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# Net Energy Savings from Solid Waste Management Options

Solid Waste Management Branch
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# NET ENERGY SAVINGS FROM SOLID WASTE MANAGEMENT OPTIONS



A Study prepared for the
SOLID WASTE MANAGEMENT BRANCH
ENVIRONMENT CANADA

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REVIEW NOTICE

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# EXECUTIVE SUMMARY

- There are basically three types of solid waste management options: materials reclamation systems, energy reclamation systems, and reduction at source. The essential difference between the first two management options lies in their treatment of the paper component of solid waste. The bulk of this study deals with the alternative treatment of the paper component. The third option was assessed separately.

- The net energy savings attributable to recycling waste paper rather than burning it for energy were found to be very sensitive to three variables: type of paper product produced, how much of the waste paper not recycled was actually burned to produce energy, and whether the trees effectively replaced by the waste paper in the recycling option were used as an energy source. Of the thirty different combinations of these variables that were examined, only two resulted in a net energy loss from recycling rather than burning the waste paper. These two cases were for newsprint and corrugated containerboard manufacture when it was assumed that 100% of the waste paper used in paper production could have been used for energy generation but none of the replaced wood had an alternative energy use.

- Two other variables were found to be of less importance for the comparison between recycling waste paper and burning it for energy: distance travelled by the waste paper to the recycling mill and the means of reclaiming the waste paper. A sixth variable, energy required for wood harvesting, was assigned a constant national average figure for the analysis.

- Energy recovery systems still form a logical and important part of an energy-conscious solid waste management program. It makes energy sense to recover energy from all paper fibres and other combustibles which cannot be separated for recycling. From this perspective, energy recovery is also clearly superior to landfilling and incineration of solid waste without energy recovery.

- Estimates of five air and water pollution indicators examined suggest that recycling, and in particular, the establishment of new capacity, may well result in a <u>decrease</u> in the air and water pollution per ton of paper produced.

- Based on an estimate of the energy savings that could be associated with a number of source reduction options, something in the order of 55 x $10^{12}$ BTU could be saved per year across Canada. This represents a savings of about 2.6% of the total industrial energy demand in Canada in 1975.

A complete summary of this study is available as a separate publication from the Solid Waste Management Branch of Environment Canada.

# RÉSUMÉ ADMINISTRATIF


- La gestion des déchets solides s'opère de trois façons: la récupération des ressources, celle de l'énergie ainsi que la réduction des rebuts à la source. Les deux premiers modes diffèrent dans le traitement appliqué à cette portion des déchets solides que forment les rebuts de papier. L'essentiel de la présente étude porte sur ces deux applications. La réduction des rebuts à la source fait l'objet d'une étude distincte. L'épargne nette d'énergie obtenue en recyclant le papier de rebut plutôt que de le transformer en combustible varie sensiblement en fonction de trois facteurs: d'abord, la nature de produit obtenue du recyclage, ensuite, le volume du papier non recyclé dont la combustion produira effectivement de l'énergie et, enfin, la conjoncture voulant que les arbres épargnés grâce au recyclage soient une source d'énergie.

- L'étude de trente combinaisons de ces facteurs en a révélé deux seules où le recyclage plutôt que la combustion a donné lieu à une perte nette. Il s'agit de la fabrication du papier journal, d'une part, et du carton ondulé, d'autre part, dans le cas hypothétique où la totalité du papier de rebut traité aurait pu produire de l'énergie sans pour autant que le bois ainsi conservé ne puisse servir à la même fin.

- Dans la comparaison entre le recyclage et la combustion, on a tenu compte de deux autres facteurs de moindre importance: celui de la distance parcourue pour transporter les rebuts à l'usine de recyclage et celui des procédés de récupération du papier. Pour fins d'analyse, une sixième facteur, l'énergie nécessaire à la récolte du bois, s'est vu attribuer une valeur constante, la moyenne nationale relative à cette activité.

- La récupération de l'énergie constitue toujours une part logique et importante de toute gestion des déchets solides qui vise à conserver l'énergie. Ainsi, il convient de pratiquer cette récupération pour toutes les fibres de papier même que pour les autres combustibles non triables en vue du recyclage. De plus, elle est éminemment supérieure à la mise en décharge et à l'incinération des déchets solides sans recouvrement d'énergie.

- Des estimations de cinq indicateurs de la pollution de l'air et de l'eau montrent que le recyclage, et notamment son accroissement, pourrait bien entraîner une diminution de la quantité de polluants rejetés dans l'air et dans l'eau par tonne de papier produit. A partir d'une évaluation de l'épargne d'énergie réalisable par suite de certaines réductions des déchets à la source, des calculs one démontré, à l'échelle du pays, une conservation annuelle possible de l'ordre de 55 X $10^{12}$ B.T.U. ce qui représente environ 2,6 p. cent de la demande industrielle totale l'énergie au Canada en 1975.

- Un résumé complet de l'étude, publié séparément, est distribué par la Direction de la gestion des déchets solides d'Environnement Canada

## Preface

The cooperation of many individuals in both the private and public sector has ensured the success of this project. The authors must first express their profound thanks to Ted Rattray of the sponsoring agency, the Solid Waste Management Branch of Environment Canada, for his support and contribution throughout the duration of the project.

A number of individuals, besides the authors, participated directly in the design, research and production of the study report and merit special mention: Roy Emery (Roy W. Emery Ltd.), William Franklin and Bob Hunt (both of Franklin Associates Ltd.) and Judy Smith.

The following are also to be thanked for their time, advice and assistance: Glen Allard (Water Pollution Control Directorate, Environment Canada), Tom Barton (Royal Military College of Canada), Bob Benjamin (Air Pollution Control Directorate, Environment Canada), Jean Berard (Forest Engineering Research Institute of Canada), Donald Boarder (Purchasing and Supply Department, City of Toronto), Carman Chisamore (Ontario Centre for Resource Recovery), Robert Ferguson (Metro Toronto Department of Works), Peter Gerkis (Toronto Public Works Department), Don Gillies (Ontario Hydro), Fred Johnson (Water Pollution Control Directorate, Environment Canada), Brian Kelly (Office of Energy Conservation, Energy, Mines and Resources), Richard Kinch (Effluent Guidelines Division, U.S. Environmental Protection Agency), Robert Laughlin (Ontario Research Foundation), C. Ross Silversides (Forest Management Institute, Environment Canada), and Fred Smith (Resource Recovery Division, U.S. Environmental Protection Agency).

By its very nature, the project required substantial assistance from experts in the pulp and paper industry and in resource recovery. We are very grateful to the following for the valuable data they provided for this project: Joseph Adlerstein (Syngas Recycling Corporation), Hugh Banfill (Domtar Fine Papers Ltd.), Ken Booth (Abitibi Paper Company Ltd.), Arnold Chantland (Ames Public Works Director), G.L. Crozier (Fraser Companies, Ltd.), Paul Davidson (Andco-Torrax Ltd.), Jeffrey Duke (American Paper Institute), Cam Gentile (Reed Ltd.), Bryan Glover (Union Carbide Canada Ltd.), Robert Greeley (AENCO, Ltd.), André Hébert (Perkins Papers Ltd.), Joseph Kennedy (Canadian Industries Ltd.), David Klumb (Union Electric Company), Frank Lorey (Garden State Paper Company, Ltd.), Stanley Lawler (American Can Company), William Martin (Reed Ltd.), Kenneth Maves (Bergstrom Paper Company), Bernard McDermott (Nashville Thermal Transfer Corporation), Gary McKnight (Dominion Bridge Company Ltd.), Robert Mendelson (Ohio Pulp Mills, Inc.), Reid Murphy, (Dominion Cellulose Ltd.), Robert Nelson (Atlantic Packaging Company), David Paavila (Canadian Pulp and Paper Association), Herbert Teeple (Technical Association of the Pulp and Paper Industry), George Preston (Occidental Research Corporation), John Reilly (Combustion Equipment Associates, Inc.), Edsel Stewart (Monsanto Enviro-Chem Systems, Inc.), Keith Thompson (Pulp and Paper Research Institute of Canada), David Tillman (Materials Associates, Inc.), Ken Voss (Ontario Paper Company Ltd.), A.A. Weaver (B.J. Fibres Inc.), and Ken Wilk (Tricil Waste Management Ltd.)

Finally, we are most grateful to the sponsoring agency for the opportunity of undertaking this most challenging study.

Respectfully submitted,

Peter Middleton, President

September 20, 1976

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# I. INTRODUCTION

## A. The Issues

Events of the past few years have required society to seriously re-evaluate its use and wastage of energy. Energy resources are no longer as inexpensive and accessible as they were. Escalation in price, anticipation of further escalations, concern regarding the long-term availability of traditional sources of energy and the serious balance of payments deficit that would result should Canada be forced to become a net importer of energy have all combined to make energy one of Canada's most important problems. By necessity, decisions which could formerly be made without a great deal of concern for energy use must now explicity consider it. This has resulted in a greatly increased interest in energy conservation and in alternative, renewable sources of energy.

At the same time, increasing attention is also being paid to different means of solid waste management. After considerable public debate, the traditional waste disposal techniques of landfill and incineration without energy recovery are now becoming less socially desirable for most large, urban communities in the medium and long term.

The debate has centred on five issues:

Resources: The discarded products which become solid waste are composed of both non-renewable and renewable (depleting and non-depleting) resources. A recent study by the Organization for Economic Co-operation and Development on the availability of certain key resources indicated that severe shortages of some of them are likely within the next 50 years (1). Even the supply of renewable resources, such as wood, is limited by the maximum sustainable yield of the forests.

Energy: The energy required to extract, refine and manufacture products as well as the energy inherent in products made from organic materials (such as wood fibre) are lost if these products are simply discarded.

Land Use: Landfill sites require land (usually in rural areas) which may be better utilized for farming or recreation. Poorly located incinerators in residential neighbourhoods can also prove unpopular. In the last few years, land use conflicts have become more and more common.

Pollution: The leachates from open dumps and poorly located landfill sites can cause serious groundwater or surface water pollution problems. Incinerators with insufficient pollution abatement equipment can contribute to air pollution.

Cost: It is estimated that more than $500,000,000 is spent annually in Canada on solid waste collection and disposal by municipalities and private contractors (2). This represents a significant component of municipal expenditures.

Each of these issues is compounded by the yearly growth in the amount of solid waste generated. It has been estimated that the amount of post-consumer solid waste generated in the United States is growing by about 4% per year; per capita solid waste generation is growing by more than 3% per year (3).

## B. Solid Waste Management Options

There are basically three options to alleviate the problems caused by solid waste. The most controversial has been reducing the amount of waste that is generated in the first place - at the source. Cutting back on the amount of packaging used, using refillable pop bottles instead of throwaway cans, and making products which last longer are examples of the type of source reduction options which are currently being discussed.

The other options, material and energy reclamation systems, have also been developed and technically proven to recover the resources in solid waste. Systems which recover paper before or after it enters the solid waste stream are in operation today, as are systems which burn wastes directly in an incinerator to produce saleable steam. Systems which produce a solid, liquid or gaseous refuse derived fuel are in various stages of development. Most of these processes reclaim a portion of inorganic components of waste as well, usually the ferrous metal.

The essential differences among the more popular systems lie in their treatment of the paper component of waste. While one group of systems attempt to maximize the recovery and recycling of the waste paper into new paper products, the other burns all the paper along with the rest of the waste. The two approaches are not, however, mutually exclusive. The reclamation of a portion of the paper component for recycling can, in fact, be followed by the burning of the rest of the paper with the remaining solid waste to produce energy.

An important problem then is to determine, from an energy conservation perspective, how much, if any, of the paper in waste should be recycled and how much burned for power.

## C. Study Objectives

This study will evaluate the energy implications of different solid waste management options in the urban context. While the energy recovery option represents a new source of energy from a material that was formerly landfilled or burned without energy recovery, the savings associated with making paper from recycled rather than virgin fibre or from producing less waste in the first place need to be investigated.

Apart from addressing itself to the energy implications of the various options, this study will also examine the environmental impacts associated with the recycling options considered to ensure that the energy savings are not gained at the expensive of environmental quality.

Although energy and environmental concerns are an essential component of any decision-making process, material resource conservation, economic, technical and social considerations are equally important. Energy analysis should never be construed as providing final answers to any single problem, but as one of a number of vital criteria that must be considered. The selection of the optimal solid waste management system cannot be based on this approach alone. This study will, however, supply answers to the energy and environmental components of the question.

## II. METHODOLOGY

The purpose of this chapter is to present in detail the methodology and major assumptions used in the analysis portion of this study.

The introduction mentioned four major approaches to dealing with the problems presented by solid waste: a) landfill, b) energy recovery, c) material reclamation/recycling, and d) reduction of solid waste at source. The overall objective of this study is to analyse the energy implications of applying these approaches to one particular component of solid waste: paper.

