estimated American average distribution between diesel and gasoline trucks has been used to allocate the environmental impacts attributable to transportation: 82% diesel and 18% gasoline (28).

6. Energy Costs of Paper Production

The energy cost of paper production depends on the type of paper being produced and the process used. It is because the process often changes when reclaimed fibre is introduced that the energy cost of production is an important variable in this analysis. This section examines the differences between energy requirements of production using different mixes of virgin and reclaimed fibre. There is a considerable amount of background information describing the operation of the pulp and paper industry has not been included in this report, but may be found in other studies (21, 29, 30).

Fourteen pulp and/or paper mills were carefully selected and surveyed to provide data for this comparison. An attempt was made to select mills which were illustrative of the differences in energy requirements in manufacturing functionally similar paper products using primarily virgin fibre and using a maximum amount of waste paper. Moreover, the mills selected had to have a type of product for which there was a promising potential for an increase in the demand for reclaimed fibre - an increase which could be met from supply.

Five criteria were used in the selection of the product categories analysed in this study: the current recycling rate within each product category, the grade of waste paper utilized, recent significant expansions within each category, the expected growth for each product and the technical practicality of different proportions of reclaimed fibre input.

Table 2 provides some recycling statistics (1973) for waste paper (excluding mill broke) across Canada by type of paper mill. Not included are two recent capacity expansions in Southern Ontario: Continental Can's new boxboard mill in Toronto and Reed Paper's new linerboard and medium mill in Mississauga. Both will utilize large amounts of waste paper, particularly corrugated. The effect of these and other expansions from 1974 - 1977 will be to increase the capacity of mills producing boxboard from waste paper by 30%, to double the capacity of mills producing linerboard from waste paper and almost triple the capacity of mills producing corrugated medium from waste paper in Canada (31).

Table 2

RECYCLING STATISTICS BY TYPE OF PAPER MILL (1973)

	Utilization Rate (Proportion of Waste Paper in Product)	Production (000 tons)	Share of Total Consumption of Waste Paper	Recovery Rate (Proportion of Domestic Production Recycled)
Wrapping Paper	0.2%	671	-	0.2%
Newsprint	0.4%	9140	4%	4.2%
Printing and Writing Paper	4.7%	983	5%	6.5%
Tissue and Sanitary Paper •	9.9%	324	4%	10.1%
Linerboard	12.5%	1104	15%	17.1%
Corrugated Medium	16.4%	494	9%	21.7%
Building Materials	35.5%	659	25%	40.9%
Boxboard	38.7%	917	38%	35.2%
Total	6.4%	14,293	100%	18.0%

Source: Burrell, Terry, et al., Paper Recycling: A Socio-Economic Perspective (30), Woods, Gordon and Company, Recycling of Mixed Office Waste from the National Capital Area (18), and Canadian Pulp and Paper Association, Reference Tables 1975 (32).

It is clear that very little waste paper is utilized by mills producing wrapping paper, and no such mills were included in the analysis. The use of waste news to produce newprint is also low because Canada does not have a newsprint deinking mill. However, in spite of its low utilization rate, newsprint's large Canadian production gives it a 4% share of total waste paper consumption.

Printing and writing paper, and tissue and sanitary paper have small but significant utilization rates; their mills use the higher (deinking) grades of waste paper. Linerboard, medium and boxboard mills are the large users of the container grades of waste paper; boxboard and building material mills use most of the news grades and the mixed grades are mainly used to make building materials.

Boxboard and building materials mills have not been included in the analysis. Although they are the two largest consumers of waste paper, they also have the highest recycling rate. Other studies have found that waste paper is already being used by building material mills to virtually the greatest practical extent (18, 30). Boxboard has also been excluded from the study in view of the recent expansions and the already high waste paper utilization. Previous studies have estimated that combination boxboard made from recycled fibre required about 40% less total energy than boxboard made from virgin fibre when the energy derived from recovery boilers is included, and about 10% less when this self-generated energy is excluded (4, 5).