Each of the four is a solid waste management technique; however, there is an important distinction between reduction at source and the other approaches. Reduction deals with the solid waste problem by reducing the amount of waste that has to be handled; the other techniques 'accept' the volume of waste and process it in one way or another. This distinction has required a different approach to the analysis of the energetics of reduction. Estimates of the energy savings from different approaches to reduction have been based upon previous studies and have been assembled and discussed separately in Chapter V. The remainder of this methodology deals exclusively with the other three options.

In evaluating these options, perhaps the greatest area of contention surrounds the comparative energy savings attributable to reclamation/ recycling, especially when compared to energy recovery. It is on this issue that the major effort of the analytical work has been performed.

While energy was the main focus of the study, an evaluation of the environmental impacts of these options is included as well.

### A. General

A given quantity of a particular type of waste paper in the solid waste stream has been selected as the conceptual point of departure for the analysis. The objective of the exercise is to compare and rank, in energy terms, the different ways of dealing with that component of waste paper. Reclamation/ recycling is the option to which the other alternatives - energy recovery and landfill - are compared.

Thus, the analysis attempts to answer the question: Will energy be saved by using a given ton of waste paper as an input in the production of a particular product rather than disposing of that ton through energy recovery or landfill?

By definition, the recycling of waste paper involves its use as an input in a production process. Both landfilling and energy recovery of waste paper, of course, precludes this possibility. Compared with reclamation/recycling, landfilling and energy recovery involve not only direct handling (waste management) of the waste paper, they also imply a different mix of materials in the production sector.

In order to rank the solid waste management options, then, it is necessary to take account of the energy impacts in the production system as well.

Throughout this study, the assumption is made that the choice of waste management options should not affect the total <u>output</u> of the production system. In other words, the total amount of products available should be the same regardless of whether the given portion of waste paper is put to use as a material input in the production of a particular product (recycled), burned for power or buried. This implies that the portion of waste paper not recycled must be 'replaced' by another <u>input</u> in such a fashion that total output of the production in question remains the same. Virgin fibre (from wood) is assumed to replace the waste paper as the input. It is assumed, as well, for purposes of this analysis, that there is no functional difference in the products manufactured using the different output mixes. (There may, however, be a difference in the quality of the final product.)

The difference in material use in the production sector implied by not recycling can be thought to manifest itself in one of two ways. The first is through the replacement of the quantity of waste paper by virgin fibre in a particular plant's process. The second is through the decrease in output of a plant using secondary fibre to produce the product and the increase in the output of a plant using virgin fibre.

The quantity of virgin fibre input in either case will be that required to maintain the same overall output of the product. Which of these is applicable will depend upon the specific situation - the product being produced, the actual mix of production techniques, and so on.

What does this mean for the energy analysis of the different options? It means that the evaluation of the options requires a comparison between different waste management/production combinations. Figure 1 gives a basic outline of what these comparisons would include.

Consider x tons of waste paper (newspapers, for example) in the solid waste stream. This waste paper could be used as an input in the production of y tons of newsprint. Assume that the alternative to using the waste paper to make newspaper is to landfill it. Given the basic approach outlined above, what would an energy comparison of these two ways of dealing with the waste paper include?

On the one hand (reclamation/recycling), there is the energy associated with collecting the waste paper, preparing it for use in the production of newsprint, processing it into newprint and transporting it to market.

On the other hand (landfill), there is the energy associated with collecting the waste paper and landfilling it. To this must be added the energy associated with acquiring wood fibre, preparing it, processing it into y tons of newsprint and transporting it to market.

The difference between the latter and the former quantities is the energy savings associated with recycling the x tons of waste paper rather than landfilling it. If the savings are positive, it makes sense in energy terms to recycle rather than landfill that particular portion of waste paper.

This is the basic analytical approach employed throughout; it is applied to the comparison between reclamation/recycling and energy recovery as well. It will be noted that the analysis expresses its evaluation of the options in terms of the energy saved from the reclamation/recycling of a particular quantity of waste paper. For purposes of uniformity, the final comparisons in the report are always made on the basis of <u>one ton of waste paper input</u>.

The outcome of the analysis could be quite different depending upon which portion (what kind) of waste paper is assumed to be recycled into what type of product. For this reason, the analysis has been applied to four different products: printing and writing paper; newsprint; tissue and sanitary paper; and corrugated containerboard. Each of these uses a specific type of waste paper. In reality, then, four separate comparative analyses have been done, each one based on a different use for components of the waste paper stream.

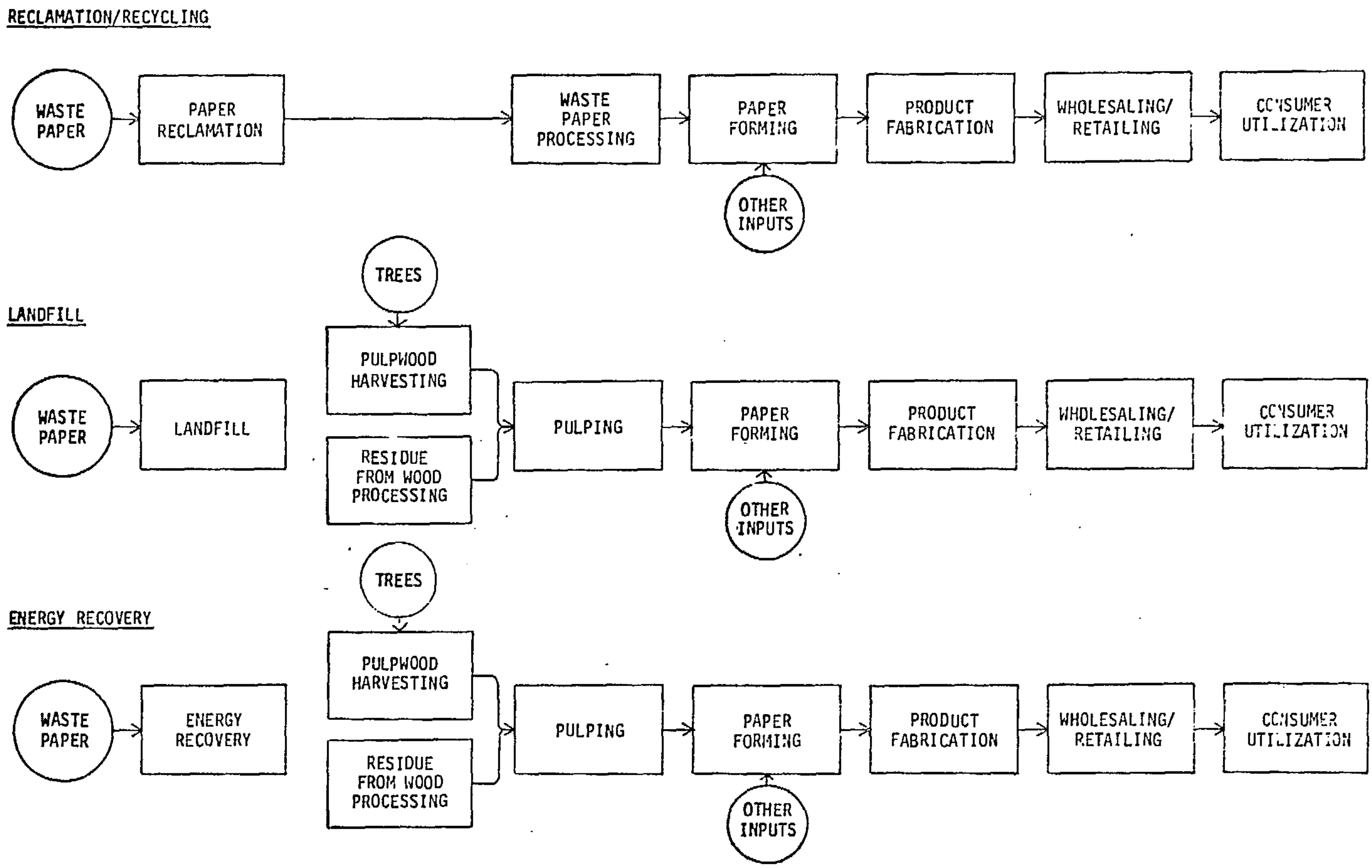
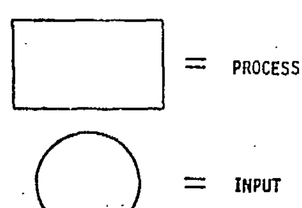



FIGURE 1 RECLAMATION/RECYCLING, LANDFILL AND ENERGY RECOVERY
The Implications for Material and Product Processing and Flow of Three Ways of Dealing with a Portion of Waste Paper.



A number of studies have dealt with aspects of the questions addressed here. One particularly useful research report, for the Ontario Government, was available just prior to the completion of this project and a number of references have been made to it (4). Other previous studies reviewed in this area have been listed in the bibliography.*

Given the experience of these efforts, it was decided to base this investigation on primary operating data. 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 more realistically characterize the energy conservation potential.

Primary data was collected from a small number of carefully selected pulp and paper mills producing, where possible, a similar type of product with a similar vintage equipment. Careful attention was paid to the distinction between integrated (pulp and paper mills located adjacent to one another) and non-integrated mills. Of the mills using secondary fibre, those that used the greatest amounts of waste paper were selected.

A similar selection was made of the various types of energy recovery systems and primary data was gathered on them. Recent Canadian operating data were used wherever available, but the relative infancy of energy and environmental analysis in Canada forced the project to rely to some extent on previously published U.S. data.

The basic calculations in the analysis were made using the Resource and Environmental Profile Analysis (REPA), developed originally 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.

REPA is an analytical tool which uses a total systems approach to determine the utilization of resources and production of effluents by a product system. The analysis begins at the point where the raw materials are taken from the earth; step-by-step it follows the entire production and consumption sequence to the point of end use, and finally to the management of the item as a component of solid waste.

The input of resources and output of effluents are recorded for distinct sub-processes, making possible a detailed energy and material balance for a basic unit of output (e.g. one ton).

* Reference numbers 5,6,7,8,9,10,11,12 & 13.

## B. Energy

The choice of which process and other energies to include in the energy analysis was made to reflect the fundamental focus of the study; that is, the comparison of different solid waste management options. The appropriate energies associated with the flows in Figure 1 are brought into the analysis, i.e. those associated with solid waste management activities, material acquisition and preparation, production and transportation.

### 1. Post-manufacture and Use

The output product from the production system has been assumed to be functionally the same whether it is made using waste paper or virgin fibre. This implies that all of the processes and activities associated with the product after it has been manufactured will be the same regardless of the mix of primary and secondary materials used in product's production. Since the objective of the analysis is to determine the differences in energy utilization by the separate options, the energies associated with the post-manufacturing processes need not be included in the analysis.

There is one exception; the product involved in the recycled and virgin options may be produced at different locations. The transportation of the products to their place of consumption therefore, need not be the same; the energy associated with the transportation is included in the analysis.

### 2. Inherent Energy

Before the study's other assumptions concerning energy are specified, it would be appropriate to clarify how the energy associated with wood and waste paper is treated. This is an important and particularly contentious issue. Should the energy inherent in the waste paper to be recycled and the energy inherent in the wood used to make paper products be charged against those processes which use them?

The answer depends on whether or not there is a true energy opportunity cost associated with the use of the material (waste paper or wood). It is a question of what would happen to the material were it not used in the way designated. For example, if the alternative use of a quantity of paper used in recycling (or a portion of it) is as a fuel, then the energy that would have been recovered should be counted as having been 'consumed' by the recycling process. If the paper would not have been put to this use, then it is 'free' from an energy perspective and no debit should be made.

The same holds true for the wood used in the production of paper products. If the wood (or a portion of it) would have been used as a fuel (through being burned for energy or being converted to methanol, for example) then that associated energy should be debited to the fibre's use. If the fibre would not have been put to this use, then it too would be 'free' energetically.

Given this perspective, there is no definitively 'correct' assumption concerning how these materials should be treated in the energy analysis. The appropriate assumption will depend upon such things as the configuration of the waste management system (whether energy recovery for waste paper exists) and the extent to which energy recovery systems for wood are actually operating. This in turn will most generally be governed by relative fibre and energy scarcities. Appendix A discusses wood as a potential source of energy.

In any case, because of the importance of the question and the considerable impact that different assumptions can have on the outcome of the analysis, analyses have been conducted under a variety of assumptions concerning the energy value of wood and waste paper.

## 3. The Cases Examined

Six different sets of assumptions (six 'cases') have been used. It is in terms of these six cases that results of the four comparative analyses of waste paper recycling (into printing and writing paper, newsprint, tissue and sanitary paper, and corrugated containerboard) are presented.

A description of each of the six cases is provided below. In addition to an outline of the assumptions made, the approach appropriate to computing the energy savings attributable to recycling in each case is also given.

All of the cases involve a comparison of waste management options under a specific set of assumptions concerning the energy value of wood and waste paper. The starting point for each case is a given amount of a certain type of waste paper which can be reclaimed and used in a particular process - Process R - to produce a specified quantity of a product. For example, x tons of used newspaper is an input in the production of y tons of newsprint. The objective of the analysis in every case is to specify the energy savings which can be associated with the reclamation/recycling of the waste paper rather than dealing with it in another way.