Four product categories were therefore included in the analysis: printing and writing paper, newsprint, tissue and sanitary paper, and corrugated containerboard (linerboard and medium). For each product category, at least two mills were analysed: one using the maximum amount of virgin fibre and the other using the maximum amount of reclaimed fibre. In addition, a third printing and writing paper mill using 34% deinked was added to the analysis. In the use of reclaimed fibre, only the major grade associated with each product was considered (deinking, news, deinking and corrugated respectively for the four product categories). Functionally similar products are produced by all mills in each product category; however, for tissue and sanitary paper, the recycled product is of lower quality.

Table 3 shows the total energies required to produce one ton of product at each of the mills studied. All but one type of product (corrugated containerboard) are in their final form. The energy required to manufacture corrugated containerboard from linerboard and corrugated medium has not been included; it would be the same for linerboard and medium made from virgin and reclaimed fibres, and thus not of significance to a comparative analysis.

All variables discussed to this point in the report are included in the energy figures in Table 3: the energy costs of reclamation, wood harvesting, transportation of the material inputs, paper fabrication, and transportation of the product to a centre for further distribution. Frequently, wood-derived energy is used in paper production; the wood fibre burned for energy is usually a by-product of the preparation of wood for pulping. Since it would go to waste if not burned, its inherent energy is not included in the energy figures. In paper processing, only energy purchased by the mill is counted.

Table 3

ENERGY SAVINGS IN PRODUCTION WITH RECLAIMED FIBRE*

	Total Energy Required Per Ton Output (10^6 BTU)	Savings From Recycling Per Ton Output (10^6 BTU)	Waste Paper Recycled Per Ton Output (Tons)	Savings Per Ton Waste Paper Recycled (10^6 BTU)	Savings Per Tonne Waste Paper Recycled (GJ)
Printing & Writing Paper					
100% Virgin	49.2	-	-	-	-
34% Recycled	44.0	5.2	0.338	15.3	17.8
83% Recycled	32.7	16.4	0.940	17.5	20.4
Newsprint					
100% Virgin	29.8	-	-	-	-
100% Recycled	19.7	10.2	1.120	9.1	10.6
Tissue & Sanitary Paper					
100% Virgin	48.9	-	-	-	-
100% Recycled	22.4	26.4	1.116	23.7	27.6
Corrugated Containerboard					
92% Virgin	26.5	-	0.081	-	-
100% Recycled	20.2	6.3	1.124	6.0	7.0

* The figures in this table have been rounded off to one decimal place.

For each of the four products, the use of reclaimed waste paper instead of virgin fibre provides energy savings. The size of the savings varies from 6 to 24 million BTUs per ton of waste paper recycled, although the greatest saving (24 million BTUs per ton for tissue and sanitary paper) is achieved with a lower quality product. For corrugated containerboard, the energy figures assume separate collection of corrugated waste. The figures for mechanical collection are very little different, and are not shown in Table 3.

7. Energy Value of Wood

The first four variables involved energy requirements for the acquisition processing and transportation of fibre and making of paper products. The purpose of Table 3 was to examine the savings in energy requirements which accrue from the substitution of reclaimed for virgin fibre. However, there are two additional energy values, quite outside paper production, which must be considered in this study.

The substitution for virgin fibre in paper production makes available some energy which society would not otherwise have; this is the energy from the wood fibre that was not used to make paper. On the other hand, where waste paper is not used in paper production, a different source of energy becomes available to society; this is the energy from the waste paper that was not recycled. These two energy values are discussed in this and the following sections respectively.

The recycling of waste paper confers an opportunity to use part or all of the wood not harvested for paper production as a fuel. The energy value of this opportunity depends on whether or not it is taken. If wood is in plentiful supply, or if other energy resources are abundant and cheap, it is unlikely that the energy value will be significant, for the fibre would probably not see use as a fuel. However, if wood is more scarce and energy relatively expensive, the energy value of the opportunity may be significant; it may be any amount up to the value of all the fibre saved, less the energy required to harvest and transport it to where the fuel is needed (assumed to be the same as the distance from the forest to the pulp mill).