In Case 1, the solid waste management alternative to the reclamation/recycling of the waste paper is landfill. In Cases 2a, 3a, and 3c, the alternative is energy recovery. In Cases 2b and 3b, it is a combination of landfill and energy recovery. In all cases, the alternative to the use of waste paper in the production of y tons of product is the use of virgin fibre in Process V to 'replace' that output.*

## Case 1

Under Case 1, neither the waste paper recycled nor the wood used in the production of the paper product have an energy opportunity cost. They are both 'free' from an energy perspective.

The alternative to recycling the waste paper is to landfill it and use virgin fibre in the production process instead. It 'makes sense' from an energy perspective to recycle the waste paper rather than landfill it if the energy consumption associated with the former is smaller than the energy consumption associated with the latter. On a per ton of waste paper reclaimed and recycled basis, this can be expressed as:

Recycle if:

$$C_r + \frac{1}{t} (P_r + T_r) < C_v + L_v + \frac{1}{t} (H_v + P_v + T_v)$$

where:

$C_r$ The energy consumption associated with reclaiming one ton of waste paper. No inherent waste paper energy is included. See Chapter III, Section C for a detailed discussion of the energies included.

$P_r$ The energy consumption associated with preparing and processing, in Process R, all inputs in order to produce one ton of <u>output</u> of the product. No inherent energy for waste paper is included. See Chapter III, Section E for a detailed discussion of the energies included.

$T_r$ The energy consumption associated with transporting one ton of final product to market. See Chapter II, Section F for a detailed discussion of the energies included.

* 'Process R' and 'Process V' are solely meant to designate the product processes associated with the use of waste paper in the reclamation/recycling of the x tons of waste paper in question and the use of virgin fibre in the production system associated with the alternative waste management option respectively. They need not refer to physically different processes or different plants. The only difference that need exist is that Process R uses this particular x tons of waste paper and Process V uses virgin fibre instead.

$C_V$ The energy consumption associated with the collection of one ton of waste paper. See Chapter III, Section A for a discussion of this energy figure.

$L_V$ The energy consumption associated with landfilling one ton of waste paper. See Chapter III, Section A for a discussion of this energy.

$H_V$ The energy consumption associated with the harvesting of virgin material required to produce one ton of output of final product. No inherent wood energy is included.* See Chapter III, Section D, for a discussion of this energy.

$P_V$ The energy consumption associated with preparing and processing in Process V, all material to produce one ton of final product. No inherent wood energy is included. * See Chapter III, Section E for a discussion of the calculation of this energy.

$T_V$ The energy consumption associated with transporting one ton of final product to place of consumption. See Chapter III, Section F for a discussion of the energies included.

t The amount (tons) of waste paper required to produce one ton of output of product. This parameter is used to transform the per ton of <u>output</u> figures into per ton of <u>input</u> figures.

The savings attributable to recycling (S) can be expressed as:

$$S = C_V + L_V + \frac{1}{t}(H_V + P_V + T_V) - C_r - \frac{1}{t}(P_r + T_r)$$

The decision criterion then becomes:

Recycle if $S \geqslant 0$

* The tables presenting the energy associated with the production processes in Chapter IV enter wood-derived energy separately. However, this energy is excluded from the purchased energy totals used in the comparative analyses. Cases 3a, b, and c discuss the treatment of this energy under the assumption that wood is a fuel.

Case 2a

Case 2a assumes that there is an energy opportunity cost associated with the waste paper used in recycling  It is assumed that energy recovery is applied to <u>all</u> of the waste paper if it is not recycled. The wood used in the paper product, however, is assumed to have no energy opportunity cost.

As in Cast 1, the decision not to recycle implies that the final product associated with the recycling of the waste paper will be made from primary fibres.

From an energy perspective, it would make sense to recycle if the energy consumption associated with recycling were less than the energy consumption associated with virgin production plus the energy recovered from waste paper. Since energy recovery should generate more energy than it purchases (in the form of fossil fuel and electricity), the energy consumption associated with it will be negative.*

On a per ton of waste paper reclaimed and recycled basis, this is expressed as:

Recycle if:

$$C_r + \frac{1}{t}(P_r + T_r) < C_v + B_v + \frac{1}{t}(H_v + P_v + T_v)$$

Or, recycle if:

$$S > 0$$

where:

$$S = C_v + B_v + \frac{1}{t}(H_v + P_v + T_v) - C_r - \frac{1}{t}(P_r + T_r)$$

and:

$B_v$ The energy consumption associated with recovering the energy from one ton of waste paper. (This should be a negative number).

* However, by the Second Law of Thermodynamics, the energy generated by any system is less than the total energy input into the system, which would include the inherent energy in the solid waste.

## Case 2b

Under Case 2b, the assumption is made that there is an energy opportunity cost associated with some, but not all, of the waste paper used in recycling. It is assumed that the alternative for the waste paper used in recycling is for half of it to be processed by an energy recovery system and half of it to be landfilled. The wood used in the production of the paper product is assumed to have no energy opportunity cost.

On the basis of energy:

Recycle if:

$$C_r + \frac{1}{t}(P_r + T_r) < C_v + \frac{L_v}{2} + \frac{B_v}{2} + \frac{1}{t}(H_v + P_v + T_v)$$

Or, recycle if:

$$S \geqslant 0$$

where:

$$S = C_v + \frac{L_v}{2} + \frac{B_v}{2} + \frac{1}{t}(H_v + P_v + T_v) - C_r - \frac{1}{t}(P_r + T_r)$$

## Case 3a

Under Case 3a, all of the waste paper and wood are assumed to have an energy opportunity cost. It would make sense, in energy terms, to recycle if the energy consumption associated with recycling waste paper and recovering the energy from the wood 'saved' by recycling were less than the energy consumption associated with virgin production and the energy recovered from waste paper.

This can be expressed as:

Recycle if:

$$C_r + \frac{1}{t}(P_r + T_r) + W_r < C_v + B_v + \frac{1}{t}(H_v + P_v + T_v)$$

In terms of energy saved, the criterion is:

Recycle if:

$$S \geqslant 0$$

where:

$$S = C_v + B_v + \frac{1}{t}(H_v + P_v + T_v) - C_r - \frac{1}{t}(P_r + T_r) - W_r$$

$W_r$: The energy consumption associated with the energy recovery of the wood 'saved' by the recycling of one ton of waste paper. (This should be a negative number.)

Wood-derived energy is frequently used in the production of paper products. It can be regarded as a by-product of the use of virgin fibre. A question arises concerning how this energy should be accounted for under this case.

The approach taken in this study is to account for the wood-derived energy only as an opportunity cost. That is, the wood-derived energy used in the virgin production sector is not 'charged' separately; it is contained in the figure credited to the energy recovery alternative under recycling.

Case 3b

Case 3b assumes that there is an energy opportunity cost associated with some, but not all, of the waste paper and wood. Of the waste paper not recycled, half is assumed to be subjected to an energy recovery system, the other half landfilled. Similarly, it is supposed that, had the given quantity of wood not been used for the production of paper, half of it would have been used as a fuel.

Recycle if:

$$C_r + \frac{1}{t}(P_r + T_r) - \frac{W_r}{2} < C_v + \frac{B_v}{2} + \frac{L_v}{2} + \frac{1}{t}(H_v + P_v + T_v)$$

In terms of energy savings attributable to recycling, the criterion is:

Recycle if:

$$S \geqslant 0$$

where,

$$S = C_v + \frac{B_v}{2} + \frac{L_v}{2} + \frac{1}{t}(H_v + P_v + T_v) - C_r - \frac{1}{t}(P_r + T_r) - \frac{W_r}{2}$$

## Case 3c

This case represents the situation in which all of the waste paper is considered to have an alternative use as a fuel, but only half of the wood has a use as fuel. The criterion is:

Recycle if:

$$C_r + \frac{1}{t}(P_r + T_r) + \frac{W_r}{2} < C_v + B_v + \frac{1}{t}(H_v + P_v + T_v)$$

Or, if the energy savings associated with recycling are not negative.

Recycle if:

$$S \geqslant 0$$

where:

$$S = C_v + B_v + \frac{1}{t}(H_v + P_v + T_v) - C_r - \frac{1}{t}(P_r + T_r) - \frac{W_r}{2}$$

## 4. Presenting the Results of the Cases - An Example

The analysis of these six cases is applied to the use of different grades of waste paper in the production of each of the paper products examined: printing and writing paper; newsprint; tissue and sanitary paper; and corrugated containerboard.

The examination of each case is preceded by the presentation of three groups of energy data required for the analyses.

The first table presents the energy associated with producing one ton of the particular product (newsprint, corrugated containerboard, etc.) under the 'virgin fibre' option and the 'waste paper' option or options. Table 9, taken from the analysis of newsprint presented in Chapter IV, illustrates the information outlined.

The first two columns of the table present the energy consumption for the two production processes (100% virgin, 100% recycled) compared for newsprint. For the virgin operation, the figures include the energy consumption associated with the harvesting, processing and transportation ($H_v + P_v + T_v$) required to deliver one ton of final product. The figures for the waste paper operation include the energy consumption associated with the collection and preparation, processing and transportation ($tC_r + P_r + T_r$) required to deliver one ton of final product.

Table 1

ENERGY ASSOCIATED WITH THE PRODUCTION OF ONE TON OF NEWSPRINT

| Associated Energy \ Input Composition | 100% Virgin | 100% Recycled | % * Savings |
|---|---|---|---|
| | $10^6$ BTU/ton | | |
| Oil & Natural Gas | 12.11 | 13.17 | |
| Coal | - | - | |
| Electricity | 17.70 | 6.49 | |
| Total Purchased | 29.81 | 19.66 | 34% |
| Wood Derived | 0.96 | - | |
| Total | 30.77 | 19.66 | 36% |

* Energy savings from recycling

The rows of the table break down this energy consumption by basic fuel type. Two totals are given. The first, 'Total Purchased", excludes all wood-derived energies, and is the figure which is used in further analysis. The second includes all of the energies listed.

The figures in Table 1 are expressed in terms of energy consumed per ton of product output. In order to be used in the comparison of solid waste options, these totals must be expressed in terms of waste paper input, as was noted previously in this chapter.

This is the purpose of the second group of data presented in each analysis; the calculations necessary to perform this conversion, taken from Chapter IV for newsprint, are reproduced on the following page.

The first two figures represent the 'Total Purchased' energy for the virgin and waste paper processes from Table 1. The third figure is the waste paper consumed in the production of one ton of output. (The figure was represented by the symbol t in the previous formulae.)

## Purchased Production Energy Savings
## Per Ton of Waste Paper Input

| | | |
|---|---|---|
| 1. | Purchased energy consumed in the production of one ton of newsprint using 100% virgin fibres | $29.81 \times 10^6$ BTU/ton |
| 2. | Purchased energy consumed in the production of one ton of newsprint using 100% recycled fibres | $19.66 \times 10^6$ BTU/ton |
| 3. | Waste paper consumed in the production of one ton of newsprint using 100% recycled fibres | 1.120 tons |
| 4. | Energy savings per ton of waste paper input | $9.06 \times 10^6$ BTU/ton |

The fourth figure, the energy savings in the production sector per ton of waste paper input, is derived by dividing the difference between the first two figures by the third figure. In other words, the fourth figure is equal to:

$$\frac{1}{t} \left[ (H_v + P_v + T_v) - (t\, C_r + P_r + T_r) \right]$$

or

$$\frac{1}{t} (H_v + P_v + T_v) - C_r - \frac{1}{t} (P_r + T_r)$$

## Energy Associated with the Alternative Disposition of Waste Paper and Wood

| | | |
|---|---|---|
| 1. | Energy required for the collection and landfilling of one ton of waste paper | $0.25 \times 10^6$ BTU/ton |
| 2. | Energy associated with the collection and energy recovery of one ton of waste paper | $-11.03 \times 10^6$ BTU/ton |
| 3. | Energy associated with the harvesting and energy recovery of the trees made available by the recycling of one ton of waste paper | $-11.54 \times 10^6$ BTU/ton |

The third group of data, reproduced above from Chapter IV for newsprint, presents the alternative disposition of waste paper or wood.

The first figure gives the energy consumption associated with collecting and landfilling one ton of waste paper ($C_V + L_V$).