In practice, the energy may be released from wood through direction combustion, or through wood-gasification to produce a fuel gas. As discussed in Section 2, for purposes of measuring wood energy, this study assumes it is used to generate steam, and calculates a fossil fuel equivalent saving by applying a muliplier of 0.7 to the heating value of wood. Using 9.0×10^6 BTU/ton as the heating value of green roundwood, gives a fossil fuel equivalent of 6.3×10^6 BTU/ton. Subtracting from this the energy required to harvest and transport the wood, leaves 5.9×10^6 BTU/ton. Based on this value, Table 4 below calculates the net energy value of all the wood made available by recycling one ton of waste paper into the selected products.

Table 4

NET ENERGY VALUE OF WOOD DISPLACED BY RECYCLING

	Quantity of Wood Made Available by Recycling One Ton of Waste Paper (tons)	Net Energy Value Fossil Fuel Equivalent Less Harvesting and Transportation Energy Requirements (10^6 BTU)
Printing & Writing Paper	3.17	18.7
Newsprint	1.95	11.5
Tissue & Sanitary	3.33	19.7
Corrugated Containerboard	2.91	17.2

The energy value of the opportunity to take energy from the quantities of wood shown in Table 4 may range from zero, if none of the wood is so used, to the full net energy values in the last column of the table, when all of the wood is harvested for fuel.

8. Energy Value of Waste Paper

The opportunity to recovery energy from waste paper, if it is not recycled, is somewhat different from the opportunity to recover energy from wood made available through recycling. If the opportunity to use the wood as fuel is not taken, the trees are simply left standing; but if the opportunity to recover energy from waste paper is not taken, it must be disposed of in another fashion(landfilled with the rest of solid waste). This disposal will require some energy.

The fossil fuel equivalent saving of waste paper may be calculated by multiplying its heating value of 16.0×10^6 BTU/ton by the solid waste to fossil fuel equivalent multiplier 0.7. From this must be subtracted the energy cost of solid waste collection, previously estimated to be 0.17×10^6 BTU/ton, which will be realized if energy recovery is practised. On the other hand, if no energy recovery is practised, the waste paper will be landfilled. Using an estimate of 0.08×10^6 BTU/ton for the energy required to landfill solid waste (6) gives a total disposal energy cost (or negative energy value) for collection and landfilling of 0.25×10^6 BTU/ton.

Thus, the energy value of the opportunity to dispose of waste paper that is not recycled will be between -0.25 and 11.0×10^6 BTU/ton, depending on how much of the paper is landfilled and how much is applied to energy recovery.

9. Net Energy Savings from Recycling Waste Paper

This section brings together the six important variables in the comparison between recycling and energy recovery in order to calculate a net energy saving from recycling. Some variation in the values of these variables is introduced in this section to show the limiting conditions for energy savings. The nature of these variations is as follows:

- Variable 1 - no variation introduced; separate collection is assumed*
- Variable 2 - no variation introduced
- Variable 3 - transportation distance for reclaimed fibre to paper mill varies
- Variable 4 - product type varies
- Variable 5 - proportion of displaced wood used as fuel varies
- Variable 6 - proportion of unreclaimed waste paper applied to energy recovery varies

In Section 6 it was calculated that from the point of view of the paper producer, that is, considering the acquisition of material, processing

* The difference between the energy required for mechanical reclamation and separate collection of waste paper was found to be insignificant in the context of this study.

and transportation, the use of reclaimed fibre produced energy savings in all four product types studied. These savings are not realistic because of the exclusion of Variable 6; they ignore the need to dispose of waste paper, or the opportunity to recover energy from it. In Table 5, two options for Variable 6 are considered. The first column shows energy savings with no energy recovery from waste paper. The energy cost of collecting and landfilling one ton of waste paper (0.25 x 10^6 BTU) is added to the production energy of virgin products and thus increases the energy savings. The second column shows that when 100% energy recovery is applied to the waste paper, the energy realized (11.0 x 10^6 BTU) significantly reduces the energy savings from recycling.