The second figure gives the energy consumption associated with the collection and energy recovery of waste paper ($C_V + B_V$). It is calculated by multiplying the waste to fossil fuel equivalent multiplier (0.7) by the higher heating value of waste paper ($16 \times 10^6$ BTU/ton) and subtracting this from the energy for the collection of solid waste:

$$0.17 \times 10^6 \text{ BTU/ton} - (0.7 \times 16 \times 10^6 \frac{\text{BTU}}{\text{ton}}) = -11.03 \times 10^6 \text{ BTU/ton}$$

The third figure gives the energy consumption associated with the harvesting and energy recovery of the wood 'made available' by the recycling of one ton of waste paper ($W_r$). It is calculated by first finding the tons of green roundwood that are necessary to produce the newsprint that could have been produced from one ton of waste paper. This figure is then multiplied by the same solid waste to fossil fuel equivalent multiplier (0.7) and by the higher heating value of green roundwood ($9 \times 10^6$ BTU/ton). This total is then subtracted from the energy required to harvest and transport the previously calculated tonage of trees:

| | | |
|---|---|---|
| since | 2.1812 | tons of green roundwood are required to make 1 ton of newsprint: |
| and | 0.893 | tons of newsprint can be produced from 1 ton of waste paper |
| then | 1.95 | tons of wood would have been required in place of 1 ton of waste paper input. |

$$(1.95 \times .38 \times 10^6 \frac{\text{BTU}}{\text{ton}}) - (1.95 \times 9 \times 10^6 \frac{\text{BTU}}{\text{ton}} \times 0.7)$$

$$= 11.54 \times 10^6 \frac{\text{BTU}}{\text{ton}}$$

The final table for each product option assembles the data for an analysis of the six cases. Table 2, taken from Chapter IV, illustrates the energy savings attributable to recycling one ton of waste paper into newsprint.

The results of the analysis of each case are presented in terms of the energy savings attributable to recycling one ton of waste paper (the final column of the table). These savings are calculated in the manner outlined in the previous discussion of each case. For example, the savings in Case 3a, 9.57 x $10^6$ BTU/ton are calculated thus: (9.06 - 11.03 + 11.54) x $10^6$ BTU/ton. This is equivalent to:

$$\frac{1}{t}(H_v + P_v + T_v) - C_r - \frac{1}{t}(P_r + T_r) + B_v - W_v$$

Table 2

ENERGY SAVINGS ATTRIBUTABLE TO RECYCLING ONE TON OF WASTE PAPER INTO NEWSPRINT

| CASE | SAVINGS OF PURCHASED PRODUCTION ENERGY | ENERGY ASSOCIATED WITH THE ALTERNATIVE DISPOSITION OF: WASTE PAPER | | WOOD | ENERGY SAVINGS FROM RECYCLING |
|---|---|---|---|---|---|
| | | COLLECTION/ LANDFILL | COLLECTION/ ENERGY RECOVERY | HARVESTING/ ENERGY RECOVERY | |
| | $10^6$ BTU/ton | | | | |
| 1 | 9.06 | 0.25 | - | - | 9.31 |
| 2a | 9.06 | - | -11.03 | - | -1.97 |
| 2b | 9.06 | 0.13 | - 5.51 | - | 3.68 |
| 3a | 9.06 | - | -11.03 | 11.54 | 9.57 |
| 3b | 9.06 | 0.13 | - 5.51 | 5.77 | 9.45 |
| 3c | 9.06 | - | -11.03 | 5.77 | 3.80 |

## C. Further Assumptions

### 1. 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.

### 2. Energy

#### a. Measurement

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 gigajoules (GJ). A discussion of the differences between enthalpy and free energy may be found in other studies (4,14).

The energy analysis used in this study includes the secondary or pre-combustion energy associated with the extraction, processing and transportation, as well as the energy contained in the various fuels used by the different processes. Electricity, which is not a fuel, has been treated in a special manner (see below).

The energy produced from solid waste (and from wood) by the various energy recovery systems has been expressed in terms of fossil fuel savings. This is further discussed in Chapter III, Section B.

## b. Electricity

Electrical energy use or savings were 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 'peak' power needs. Thus, any marginal increase or decrease in electrical energy requirements is taken up by the thermal generation stations. An Ontario Research Foundation study made a similar assumption (15).

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. Such thermal generators have the added advantage that the steam produced can also be used in the process. Further discussion of topping turbines may be found in other studies (15).

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.

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 direct use conversion factor of 3413 BTU/kwh. The energy associated with the extraction and transportation of the coal used to generate the electricity has been included in this figure.

## c. 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 burning for energy - 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 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 questions 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 signficant portion of the total energy associated with the options. Calculations made in other studies, however, suggest that this is not so. Recent estimates for Ontario (4) indicate that captial-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 the capital-related energy consumption for energy recovery systems is about 1% of the fossil fuel equivalent energy saving. This order of magnitude has no substantive effect on the outcome of the comparision, 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.

### d. Secondary Impacts

The extraction, processing and transportation of fuels consume energy and cause environmental disruption. These secondary impacts are considered in this analysis, as were the environmental impacts resulting from fuel combustion. As noted previously, the secondary energy impacts resulting from manufacuturing the capital equipment used in pulp and paper mills or reclamation plants were excluded.

### e. Marketable Coproducts and Byproducts

If marketable coproducts or byproducts were produced, an attempt was made to deduct from the total process the energy consumption specifically attributable to their production. Because it was often difficult to arrive at reasonable estimates directly, the energy requirements for producing the byproducts by an alternative, known process were used where possible. If both these accounting proceedures proved impossible, the energy consumption was adjusted on a weight basis to account for coproduct and byproduct production.

## 3. Environmental Variables

### a. Environment

"Environment" was defined for this study as the global environment with no impacts being excluded a priori regardless of location.

### b. Atmospheric Emissions

The emissions in lbs/ton associated with the three major pollutants (namely, particulate matter, sulfur oxides and total reduced sulphur) were determined from available data. The amounts reported represent actual discharges into the atmosphere after existing emission controls have been applied.

### c. Waterborne Wastes

The two major effluent indicators from pulp and paper mills are biological oxygen demand ($BOD_5$) and total suspended solids (TSS). The effluent values are those after any waste water treatment has been applied, either at the mill site or in a municipal sewage treatment plant, and represent discharges into receiving waters.

### d. Small Quantities of Materials

The impacts associated with materials used in production which aggregate to less than five pereent by weight of the end product were not included. These inputs were examined, however, to ensure that no known "high environmental impact" materials were excluded from the analysis.

# III. DESCRIPTION OF WASTE MANAGEMENT AND PAPER PRODUCTION SUB-SYSTEMS

This chapter examines each of the relevant components of the waste management and paper production sub-systems and presents the energy and environmental data which underlie the analysis in the following chapter. The six sub-systems identified are solid waste collection and disposal; energy recovery from solid waste; paper reclamation; forestry operations; pulp and paper manufacturing; and transportation.

The energy required to convert the paper produced by a paper mill (newsprint, for instnace) into a final product (a newspaper) and the energy required to retail that product are not discussed since they would be exactly the same whether the product is made from virgin or secondary fibre and fall out immediately in comparative analysis.

The data from this chapter will be used to undertake the comparative analysis of alternative solid waste management techniques, as outlined in the previous chapter.

## A. Solid Waste Collection and Disposal

The energy required for the collection of solid waste has been estimated to be approximately $0.15 \times 10^6$ BTU/ton, based on actual experience in a densely populated urban centre (4). The only environmental impacts associated with solid waste collection are those resulting from the pre-combustion and combustion of the fuel used by the garbage trucks.

Landfilling solid waste, the most common disposal system now used, has been previously estimated to require approximately $0.07 \times 10^6$ BTU/ton (9). The only environmental effects associated with landfilling that have been included in this analysis are those resulting from the pre-combustion and combustion of the fuel required by the landfill equipment. Although the landfilling of solid waste can cause groundwater or surface water pollution problems, no quantitative estimate of this environmental impact was made due to the lack of applicable data in this area and the importance of the location and maintenance of such sites.

## B. Energy Recovery From Solid Waste

The solid waste stream in Canada is now receiving increased attention as a potential source of both materials and energy. Although, at present, very little of the energy inherent in Canada's solid waste is being recovered, plans are being considered that could change this situation. This section estimates the energy that could be effectively recovered from this previously unused energy source.

Many systems for energy recovery have now been demonstrated and many more are in various stages of development. Extensive descriptions of the various processes can be found in other studies (16, 17, 18, 19). For the purposes of this review, the various energy recovery processes were seen to fall into two general categories: those which utilize the solid waste directly in a combustion process to produce steam and those which process the waste in varying degrees to produce, in effect, an improved fuel. A hard distinction is not always possible but this concept provides a useful method of classification.

This study evaluated, from an energy efficiency perspective, a number of different systems, with the emphasis on systems having actual operating experience. A questionnaire* was sent to all the major energy recovery facilities or promotors of such facilities that were found through an exhaustive literature search. This was followed up by site visits in a number of cases where the facility was in operation. The data obtained was then used to estimate the net energy efficiency of each system.

### 1. Energy Efficiency of Energy Recovery Systems Analysed

Energy efficiency has been defined in this report as the ratio, expressed as a percentage, of the amount of energy in the form of high pressure steam that could be produced by the system being considered to the amount of inherent energy in the solid waste feed, plus all process energy required.

$$\text{Energy Efficiency (\%)} = \frac{\text{Energy Output (as steam)}}{\text{Enery Inputs (refuse, electricity, fuel)}} \times 100\%$$

A fuel recovery efficiency was estimated for those systems that produce either a refuse-derived solid fuel or pyrolytic gas or oil instead of steam.

$$\text{Fuel Recovery Efficiency (\%)} = \frac{\text{Energy Output (fuel)}}{\text{Energy Inputs (refuse, electricity, fuel)}} \times 100\%$$

* The questionnaire that was used has been included in Appendix G.

To facilitate a comparison of the relative performance of the various systems, all the processes were evaluated with steam production as the common base. The energy efficiency for refuse-derived fuel (RDF) systems was calculated by multiplying the fuel recovery efficiency by a steam generation efficiency. The steam generator efficiency for most solid refuse-derived fuels was estimated to be 87.5% (the efficiency of conversion of coal to steam) less a 10% loss in boiler efficiency due to the moisture content of solid waste, resulting in a steam generation efficiency of 77.5%. For certain refuse-derived fuels, such as ECO-FUEL II, the steam generation efficiency was estimated to be as high as 84.5%. A steam generation efficiency of 85% was used for oil boilers and 83% for gas boilers.

Many of the energy recovery systems examined also reclaimed various other components of solid waste, most often the ferrous metals. However, this does not significantly alter the energy efficiency figures since the amount of ferrous scrap recovered is a relatively small percentage of the total input to a system (about 5%) and the energy required for the magnetic separation process is also relatively small (10 kwh/ton of metal recovered or 0.5 kwh/ton of solid waste) (20 ).

The energy efficiency calculated here is based on the conversion of solid waste to steam. However, steam, unlike coal or oil, is not a primary source of energy. It was thus necessary to translate the energy efficiency figure into one which reflects the primary energy savings due to the use of solid waste as a fuel. A more relevant figure for this study is thus the "fossil fuel savings" from using solid waste as a fuel. This new figure, expressed as a multiplier, is calculated by dividing the previously calculated energy efficiency of steam conversion by the efficiency of converting fossil fuel to steam (87.5%). This is the same approach used by the Ontario Research Foundation (4). For a more complete discussion of this conversion, the interested reader should refer to the Ontario Research Foundation study. For those systems producing a synthetic gas or oil, the fuel recovery efficiency was used to calculate the fossil fuel savings directly.

The energy efficiency (solid waste to steam) and the solid waste to fossil fuel equivalent multiplier for twelve energy recovery systems are summarized in Table 3.

Comments on the operation and thermodynamics of these and various other energy recovery systems have been included in Appendix C, along with the derivation of the energy efficiency of the different systems.

Table 3

EFFICIENCIES OF SELECTED ENERGY RECOVERY SYSTEMS

| TYPE OF SYSTEM | IDENTIFICATION OF SYSTEM | COMMENTS ON SYSTEM | ENERGY EFFICIENCY (solid waste) to steam) | SOLID WASTE TO FOSSIL FUEL EQUIVALENT MULTIPLIER |
|---|---|---|---|---|
| DIRECT-FIRED INCINERATOR | -Incinerateur No. 3, Montreal<br>-Incinerateur C.U.Q. Quebec City<br>-Boston North Shore System Saugus, Massachusetts | Von Roll Grate Systems | 65% | .74 |
| REFUSE-DERIVED FUEL | -Canadian Industries, Ltd. SWARU | semi-suspension fired steam generator | 66% | .75 |
| | -Ames Solid Waste Recovery System | electricity generation | 55% | .63 |
| | -Monsanto LANDGARD | gas pyrolysis with steam production | 51% | .58 |
| | -Andco-Torrax, ANDCO-TORAX PROCESS | gas pyrolysis with steam production | 68% | .78 |
| | -Union Carbide PUROX | gas pyrolysis | 56% | .67 |
| | -Syngas Recycling SYNGAS PROCESS | hydro-gasification | | .68 |
| | -Occidental Research FLASH PYROLYSIS | oil pyrolysis | 33% | .39 |
| | -Combustion Equipment Associates ECO-FUEL II | powder-like dry fuel | 61% | .70 |
| | -American Can AMERICOLOGY | dry fuel | 45% | .51 |

Since this portion of the study was intended to be illustrative, not exhaustive, an energy efficiency of 60% and a solid waste to fossil fuel equivalent multiplier of 0.7 have been used as representative values in the analysis portion of this study.