Table 5

ENERGY SAVINGS FROM RECYCLING FOR LANDFILL AND ENERGY RECOVERY OPTIONS

Assumptions: (3) Waste paper transported 100 miles
(5) No displaced wood used as fuel

	Variable 6: Energy Savings From Recycling One Ton (Tonne) of Waste Paper				Proportion of Waste Applied to Energy Recovery Above Which Energy Savings No Longer Realizable
	Compared to Land Fill		Compared to Energy Recovery		
	(10^6 BTU)	(GJ)	(10^6 BTU)	(GJ)	
Printing & Writing Paper					
- 34% Recycled	15.6	18.1	4.3	5.0	
- 83% Recycled	17.7	20.6	6.4	7.5	
Newsprint - 100% Recycled	9.3	10.8	-2.0	-2.3	0.83
Tissue & Sanitary Paper - 100% Recycled	23.9	27.8	12.7	14.7	
Corrugated Containerboard - 100% Recycled	6.3	7.3	-5.0	-5.8	0.56

Two products, newsprint and corrugated containerboard, fail to show energy savings in the use of reclaimed fibre when compared to virgin fibre production and the disposal of waste paper with full energy recovery. For the other two products, printing and writing paper and tissue and sanitary paper, the use of reclaimed fibre brings energy savings even in comparison to full energy recovery, although it should be recalled that the recycled tissue product is of lower quality than its virgin counterpart.

The last column of Table 5 shows the limiting proportion of waste applied to energy recovery above which there are no energy savings from recycling. If less than 83% of unreclaimed waste paper is applied to energy recovery, then the use of reclaimed fibre in newsprint production will show energy savings. The limiting proportion for showing energy savings in corrugated containerboard production is 56%.

In view of the current level of interest in energy conservation, it may be reasonable to assume in the short to medium term that half of Canada's unreclaimed waste paper will be applied to energy recovery; however, energy resources are not so scarce and expensive that trees saved through paper recycling are needed for fuel during this period. Thus, Table 5 is of particular relevance for the short to medium term.

In the longer term, however, it is likely that wood will be an increasingly valuable resource in Canada for both fibre and energy, and that it will see more use as a fuel, particularly in peripheral communities. It would not be surprising then if half of the wood displaced by the use of reclaimed fibre in paper making were to become an energy resource. Table 6 shows the energy savings from recycling in this type of energy environment, where all unreclaimed waste paper is applied to energy recovery and half of the wood fibre displaced by recycling is used for energy.

Table 6

ENERGY SAVINGS FROM RECYCLING IN AN ERA OF ENERGY SCARCITY

Assumptions: (3) Waste paper transported 100 miles
(5) Half of displaced wood used as fuel
(6) 100% energy recovery practised in waste disposal

Type of Product	Energy Savings From Recycling One Ton (Tonne) of Waste Paper	
	(10^6 BTU)	(GJ)
Printing & Writing Paper		
- 34% Recycled	13.7	15.8
- 83% Recycled	15.8	18.4
Newsprint		
- 100% Recycled	3.8	4.4
Tissue & Sanitary Paper		
- 100% Recycled	22.5	26.2
Corrugated Containerboard		
- 100% Recycled	3.6	4.2

Energy savings in this table are positive for all products; the energy value of half of the wood displaced by recycling has partly countered the influence of energy recovery from waste paper. Further calculations for corrugated containerboard show that energy savings from recycling remain positive if even as little as one-third of the displaced wood is used for energy.

A final variable to examine is the transportation distance for waste paper between the points of discard and of use in a recycling mill. A distance of 100 miles has been assumed in Tables 5 and 6. Table 7 shows how much this distance could be increased without eliminating the energy savings which accrue from the recycling of waste paper. All assumptions, except for transportation (Variable 3) are the same as in Table 6.