The effect that paper reclamation will have on the recovery of energy from solid waste is an important part of the debate of whether to burn paper for energy or to recycle it. Although this study was unable to completely resolve the debate, comments on the effect of paper reclamation have been included in Appendix D. Although inconclusive, the results of this Appendix indicate that both energy recovery and a certain amount of paper reclamation are compatible.

## 2. Energy and Environmental Effects of Energy Recovery Systems

Although each of the different recovery systems identified emit a certain quantity of air pollutants, primary raw data was not available for each system. Estimates from a previous study (20) for the atmospheric emissions from incineration with energy recovery have been used as representative: 1.5 pounds of particulate matter and 1.5 pounds of sulphur oxides per ton of solid waste processed.

## C. Paper Reclamation Systems

This section examines the energy use associated with the various ways in which waste paper can be made available to paper mills for recycling.

There are three basic types of waste paper reclamation techniques:

1. Mechanical systems which shred mixed solid waste at a central facility specifically to reclaim paper
2. Separate collection systems for waste paper that has been kept segregated from the rest of solid waste by the consumer
3. 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.

### 1. Mechanical Systems

Mechanical systems, specifically designed to maximize the recovery of paper fibres from solid waste, are in various stages of development. Five have been identified for the purposes of this study.

<u>Black Clawson Fibreclaim System</u>

This system is built around a wet process in which the mixed waste is pulped into a slurry in a Hydrapulper. The paper fibres are then removed mechanically using a series of screens augmented by contaminant removal equipment. A 50-ton per day (TPD) pilot plant began operating in 1971 with EPA funding.

The other four are dry systems that shred and air classify the mixed waste to recover paper fibres:

<u>Environment Resources Corporation System</u>

They have signed a 20-year contract with Fort Lauderdale, Fla., to construct and operate a 400 TPD plant.

<u>Forest Products Laboratory Recovery System</u>

A 20 TPD pilot plant operated in Madison, Wisconsin from 1971-1974. A Swedish company, A.B. Svenska Flaktfabriken, are currently promoting a system based on the Madison research project.

<u>Franklin Institute/Waste Resources Corporation System</u>

A pilot plant was partially installed in Philadelphia by the Franklin Institute in 1972 but the project funding expired. In 1974, Waste Resources Corporation reactivated the project and is now experimenting with a pilot plant.

Sorain/Cecchini System

Three large recycling plants operating in Rome and Perugia, Italy, are using this system which does not shred the mixed waste. The system burns the unreclaimed portion of the paper with the rest of the waste to produce energy.

Additional information on each of these systems is available in previous studies (16,21).

A critical feature of each system is, of course, the resulting type of fibre which determines the type of paper mills that could use it. It is to be expected that most processes will produce a low grade of mixed waste paper; the traditional users of the mixed grades of waste paper are mills producing building material and boxboard. It is significant to note that these are not among the mills selected as having a large potential for increased demand for secondary fibre.

Linerboard and corrugating medium mills may be able to use reclaimed paper containing a high percentage of corrugated containers. It appears unlikely that a mechanical reclamation process would produce fibres suitable as a furnish in manufacturing printing and writing paper, tissue paper or newsprint. The mixture of both mechanical and chemical pulps and the presence of impurities, particularly plastic, would present significant problems for these mills which generally require a homogeneous, relatively pure supply of waste paper.

Complete energy data was available on the Sorain/Cecchini System from Reed Paper Ltd. of Toronto who have the Canadian rights to this process. It was estimated that the direct energy requirements for paper recovery from this system are as follows (22):

| | |
|---|---|
| Corrugated Cartons | $1.74 \times 10^6$ BTU/ton of paper recovered |
| Mixed Papers | $1.03 \times 10^6$ BTU/ton of paper recovered |
| Mixed Papers and Corrugated Cartons | $0.783 \times 10^6$ BTU/ton of paper recovered |

A previous Canadian study estimated the direct energy requirements for shredding and separating solid waste to be $0.635 \times 10^6$ BTU/ton, and the total energy - including capital and maintenance costs - to be $0.711 \times 10^6$ BTU/ton ( 4 ). The figure for reclaiming one ton of corrugated cartons using the Cecchini process $(1.74 \times 10^6$ BTU/ton) will be used in this study.

## 2. Separate Collection

This study examined the separate collection of three different grades of waste paper* that can be recovered from three different sources:

Newspaper from households
Corrugated from stores and industries
Pulp substitutes and deinking grades from offices

Depending upon the degree of co-operation, the quality of the paper recovered can vary considerably. Successful examples of each approach exist and can be used as models.

A number of different techniques have been used to collect waste newspapers from homes using various racks, trailers and special trucks. Details concerning the operation of various separate paper collection systems are available in other studies (23).

Newspapers were collected in Ottawa using a rack installed in the rear of the regular garbage trucks. London, Ontario used trailers successfully. No significant amount of additional energy, either direct energy to operate the trucks on the route or indirect energy to buy new trucks, was required by either system, other than the energy to manufacture the racks and trailers. Both systems were successful but were discontinued during the market slump for waste newspaper in 1974.

Newspapers have been collected using a separate truck in Toronto for more than three years. Like most other separate newsprint collection programs, the manpower and trucks required were made available by schedule changes. Figures received from officials there indicate that about 320 gallons of gasoline are used per week to collect newspapers (24,25). An average of 60 tons of newspapers were collected weekly in the city of Toronto in 1975 (26). However, if the present low-recovery rate of 9% were increased to 50%, a rate believed to be possible by other studies (3,23) the energy required to collect one ton of newspapers would drop (assuming that no additional energy is required to collect this increased amount of paper since routes remain the same).

* Although mixed paper could also be collected from each of these sources, this grade of waste paper is not a major input to the manufacturing of the four types of paper examined in this study.

A 50% recovery rate may be difficult in Toronto because 50% of the residents live in apartments. A recovery rate of 30% has been assumed in this study - mid-way between the two figures. It should, however, be borne in mind that if racks or trailers were used to collect newspapers, the energy required to collect them separately would be the same as that required to collect mixed solid waste.

It has been assumed that the only energy required to reclaim corrugated containers from stores and industry and discarded fine paper from offices is the energy to transport the material to the nearest waste paper dealer and from there to the user mill. The sum of these two distances has been assumed to be 100 miles in this study.

### 3. Hand Picking Waste Paper at a Resource Recovery Plant

This recovery option has been included in the plans for the Ontario Resource Recovery Centre and has been mentioned in various studies of waste paper recycling (35). 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 as not been included in the analysis.

### 4. Final Waste Paper Preparation

The waste paper reclaimed by the various 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 $0.09 \times 10^6$ BTU are required to bale one ton of waste paper using a mill-size baler (27). 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.

Although work has been progressing on fractionation processes that mechanically sort and upgrade waste paper, none of these systems are operational yet and no estimate of the energy that might be required by this process was made. The energy associated with reclamation systems may, however, be more significant in the future if fractionation is used to reclaim waste paper.

## D. Forestry Operations

The first process in the pulp and paper manufacturing cycle is the acquisition of the virgin raw materials. The following section estimates the energy requirements of forestry operations and comments on their environmental impact.

The forestry operations considered in this study include felling and de-limbing of the trees, skidding them to the roadside and then loading them onto trucks. Water transport of wood, although still used by some mills, has been replaced by truck transport as the most common method of delivering pulpwood in Canada east of the Rockies ( 28 ). None of the pulp and paper mills examined in this study had a major wood floatage operation. The transportation energy to haul the roundwood to the pulp mill is considered later in this chapter.

As may be expected, there are a number of different logging systems employing different combinations of equipment. Although a great deal of mechanization has occured in forestry operations over the past 10 years, 50% of the wood is still cut by hand (29). The following is an estimate of the average amount of fossil fuel required to fell, skid and load roundwood in Canada (30):

| | |
|---|---|
| Felling | 0.6 Imperial gallons/cord |
| Skidding | 1.0 Imperial gallons/cord |
| Loading | 0.5 Imperial gallons/cord |
| Total | 2.1 Imperial gallons/cord |
| | or 1.05 Imperial gallons/green ton of roundwood |

This figure is similar to the results of an American Pulpwood Association survey in 1974 which estimated that 2.45 U.S. gallons/cord (2.04 Imperial gallons/cord) were required to harvest pulpwood (31).

Many pulp mills also buy wood chips and other residue from lumber operations. These materials were formerly considered waste products and were dumped or burned. It has been assumed in this study that these residues are 'free' from an energy standpoint to the pulp mills. The energy associated with debarking and chipping the wastes from lumber mills has been attributed to the lumber mills, not to the pulp mills which use them. The transportation energy required to deliver these residues to the pulp mill have, however, been included in this analysis and are discussed later.

Although each of the pulp mills surveyed was asked for the amount of roundwood and residues purchased, the data received was expressed with varying assumptions as to the moisture content of the roundwood. This is particularly significant for roundwood since the moisture content can vary from bone dry (0% moisture) to kiln dry (8%) and air dry or seasoned (15-25%) to green (50% moisture)(32). It was thus decided to use average yield figures for different pulp mills to estimate the amount of raw materials required for each mill on a consistent moisture basis. The following estimated percentage yields (tons of air dry output per ton of green roundwood and residue input) were used:

| | |
|---|---|
| Bleached softwood kraft | 27.5% |
| Groundwood | 55.0% |
| Neutral sulphite semi-chemical (NSSC) | 45.0% |

These percentages were derived from previous estimates (30) and average fibre yield figures. The ratio of roundwood to wood residues for input to the mill, as reported in the questionnaire, was used to estimate the breakdown of the input.

Some of the pulp mills surveyed purchased debarked roundwood, so a separate estimate of the energy required to debark wood was necessary. A figure of 13.5 kwh/ton of green roundwood was used, based on the figure used in the Ontario Research Foundation report of 26.99 kwh/oven dry ton of wood (4).

The only air and water pollution impacts associated with forestry operations considered in this analysis are those associated with the production and combustion of the fuels used in these operations. A summary of the environmental impacts resulting from the pre-combustion and combustion of fossil fuels is included in Appendix H (Table 54). The waterborne wastes associated with the water transport of wood were not included because, for the mills considered in this study, truck transport was the principal mode of transportation. Air pollution resulting from the prescribed burning of logging residues was not included because this is not a common practice in eastern Canadian forests.

## E. Pulp and Paper Mills

This section comments on the energy requirements and environmental impacts of selected pulp and paper mills. Some of the mills manufacture paper from 100% virgin resources while others manufacture the same or a comparable paper product using a certain amount of waste paper. The paper product produced by all but one type of mill (linerboard and medium mill) is in its final form. In the case of newsprint and printing and writing paper, all that is required is the printing and distributing of the paper. The energy required to manufacture corrugated containerboard from linerboard and corrugating medium has not been included; it would be the same, however, for linerboard and medium made from virgin and secondary fibres, and thus not of significance to a comparative analysis.
A considerable amount of literature has been published which describes the operation of the pulp and paper industry. This background information has not been included in this report but may be found in other studies (29,33,34).

### 1. Selection of Mills

As mentioned in Chapter II of this report, it was decided to solicit primary data from a few carefully chosen pulp and paper mills rather than rely on previously published industry averages or on estimates of the energy required for each operation within a pulp and paper mill.

This study has considered each integrated pulp and paper mill as one unit from an energy standpoint because purchased energy data was only available for the whole integrated process, not for the pulp or for the paper manufacturing processes.

Eight basic types of paper are produced by paper mills in Canada: newsprint, printing and writing paper; tissue and sanitary paper; wrapping paper; boxboard; linerboard; corrugating medium and building material. Most of these products can be manufactured using either virgin or secondary fibre as the primary input.

An attempt has been made to select mills which are illustrative of the differences in energy used and environmental impacts of manufacturing the same paper product using primarily virgin pulp and using some waste paper. Before selecting these specific mills, a few brief comments on the potential for increased demand for waste paper are advisable.

An increase in demand for waste paper can come from either the substitution of reclaimed fibres for some virgin fibres in existing mills or from the construction of new facilities requiring waste paper to meet expanded demand for paper products.

There are two general ways waste paper can be used by a paper mill: either as a minor supplement to the furnish in an existing virgin process or as a major component of the furnish in a mill designed to use large amounts of waste paper.

Although more waste paper will generally be utilized by the second method, the first could be of particular revelance to the recycling of waste newsprint in Canada since over 90% of Canada's newsprint production is exported. If, for instance, used news supplied 5% of the furnish for all newsprint mills in Canada, then over 50% of all newsprint discarded in Canada would be required by these mills.

Five criteria were used in the selection of the product categories 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 processing options.

Every attempt was made to select for purposes of comparison mills which produce similar products with machines of similar vintage. However, in the comparison between tissue and sanitary paper made from virgin and secondary fibre, there is a considerable difference in the duality of the functionally similar end products.

Table 4 shows the current recycling rates of waste paper (excluding mill broke) across Canada by type of paper mill.

Not included in Table 4 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 the container grades. 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 (37).

The annual growth rate for various paper products has been previously estimated to be: 6.5% for printing and writing paper, 4.0% for newsprint, 5.5% for containerboard, and 2.5% for boxboard (35).

Table 4

CONSUMPTION OF WASTE PAPER IN CANADA BY END PRODUCT 1973

(000 tons)

| | Newsprint | Printing & Writing | Tissue & Sanitary | Wrapping | Boxboard | Linerboard | Corrugating Medium | Building Papers | Building Boards | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| Production | 9140 | 983 | 324 | 671 | 917 | 1104 | 494 | 163 | 496 | 14,293 |
| Domestic Consumption (A) | 855 | 703 | 316 | 506 | 1009 | 812 | 373 | 572 | | 5,146 |
| Secondary Fibre Used (B) | 36 | 46 | 32 | 1 | 355 | 139 | 81 | 234 | | 924 |
| Recycling Rate (B/A x 100%) | 4.2 | 6.5 | 10.1 | 0.2 | 35.2 | 17.1 | 21.7 | 40.9 | | 18.0 |

Source: Woods, Gordon and Company, Recycling of Mixed Office Waste from the National Capital Area (35)
CPPA, "Reference Tables 1975" (36)

For all but one product, a maximum recycle option was considered. From Table 4, it is clear that very little waste paper is utilized by mills producing wrapping paper. In this case, therefore, the 100% option was discarded as unrealistic.

Table 5 shows the 1973 Canadian input of waste paper by grade to paper mills and the percent of total input represented by waste paper for the different types of mills. It indicates that printing and writing paper, and tissue and sanitary paper mills utilize large amounts of the higher grades of waste paper (deinking grades).

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. The use of waste news to produce newprint is low because Canada does not have a newsprint deinking mill.

Although boxboard and building materials mills are the two largest consumers of waste paper, they were not included in the list of mills to be analysed because they already have the highest recycling rates. Other studies have found that waste paper is already being used by building material mills to the greatest possible extent (34, 35).

Boxboard has also been excluded from the study in view of the recent expansions and the already high waste paper utilization. Conversations with representatives of the various boxboard mills in southern Ontario confirmed the predominance of combination boxboard (boxboard made from waste paper) in this area. Previous studies have estimated that combination boxboard requires 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. (7,8)

Table 6 describes the particular mills that were chosen for analysis on the basis of the above criteria and represents the most significant technically possible options currently available. The four product categories included in the analysis are: 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. (except for the addition of a third printing and writing paper mill using 34% deinked fibre). In the use of reclaimed fibres, only the major grade associated with each product was considered (deinking, news, deinking and courrugated respectively for the four product categories).

Table 5

PERCENTAGE CONSUMPTION OF WASTE PAPER BY END PRODUCT IN CANADA 1973

| Paper Products \ Grades of Waste Paper | Pulp Substitutes | Deinking | Container | News | Mixed | Percent of Total Consumption of Waste Paper |
|---|---|---|---|---|---|---|
| Printing & Writing Paper | 45 | 55 | | | | 5% |
| Newspaper | 66.7 | | | 5.5 | 27.8 | 4% |
| Tissue & Sanitary Paper | 65 | 21.7 | 6.6 | 6.7 | | 4% |
| Linerboard | 21.3 | 1.2 | 75.5 | 1.7 | | 15% |
| Corrugated Medium | | | 98.1 | 1.9 | | 9% |
| Boxboard | 14.2 | 6.9 | 53.6 | 18.7 | 6.6 | 38% |
| Building Materials | 9.0 | 1.7 | 41.8 | 14.4 | 33 | 25% |
| | | | | | | 100% |

Source: Burrell, Terry, et al, Paper Recycling: A Socio-Economic Perspective (19), and Woods, Gordon & Company, Recycling of Mixed Office Waste from the National Capital Area (20)

Because non-integrated mills that use virgin pulp must acquire this pulp from other mills, a bleached softwood kraft mill, which produces only market pulp, was included in the energy analysis. A bleached hardwood kraft mill was also studied but the energy requirements of the two mills were found to be so similar that only the energy figures for the softwood mill were used. Sulphite market pulp is not a major input into any of the mills considered and was thus not included. Two American mills using waste paper to produce slush market pulp were included for comparison with the virgin market pulp mill.

Table 6

PULP AND PAPER MILLS SELECTED FOR ANALYSIS

| Product | Material Input | Description |
|---|---|---|
| PRINTING & WRITING PAPER | 100% Virgin | Integrated mill, producing enough bleached hardwood kraft pulp to supply over 70% of the mill's needs. The mill has a chemical recovery process.<br>Main porducts: bonds, ledger, mimeo, duplicating, stationery, text, cover, book, offset, plus some bristol boxboard and foodboard. |
| | 66% Virgin<br>34% Deinked | Non-integrated paper mill with a deinking and bleaching process.<br>Main products: bond, mimeo, duplicating, book, litho, drawing, etc. |
| | 17% Virgin<br>83% Deinked | Integrated deinking pulp and paper mill with a bleaching process. Mill also produces some of its own electricity in a steam topping turbine.<br>Main products: bible, book, bond, mimeo, etc. |

Table 6 (continued)

| Product | Material Input | Description |
| --- | --- | --- |
| NEWSPRINT | 100% Virgin | Integrated mill with a groundwood (stone) and sulphite (sodium base) pulp mill and a bleaching process for the groundwood. |
| | 95% Virgin<br>5% Non-deinking Waste News | Integrated mill with groundwood (stone and refiner) and sulphite (sodium base) pulp mills. The mill also produces three secondary outputs: salt cake, ethanol and vanillin products. Some electricity is produced for on-site use from a reducing steam turbine*. Some of the unbleached sulphite pulp is sold as market pulp. |
| | 100% Deinked | Integrated newsprint deinking mill using 100% used news and overissue news. |
| TISSUE & SANITARY PAPER | 100% Virgin | A non-integrated mill.<br>Main products: facial and toilet tissue, towels, napkins, cellulose wadding, diapers, hygenic paper specialties and related light weight products. |

* Note: No heat rate is applied to self-generated, thermal electricity because the heating value of the various input fuels in known. The fact that mills which generate their own thermal electricity are also able to use the same steam in their process will be reflected in lower purchases of fossil fuels.

Table 6 (continued)

| Product | Material Input | Description |
|---|---|---|
| TISSUE & SANITARY PAPER -cont'd. | 100% Deinked | A relatively small deinking mill. Main products: toilet and facial tissues, napkins and toweling. |
| LINERBOARD | 100% Virgin | An integrated mill with a groundwood (stone) and softwood kraft pulp mill, most of which is not bleached. The mill has a chemical recovery plant and a hog fuel boiler burning bark to produce process steam. 30% of the output of the mill is newsprint. |
| | 100% Waste Paper | A composite of an existing and planned mill. Other products: corrugating medium. |
| CORRUGATING MEDIUM | 75% Virgin<br>25% Waste Paper | An integrated mill with a NSSC pulp mill. |
| | 100% Waste Paper | A composite of an existing and planned mill.<br>Other products: linerboard. |

Table 6 (continued)

| Product | Material Input | Description |
|---|---|---|
| MARKET PULP | 100% Virgin | Mill has a chemical recovery process and generates half of its own electricity requirements from on-site hydro electric generator*. Main products: bleached softwood, kraft market pulp. |
| | 100% Deinked | Main products: bleached, deinked market pulp. |
| | 100% Waste Paper | This small pulp mill produces market pulp from poly-coated milk cartons, food board and paper diapers. It does not need a deinking process for the high grades of paper stock used. Main products: repulped market pulp. |

* Note: A heat rate of 10,500 BTU/kwh was applied to the production of electricity. It could theoretically have been added to the Ontario Hydro grid system (see discussion of electricity on P.22).

Source: Lockwood's Directory of the Paper and Allied Trades 1975 (38).

## 2. Energy Requirement for Selected Mills

The energy and material data necessary to construct an energy balance on each of the selected mills was requested using a questionnaire*, followed by a personal visit in a number of cases. Due to the confidentiality of the data gained from these questionnaires, the energy figures for each mill have not been included here.

## 3. Environmental Impacts from Different Types of Mills

### a. Waterborne Wastes

As stated in the methodology section of this report, every attempt was made to use actual operating data for the specific mills selected for investigation. This is of particular importance when dealing with waterborne wastes because the effluents from mills will depend a great deal upon the age and type of processing equipment, type of furnish, the end product characteristics demanded, degree of integration, amount of water reused within the mill, the on-site wastewater treatment facilities and whether or not the mill has a bleaching operation or a chemical recovery boiler.

Confidential data on the water effluents from the Canadian pulp and paper mills selected for analysis was made available for this study by the Water Pollution Control Directorate of Environment Canada. These figures have been used in the analysis, but have not been included in this chapter.

Data was available for the two most important effluent indicators, $BOD_5$ and TSS, entering the receiving water after any treatment. Data for the other effluents from pulp and paper mills which may be significant, such as resin acids, were not available and thus were not included in this study.

Data on the post treatment effluents from four mills were not available: three of the deinking mills (news, tissue and the 83% deinking printing and writing paper mill) and the mill producing linerboard and corrugating medium from waste paper. The best available data on water effluents from deinking mills

* The questionnaire that was used has been included in the Appendix G.

is summarized in Table 7. The figures for deinked printing and writing paper and tissue and sanitary mills are the effluent parameters for exemplary mills with biological treatment of total mill effluent. The printing and writing paper mill studied is generally considered to be one of the better deinking mills in the U.S. Because effluent data was not available on the deinking tissue mill examined, the exemplary figures were used although they may, in this case, represent a lower limit of the effluents that might be expected. The raw effluents from newsprint deinking mills, which are treated by municipal treatment plants, were assumed to receive an average amount of effluent treatment as per a previous study(7).

Table 7

ESTIMATED WATERBORNE WASTES FROM DEINKING MILLS

| Type of Mill | Raw Waste (lb/ton output) | | Average Treatment Level % Reduction | | Post-Treatment Effluent (lb/ton output) | |
|---|---|---|---|---|---|---|
| | $BOD_5$ | TSS | $BOD_5$ | TSS | $BOD_5$ | TSS |
| Printing & Writing | | | | | 20.4 | 33.1 |
| Tissue & Sanitary | | | | | 20.4 | 33.1 |
| Newsprint | 30 | 39 | 58% | 31% | 17.4 | 12.1 |

Source: Gove and McKeown, "Current Status of Paper Reprocessing Effluent Characteristics and Disposal Practice". TAPPI, Vol. 58, No. 11, November 1975 (25). and Hunt, Environmental Effect of Recycling Paper, 1973 (7).

b. Air Emissions

The air emissions attributable to the actual production of paper can be traced to two basic sources: emissions due to the process itself, and emissions due to the combustion of fuel to produce process steam and/or electricity required by the mill.

i. Process Emissions

Complete operating data on the air emissions from the mills analysed in this study was not available. Although the Environmental Protection Service conducted a survey of atmospheric emissions in the wood pulping industry in 1974, the results were of limited use for this study and mill-specific data was not available.

Just as was the case for waterborne wastes, the air emissions from a particular mill will depend upon a number of factors - age and type of equipment, whether or not the mill has a hog fuel boiler or a chemical recovery unit and the amount of pollution abatement equipment. In the absence of mill-specific data, industry averages were used.

The following data on the process air emissions from kraft mills was drawn from three sources: a Canadian air pollution inventory (40) and two American emissions surveys (41,42 ). The figures represent emissions to the atmosphere after air pollution control measures have been applied.

| | lb/ton |
|---|---|
| Particulate Matter | 20 |
| $SO_x$ (sulphur oxides) | 5 |
| TRS (total reduced sulphur) | 8 |

These are average figures assuming average control facilities. The characteristic odour from a kraft pulp mill is due primarily to the TRS compounds hydrogen sulphide, methyl mercaptan, dimethyl sulphide, and dimethyl disulphide. These gases are produced during the recovery of chemicals from the spent liquor in specially designed boilers.

No significant emission data was obtained by either of the American studies for sulphite or semichemical pulp mills. Sulphur dioxide was, however, identified as the principal air pollutant from both processes. The Canadian emission inventory study estimated the total sulphur dioxide emissions from all Canadian sulphite mills in 1970. When divided by the total sulphite pulp production, this resulted in an average of 106 lb. of sulphur dioxide per ton of sulphite pulp produced.

The figure was used to estimate the air emissions from newsprint mills that have sulphite pulp mills to supply their chemical pulp requirements. The air emissions from a semi-chemical pulp mill were estimated to be 4 pounds of $SO_2$ per ton of air dry pulp (43).