Table 7

MAXIMUM WASTE PAPER TRANSPORTATION DISTANCES

Assumptions: (5) Half of displaced wood used as fuel
(6) 100% energy recovery practised in waste disposal

Type of Product	Energy Savings From Recycling One Ton of Waste Paper - With Variable 3 Set at 100 Miles (10^6 BTU)	Waste Paper Transportation Distance at Which Energy Savings Disappear (Miles)
Printing & Writing Paper		
- 34% Recycled	13.7	3510
- 83% Recycled	15.8	4050
Newsprint		
- 100% Recycled	3.8	1050
Tissue & Sanitary Paper		
- 100% Recycled	22.5	5720
Corrugated Containerboard		
- 100% Recycled	3.6	1000

For all products, waste paper transportation distances of 1000 miles or more could be justified from an energy point of view. This finding is of interest because it puts paper mills in the northern parts of Ontario and Quebec within energy-justifiable reach of waste paper from the large urban centres. In this calculation, all transportation of the waste paper has been assumed to be by truck; if rail were used, the maximum distances would be even larger.

10. Environmental Impact of Recycling

Throughout the study, estimates were made of the air and water pollution associated with the production or use of energy at any stage in the processing of waste paper or paper products. Where possible, primary data from systems or mills in operation were used. Where data were inadequate, previous studies were referenced (4, 33, 34, 35, 36, 37, 38).

In particular, estimates were made of air pollution (particulates, sulphur oxides, total reduced sulphur) and water pollution (BOD_5 and suspended solids) associated with:

- the use of fuels for waste paper reclamation; wood harvesting; and fibre transportation
- burning waste paper for energy recovery
- collection and landfilling of waste paper (air pollution only)
- direct combustion of wood for energy
- pulp and paper fabrication in the mills selected in the study

The estimates were tabulated to show the comparative environmental impacts of waste paper recycling and burning for energy for each of the four product categories considered in the study. In all four cases, the air pollutants associated with the production from recycled fibres were less than those associated with the virgin production options.

Water pollution was also generally less severe for the recycling options, with the exception of the 34% recycled input mill (it is a relatively old mill). However, the estimates for the 83% recycled printing and writing paper mill and for the deinking tissue and sanitary mill were those associated with an "exemplary" deinking operation and thus represented a lower limit to the emissions that were to be expected. These results should be interpreted as indicating that increased levels of recycling through deinking need not result in increased amounts of water pollution.

Of the estimates made for the environmental impacts associated with the alternative methdds for the disposition of waste paper and wood, only the burning of wood for energy showed increases in air pollutants worthy of note. However it should also be borne in mind that if the energy generated by burning wood were generated by burning another fuel (coal, for instance), air pollution would also be produced.

Thus, it can be concluded that the recycling of waste paper need not result in increased environmental impacts if the proper water effluent equipment is installed and operated correctly. Indeed, the establishment of new recycling capacity in Canada may well bring a decrease in air and water pollution per ton of production output.

HOW MUCH ENERGY CAN BE SAVED THROUGH SOURCE REDUCTION?

This chapter summarizes the potential energy savings per year in Canada that could be expected if a few selected steps were implemented to reduce the amount of solid waste generated at the source. The assumptions and calculations used to derive these estimates are documented in the larger edition of the study report. Source reduction represents a qualitatively different way of managing the solid waste problem than either recycling or energy recovery; it minimizes the generation of the waste in the first place rather than dealing with the waste after it has been discarded. Because of this difference, the energy savings derived from source reduction options are calculated and analysed separately.

Almost all consumer goods entering the waste stream are susceptible to some degree of source reduction, with the exception of food and yard wastes, although it could be argued that composting is a reduction option since it prevents these materials from entering the municipal solid waste stream.

Source reduction has several advantages over post-consumer solid waste management options:

- it can in many cases be brought about voluntarily, with economic advantages for industry (except materials suppliers)
- it operates at design and production stage and thus the impact of source reduction is not restricted to one geographical area
- it can be introduced relatively quickly
- once introduced, it is more or less permanent
- it will result in reduced costs for collection and disposal of solid waste
- it strikes directly at the wasteful and throwaway aspects of our society

The principal problems associated with source reduction are the following:

- strong opposition from groups who feel threatened by it (materials suppliers, labour unions, etc.)
- transitional economic and social dislocations

Five source reduction measures have been reviewed in this report:

- reducing the overall level of consumption of packaging
- replacing single-use packages with multiple-use ones.
- reducing the material intensity of packaging
- buying products in large package size
- increasing product lifetime

Further discussion of source reduction can be found in other studies (7, 16, 39, 40, 41).