It was assumed that there were no process emissions from either groundwood pulp mills, deinking mills, or non-deinking mills using secondary fibres. Each of these mills would, however, be responsible for the air pollutants emitted during combustion of fuel for steam and/or electricity.

ii. Combustion Emissions

The air pollution emission data contained in Appendix H of this report was used along with reported fuel and electrical power requirements for the mills to estimate the air pollution from combustion for each mill. The emissions from hog fuel boilers burning bark are included here, however, the emissions from recovery furnaces are not because they are included in the previous estimates of process emissions. These rather detailed calculations have not been included in this chapter but are incorporated in the analysis.

## 4. Secondary Inputs to Pulp and Paper Mills

All but three of the mills evaluated in this study provided estimates of the secondary input required (chemicals, fillers, coatings, etc.). The three exceptions were the deinked newsprint mill, the virgin tissue mill and the recycled linerboard and medium mill, and in each case the secondary inputs necessary can be expected to be relatively minor (less than 5% of the total input).

The energy and environmental impact resulting from the manufacture and delivery of the major secondary inputs was available from previous Resource and Environmental Profile Analysis work (43).

## F. Transportation

The transportation necessary in the life-cycle of paper production may be seen from Figure 1 in the previous chapter. Transportation is required between each process shown; sometimes the material is merely moved on a conveyor to the next stage, sometimes it is shipped as far as 800 mi. by rail. It was assumed that Toronto was the final destination of the finished products. The types of recycling mills studied which are not currently found in the Toronto area were assumed to be within 100 miles of Toronto for the purposes of this analysis. The major transportation steps involved are:

| | |
|---|---|
| forest or saw mill to pulp mill | - Based on estimates by the Forest Engineering Research Institute of Canada, roundwood and wood residues were assumed to travel an average of 50 miles to a pulp mill (although some residues may travel further)(44). Specific distance figures were gathered for the virgin pulp and paper mills located in southern Ontario. |
| pulp mill to paper mill | - For integrated mills, this figure is 0; for non-integrated mills, the exact distance, by rail, from the one market pulp mill analysed to each of the paper mills was used. |
| paper mill to final conversion and final conversion to centre for further distribution | - Taken together, these two transportation steps will be much larger for virgin mills (located near the forests) than for secondary mills (located in urban areas). Because the various stages of conversion of virgin products could be either near the forests and/or in urban areas, these two steps have been considered together to simplify the calculations. |
| centre for further distribution to retail and retail to product end us | - Because these distances are the same regardless of whether or not the products contain reclaimed fibre, they have been left out of this analysis. |

| | | |
|---|---|---|
| product end use to waste management site | - | A previous study estimated the energy required to collect mixed solid waste to be 0.15 x $10^6$ BTU/ton collected ( 4 ). Estimations were also made of the energy required for collecting paper separately and delivering it to a waste paper dealer. |
| paper stock to paper mill | - | An average distance of 100 miles was assumed for this factor, except for the transport of waste newsprint as a supplemental furnish to a newsprint mill near the forests where a distance of 500 miles by rail was assumed. |

Truck and rail are the two principal modes of freight transportation used in the pulp and paper industry. At least eight studies have developed estimates of the direct energy required to transport freight by truck or rail, usually expressed in terms of BTU/ton-mile. A recent Canadian study estimated the national average direct energy required for each system with results similar to these other estimations (45); the rail figure was further confirmed by estimates from CNR and CPR.

These figures have been used as the basis of this analysis but were revised to include the 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 study by Hannon and Herendeen 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 (46).

These results are in contrast to the manufacturing sector of society, where the indirect energy required to build and operate the capital equipment has been estimated to be less than 5% of the total energy (see discussion, page 23); this represents a total/direct energy ratio of 1.05. Because the Hannon/Herendeen 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 on the next page.

| | DIRECT ENERGY ($10^6$ BTU/ ton-mile) | TOTAL/ DIRECT RATIO | TOTAL ENERGY ($10^6$ BTU/ ton-mile |
|---|---|---|---|
| TRUCK | $2.50 \times 10^{-3}$ | 1.4 | $3.50 \times 10^{-3}$ |
| RAIL | $5.60 \times 10^{-4}$ | 1.7 | $9.52 \times 10^{-4}$ |

Because these figures are national averages, they take into account the fact that sometimes a truck or frieght 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 transporting pulp and paper being different from national average figures.

Although an American study subdivided estimated truck and rail transport energy figures into figures for the pulp and paper industry specifically ( 6 ), these have not been used since the average figures used in that study differ significantly from the other studies examined. The non-industry specific, national average figures developed above are used in this study.

The transportation energy required by each of the paper manufacturing options examined in this study have not been summarized in this chapter; Appendix B, however, contains an analysis of the transportation requirements for the different paper production options with an analysis of the importance of transportation distances to the viability of recycling.

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 (47).

The air and water pollution resulting from the combustion of fuel to propel these two modes of transport is included in this analysis and is based on the data contained in Table 54 in Appendix H of this report.

## IV. ANALYSIS OF ENERGY SAVINGS AND ENVIRONMENTAL IMPACT ASSOCIATED WITH RECYCLING PAPER

This chapter presents the results of the analysis that was used to estimate the energy savings attributable to paper recycling to produce four types of paper. The environmental impacts of the various options are also checked to ensure that serious environmental problems were not being traded off for energy savings.

The data necessary to perform the analysis is presented in the previous chapter and includes sections on forestry operations, pulp and paper mills, transportation, solid waste collection and disposal, energy recovery from solid waste and paper reclamation.

There are three significant features about the approach used to calculate the energy savings attributable to recycling. First, the approach aimed at determining the energy savings attributable to recycling waste paper, not the absolute amount of energy required by any one option. Second, these savings are expressed in terms of energy per ton of waste paper input into the paper production process.

In other studies, energy savings are usually expressed in terms of energy per ton of production output. In this study, however, a more appropriate focus has been chosen: one ton of waste paper as an input into either a paper-making process or an energy recovery system. And third, six cases have been outlined for each production option (summarized below). These cases show the effect of different assumptions as to whether waste paper and/or wood are considered as potential energy sources.

Case 1: Neither the waste paper nor wood used in paper production processes has an alternative energy use; both are 'free' goods from an energy perspective.

Case 2a: 100% of the waste paper used in paper production processes has an alternative energy use; wood is a 'free' good.

Case 2b: 50% of the waste paper used in paper production processes has an alternative energy use; wood is a 'free' good.

Case 3a: 100% of the waste paper and wood used in paper production processes has an alternative energy use.

Case 3b: 50% of the waste paper and wood used in paper production processes has an alternative energy use.

Case 3c: 100% of the waste paper and 50% of the wood used in paper production processes have an alternative energy use.

The energy savings associated with paper recycling are calculated for four types of paper products: printing and writing paper, newspaper, tissue and sanitary paper and linerboard and corrugating medium. An additional option which could not be fully analysed by this study was the production of market pulp from waste paper. Comments on this option, which may be of particular importance in certain parts of Canada, have been included in Appendix A.

The energy savings associated with each of the four paper product categories are considered and analysed separately. For each type of paper, the energy associated with alternative production processes is first considered. The purchased production energy (which includes all the energy associated with the production of a ton of paper, except wood-derived energy) for various options is then compared and the energy savings attributable to the recycling option are expressed per ton of waste paper input.

The energy associated with three alternative dispositions for waste paper and wood is then presented. The energy associated with collecting and landfilling one ton of waste paper, $0.25 \times 10^6$ BTU/ton, is the same as that required to collect and landfill one ton of solid waste.

The solid waste to fossil fuel equivalent multiplier (estimated to be 0.7 in the previous chapter) has been applied to the recovery of energy from one ton of waste paper since waste paper would be collected and burnt along with the rest of solid waste, not separately. The energy associated with the collection of the waste paper (the same as the energy to collect solid waste) was then deducted from the energy recovered to yield a net energy figure for the collection and recovery of energy from waste paper.

The energy associated with the recovery of energy from the trees made available by the recycling of one ton of waste paper was calculated by applying the same fossil fuel equivalent multiplier calculated in the last chapter for solid waste to the estimated quantity of wood available for energy recovery. The energy required for harvesting and transporting* the wood was deducted from the energy recovered to yield a net energy figure for the harvesting and recovery of energy from wood.

The final table for each paper product category details the energy savings attributable to the recycling of one ton of waste paper for each of the six cases. The energy associated with the collection/landfilling of waste paper and the harvesting/recovery of energy from wood have been added on to the savings attributable to recycling waste paper: the energy associated with the collection/recovery of energy from waste paper has been subtracted from the savings attributable to recycling one ton of waste paper.

* It was assumed that the distance travelled by the wood to an energy recovery site would be the same as would be travelled to a pulp mill.

After all four paper product categories have been examined, the purchased energy associated with each of the production options and the energy savings attributable to recycling one ton of waste paper into the four paper products are summarized in two tables.

Following the analysis of the energy savings, the environmental impacts associated with the production of paper by each option are presented (on a per ton of output basis*) along with the environmental impacts associated with the alternative disposition of waste paper and wood. The environmental impacts assessed in this study were air emissions of particulate matter (particulates), sulphur oxides ($SO_x$) and total reduced sulphur (TRS); and water emissions measured by biological oxygen demand ($BOD_5$) and total suspended solids (TSS). Because the environmental analysis was designed to only serve as a check to ensure environmental quality was not being traded for energy savings, a detailed analysis of all six cases was unnecessary for each recycling option.

* Note: As stated previously, the aim of this report was to analyse net energy savings on the basis of a ton of waste paper as input to paper-making processes. Additionally, various environmental pollutants are analysed but this time on the basis of one ton of output of the process in question. This report makes the simplifying assumption that the pollution impacts associated with output tons are equivalent to those associated with input tons.

## A. Associated Energy Savings

### 1. Printing and Writing Paper

The following tables present the energy data relevant to the evaluation of recycling waste paper into printing and writing paper as a solid waste management option. The final table in this section expresses the results in terms of the energy savings attributable to recycling (per ton of waste paper).

Table 8

ENERGY ASSOCIATED WITH PRODUCTION OF PRINTING AND WRITING PAPER ON A PER TON OF OUTPUT BASIS

| Input Composition / Associated Energy | 100% Virgin | 34% Recycled | %* Savings | 83% Recycled | %* Savings |
|---|---|---|---|---|---|
| | — $10^6$ BTU/Ton — | | | $10^6$ BTU/Ton | |
| Oil & Natural Gas | 29.42 | 27.89 | | 22.44 | |
| Coal | - | 0.11 | | - | |
| Electricity | 19.73 | 15.98 | | 10.29 | |
| Total Purchased | 49.15 | 43.98 | 11% | 32.73 | 33% |
| Wood-Derived | 12.49 | 8.51 | | 2.44 | |
| Total | 61.64 | 52.49 | 15% | 35.17 | 43% |

* Energy savings from recycling

## Purchased Production Energy Savings
## Per Ton of Waste Paper Input

| | | 34% Recycled | 83% Recycled |
|---|---|---|---|
| 1. | Purchased energy consumed in the production of one ton of printing and writing paper using 100% virgin fibre | $49.15 \times 10^6$ BTU/ton | |
| 2. | Purchased energy consumed in the production of one ton of printing and writing paper using 34% and 83% recycled fibres | $43.98 \times 10^6$ BTU/ton | $32.73 \times 10^6$ BTU/ton |
| 3. | Waste paper consumed in the production of one ton of printing and writing paper using 34% and 83% recycled fibres | 0.338 tons | 0.940 tons |
| 4. | Energy savings per ton of waste paper input | $15.30 \times 10^6$ BTU/ton | $17.47 \times 10^6$ BTU/ton |

## Energy Associated with the Alternative
## Disposition of Waste Paper and Wood

| | | |
|---|---|---|
| 1. | Energy required for the collection and landfilling of one ton of waste paper | $0.25 \times 10^6$ BTU/ton |
| 2. | Energy associated with the collection and energy recovery of one ton of waste paper | $-11.03 \times 10^6$ BTU/ton |
| 3. | Energy associated with the harvesting and energy recovery of the trees made available by the recycling of one ton of waste paper | $-18.72 \times 10^6$ BTU/ton |

Table 9

ENERGY SAVINGS ATTRIBUTABLE TO RECYCLING ONE TON OF WASTE PAPER INTO PRINTING AND WRITING PAPER USING 34% RECYCLED FIBRE

| CASE | SAVINGS OF PURCHASED PRODUCTION ENERGY | ENERGY ASSOCIATED WITH THE ALTERNATIVE DISPOSITION OF: | | | ENERGY SAVINGS FROM RECYCLING |
|---|---|---|---|---|---|
| | | WASTE PAPER | | WOOD | |
| | | COLLECTION/ LANDFILL | COLLECTION/ ENERGY RECOVERY | HARVESTING/ ENERGY RECOVERY | |
| | 10^6 BTU/ton | | | | |
| 1 | 15.30 | 0.25 | - | - | 15.55 |
| 2a | 15.30 | - | -11.03 | - | 4.27 |
| 2b | 15.30 | 0.13 | - 5.51 | - | 9.92 |
| 3a | 15.30 | - | -11.03 | 18.72 | 22.99 |
| 3b | 15.30 | 0.13 | - 5.51 | 9.36 | 19.28 |
| 3c | 15.30 | - | -11.03 | 9.36 | 13.63 |

Table 10

ENERGY SAVINGS ATTRIBUTABLE TO RECYCLING ONE TON OF WASTE PAPER INTO PRINTING AND WRITING PAPER USING 83% RECYCLED FIBRE

| CASE | SAVINGS OF PURCHASED PRODUCTION ENERGY | ENERGY ASSOCIATED WITH THE ALTERNATIVE DISPOSITION OF: | | | ENERGY SAVINGS FROM RECYCLING |
|---|---|---|---|---|---|
| | | WASTE PAPER | | WOOD | |
| | | COLLECTION/ LANDFILL | COLLECTION/ ENERGY RECOVERY | HARVESTING/ ENERGY RECOVERY | |
| | 10^6 BTU/ton | | | | |
| 1 | 17.47 | 0.25 | - | - | 17.72 |
| 2a | 17.47 | - | -11.03 | - | 6.44 |
| 2b | 17.47 | 0.13 | - 5.51 | - | 12.09 |
| 3a | 17.47 | - | -11.03 | 18.72 | 25.16 |
| 3b | 17.47 | 0.13 | - 5.51 | 9.36 | 21.45 |
| 3c | 17.47 | - | -11.03 | 9.36 | 15.80 |

Table 8 shows that the energy associated with producing printing and writing from waste paper is less than that associated with producing the same paper from 100% virgin fibre; the percent savings are 11% and 33% on purchased energy, 15% and 43% on total energy (including wood derived) for the 34% and 83% recycled cases respectively.