While the decision about how to treat the paper component of solid waste is the key to a post-consumer solid waste management policy, it does not follow that paper is also the key to a pre-consumer solid waste policy; that is, a policy aiming at source reduction. In fact, it turns out that there are other materials equally or even more susceptible to source reduction measures.

The examples reviewed here are by no means exhaustive. They were chosen to illustrate the various source reduction measures available, and to expose the problems and advantages of taking the source reduction route. The selection of the examples was generally limited to those options where comparative energy analyses had previously been undertaken.

Each of these examples would, if implemented, reduce the amount of solid waste produced. There would thus be a reduction in the energy use for collection and disposal. The purpose of this section is to determine to what degree other energy savings also result from the replacement of one system with another.

The summary of energy savings which follows by no means represents the total energy saving possible for a source reduction policy, since only a few of the many products which make up the solid waste stream have been examined. The total energy savings that could be realised are certainly larger than the 55 x 10^{12} BTU (58 x 10^{6} GJ) which could be saved by a general reduction in the level of packaging and the introduction of a 100,000 mile tire. However, this figure can be used as an indication of the order of magnitude of the potential energy savings that could be attributable to source reduction options.

The energy savings summarized in Table 8 would have been realized in 1975 had these source reduction measures been in place.

Table 8

SUMMARY OF ENERGY SAVINGS FROM SOURCE REDUCTION

Source Reduction Options	Annual Energy Savings (10^{12} BTU)
Packaging	
General packaging reduction	40.68
Returnable Containers	
Increase in refillable soft drink containers	7.03
Increase in reusable soft drink carriers	1.53
Increase in 3-quart plastic milk jugs	0.23
10% increase in reusable corrugated containers	2.83
Package Redesign	
Replacement of squat 1/2 pint milk pack with "Ecopak"	0.01
Lightweighting, new processes in soft drink containers	2.98
Larger Package Size	
Increasing sales of larger size soft drink containers	0.43
Products	
Introduction of 100,000 mile passenger car tire	15.12
Reduced use of disposable plates and cups	0.94
Reduced use of disposable diapers	-
Reduced use of paper towels	-

RECOMMENDATIONS FOR FUTURE INVESTIGATION

During the course of this project, three key areas were identified which require further investigation with specific reference to the Canadian context.

1. Reduction at Source

Although it would appear that substantial savings could be realized by the implementation of various measures to reduce solid waste generation, very few empirical studies have been conducted to date in Canada to determine the precise conditions under which quantifiable results could be achieved. Just as important as estimates of energy and waste savings are calculations of the social and economic costs associated with any transition to lower levels of energy and resource use.

Recommendation: That key reduction at source options be analysed rigorously to identify energy and resource as well as social and economic costs and benefits which may accrue at various levels of implementation.

2. The Thermodynamic Implications for Energy Recovery of Waste Paper Recycling

Generally, it may be said that all energy recovery systems benefit from increased levels of waste paper in solid waste. A high percentage of waste paper means a higher average BTU value and (usually) a lower average moisture content on a per ton basis.

While few proponents of energy recovery will argue that all paper must remain in the solid waste mix for their systems to function, it remains to be determined at what levels of paper reclamation the efficiency of each technology seriously begins to decline. At a certain point the economics of the operation may be expected to be adversely affected as well.

Recommendation: That the possible impacts on the efficiency and economics of major energy recovery technologies be identified for various levels of reclamation of waste paper (and other combustible fractions).

3. Potential Energy Savings in Specific Regions and Paper-making Operations

This study has indicated that significant energy advantages accompany certain combinations of waste management approaches. The degree to which they can be realized in each region is a function of economics and demography. If energy conservation is to be an important goal of a comprehensive waste management program, however, an understanding of the energy implications of specific regional reclamation, recovery and disposal options is most desirable.

Recommendation: That efforts be made by the companies and provincial agencies involved to identify the real energy savings that could be achieved on a regional basis through public and/or private waste management and recycling initiatives.

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