Tables 9 and 10 indicate that in all six cases considered, there are net energy savings attributable to the recycling options. The savings associated with the 34% recycle option are slightly lower than that for the 83% recycle option because a non-integrated mill was examined which purchases large amounts of air dry market pulp. Thus, two energy-intensive dryings (one to dry the pulp for transport, the other to dry the final product) are necessary.

## 2. Newsprint

The following tables present the energy data relevant to the evaluation of recycling waste paper into newspaper as a solid waste management option. The final table in this section expresses the results in terms of the energy savings attributable to recycling (per ton of waste paper).

Table 11

ENERGY ASSOCIATED WITH THE PRODUCTION OF ONE TON OF NEWSPRINT

| Input Composition / Associated Energy | 100% Virgin | 100% Recycled | % Savings* |
|---|---|---|---|
| | $10^6$ BTU/ton | | |
| Oil & Natural Gas | 12.11 | 13.17 | |
| Coal | - | - | |
| Electricity | 17.70 | 6.49 | |
| Total Purchased | 29.81 | 19.66 | 34% |
| Wood Derived | 0.96 | - | |
| Total | 30.77 | 19.66 | 36% |

* Energy savings from recycling

## Purchased Production Energy Savings Per Ton of Waste Paper Input

| | | |
|---|---|---|
| 1. | Purchased energy consumed in the production of one ton of newsprint using 100% virgin fibres | $29.81 \times 10^6$ BTU/ton |
| 2. | Purchased energy consumed in the production of one ton of newsprint using 100% recycled fibres | $19.66 \times 10^6$ BTU/ton |
| 3. | Waste paper consumed in the production of one ton of newsprint using 100% recycled fibres | 1.120 tons |
| 4. | Energy savings per ton of waste paper input | $9.06 \times 10^6$ BTU/ton |

## Energy Associated with the Alternative Disposition of Waste Paper and Wood

| | | |
|---|---|---|
| 1. | Energy required for the collection and land-filling of one ton of waste paper | $0.25 \times 10^6$ BTU/ton |
| 2. | Energy associated with the collection and energy recovery of one ton of waste paper | $-11.03 \times 10^6$ BTU/ton |
| 3. | Energy associated with the harvesting and energy recovery of the trees made available by the recycling of one ton of waste paper | $-11.54 \times 10^6$ BTU/ton |

Table 12

ENERGY SAVINGS ATTRIBUTABLE TO RECYCLING ONE TON OF WASTE PAPER INTO NEWSPRINT

| CASE | SAVINGS OF PURCHASED PRODUCTION ENERGY | ENERGY ASSOCIATED WITH THE ALTERNATIVE DISPOSITION OF: WASTE PAPER | | WOOD | ENERGY SAVINGS FROM RECYCLING |
|---|---|---|---|---|---|
| | | COLLECTION/ LANDFILL | COLLECTION/ ENERGY RECOVERY | HARVESTING/ ENERGY RECOVERY | |
| | $10^6$ BTU/ton | | | | |
| 1 | 9.06 | 0.25 | - | - | 9.31 |
| 2a | 9.06 | - | -11.03 | - | -1.97 |
| 2b | 9.06 | 0.13 | - 5.51 | - | 3.68 |
| 3a | 9.06 | - | -11.03 | 11.54 | 9.57 |
| 3b | 9.06 | 0.13 | - 5.51 | 5.77 | 9.45 |
| 3c | 9.06 | - | -11.03 | 5.77 | 3.80 |

Table 11 shows that 34% less purchased energy is associated with the production of the newsprint made from 100% recycled fibre. The small amount of wood derived energy associated with the 100% virgin mill (0.96 x $10^6$ BTU/ton) is from a hog-fired boiler which burns bark. It is significant to note that only two of Ontario's newsprint mills have chemical recovery furnaces which generate usable energy in the process of recovering chemicals from spent liquors. Although the one newsprint mill in Ontario using kraft pulp as its chemical pulp has a recovery furnace, only one of the other eight newsprint mills using sulphite pulp as its chemical pulp has a recovery furnace. However, processes to recover the spent liquors from these sodium and magnesium based sulphite mills could be added; no estimation has been made of the effect this would have on the purchased energy of these mills.

Table 12 shows that energy savings are attributable to recycling in five of the six cases considered. Thus, the selection of the relevant assumptions concerning waste paper or wood is particularly critical for newspaper because the actual amount of purchased energy consumed in newsprint mills is not much greater than the energy that could be derived from recovering the energy from either waste paper or wood.

It is noteworthy that if the level of implementation of systems to recover energy from solid waste is less than 83%, then energy savings can be attributed to recycling waste paper.

Not included in these two tables was the option of using 5% non-deinked waste newsprint in the production of newsprint. This option was analysed but no energy savings could be attributable to this option as inherent mill differences outweigh any savings that might have occured.

## 3. Tissue and Sanitary Paper

The following tables present the energy data relevant to the evaluation of recycling waste paper into tissue and sanitary paper as a solid waste management option. The final table in this section expresses the results in terms of the energy savings attributable to recycling (per ton of waste paper).

Table 13

ENERGY ASSOCIATED WITH THE PRODUCTION OF ONE TON OF TISSUE AND SANITARY PAPER

| Associated Energy \ Input Composition | 100% Virgin | 100% Recycled | Energy Savings from Recycling |
|---|---|---|---|
| | $10^6$ BTU/ton | | |
| Oil & Natural Gas | 25.58 | 13.11 | |
| Coal | - | - | |
| Electricity | 23.29 | 9.32 | |
| Total Purchased | 48.87 | 22.43 | 54% |
| Wood Derived | 12.92 | - | |
| Total | 61.79 | 22.43 | 64% |

Although the two tissue mills considered both produce toilet paper, facial tissue, napkins, etc. which could be considered 'functionally' comparable, the tissue from the 100% virgin mill is of the highest quality available whereas the tissue from the deinking mill is of a lower quality. Thus, the energy savings attributable to this recycling option involve a decrease in product quality.

## Purchased Production Energy Savings Per Ton of Waste Paper Input

| | | |
|---|---|---|
| 1. | Purchased energy consumed in the production of one ton of tissue and sanitary paper using 100% virgin fibre | $48.87 \times 10^6$ BTU/ton |
| 2. | Purchased energy in the production of one ton of tissue and sanitary paper using 100% recycled fibres | $22.43 \times 10^6$ BTU/ton |
| 3. | Waste paper consumed in the production of one ton of newsprint using 100% recycled fibres | 1.116 tons |
| 4. | Energy savings per ton of waste paper input | $23.69 \times 10^6$ BTU/ton |

## Energy Associated with the Alternative Disposition of Waste Paper and Wood

| | | |
|---|---|---|
| 1. | Energy required for the collection and landfilling of one ton of waste paper | $0.25 \times 10^6$ BTU/ton |
| 2. | Energy associated with the collection and energy recovery of one ton of waste paper | $-11.03 \times 10^6$ BTU/ton |
| 3. | Energy associated with the harvesting and energy recovery of the trees made available by the recycling of one ton of waste paper | $-19.65 \times 10^6$ BTU/ton |

Table 14

ENERGY SAVINGS ATTRIBUTABLE TO RECYCLING ONE TON OF WASTE PAPER INTO TISSUE AND SANITARY PAPER

| CASE | SAVINGS OF PURCHASED PRODUCTION ENERGY | ENERGY ASSOCIATED WITH THE ALTERNATIVE DISPOSITION OF: WASTE PAPER | | WOOD | ENERGY SAVINGS FROM RECYCLING |
|---|---|---|---|---|---|
| | | COLLECTION/ LANDFILL | COLLECTION/ ENERGY RECOVERY | HARVESTING/ ENERGY RECOVERY | |
| | $10^6$ BTU/ton | | | | |
| 1 | 23.69 | 0.25 | - | - | 23.94 |
| 2a | 23.69 | - | -11.03 | - | 12.66 |
| 2b | 23.69 | 0.13 | - 5.51 | - | 18.31 |
| 3a | 23.69 | - | -11.03 | 19.65 | 32.31 |
| 3b | 23.69 | 0.13 | - 5.51 | 9.83 | 28.14 |
| 3c | 23.69 | - | -11.03 | 9.83 | 22.49 |

Tables 13and Table 14 indicate large energy savings in the production of the recycled tissue and associated with recycling one ton of waste paper, respectively. However, two comments are necessary: as mentioned previously, the virgin option produces a much higher quality product;but even more importantly, the virgin option is a totally non-integrated operation, whereas the deinking mill is totally integrated. The additional drying step necessary in a non-integrated operation is energy intensive and if the virgin tissue mill were an integrated mill, the energy associated with this option could be lower, although probably still higher than that for the deinking option.

## 4. Corrugated Containerboard

The following tables present the energy data relevant to the evaluation of recycling waste paper into corrugated containerboard as a solid waste management option. The final table in this section expresses the results in terms of the energy savings attributable to recycling (per ton of waste paper).

The virgin linerboard and medium is produced in two separate mills and have been combined together in the ratio necessary to construct corrugated containers: 70% linerboard and 30% corrugating medium.

The linerboard and corrugating medium made from virgin and secondary materials are compared on a ton for ton basis. In the past, corrugated containers made from secondary fibres sometimes required a larger 'basis' weight (amount of fibre per area of containerboard ) than a competitive container made from virgin fibres. However, improved technology in the recycling of secondary fibres can now produce a similar strength corrugated container with the same basis weight as a corrugated container made from virgin fibre.

Two reclamation alternatives have been included in the energy associated with the production of corrugated containerboard: separate collection and mechanical separation. Due to the small difference in the energy associated with each of these two options, the following analysis was calculated solely on the separate collection option.

Table 15

ENERGY ASSOCIATED WITH THE PRODUCTION OF ONE TON OF CORRUGATED CONTAINERBOARD

| INPUT COMPOSITION / ASSOCIATED ENERGY | 100% VIRGIN LINER-BOARD 81% VIRGIN MEDIUM | 100% RECYCLED LINERBOARD AND MEDIUM | | | |
|---|---|---|---|---|---|
| | | Separate Collection | % Savings* | Mechanical Reclamation | % Savings* |
| | $10^6$ BTU/ton | $10^6$ BTU/ton | | $10^6$ BTU/ton | |
| Oil & Natural Gas | 16.76 | 13.08 | | 12.95 | |
| Coal | - | - | | - | |
| Electricity | 9.76 | 7.14 | | 8.01 | |
| Total Purchased | 26.52 | 20.22 | 24% | 20.96 | 21% |
| Wood Derived | 6.86 | - | | - | |
| Total | 33.38 | 20.22 | 39% | 20.96 | 37% |

* Energy savings from recycling

## Purchased Production Energy Savings Per Ton of Waste Paper Input

| | | |
|---|---|---|
| 1. | Purchased energy consumed in the production of one ton of corrugated containerboard using the maximum virgin fibre option* | $26.52 \times 10^6$ BTU/ton |
| 2. | Waste paper consumed in the production of one ton of corrugated containerboard using the maximum virgin fibre option | 0.081 tons |
| 3. | Purchased energy consumed in the production of one ton of corrugated containerboard using 100% recycled fibres (and separate collection) | $20.22 \times 10^6$ BTU/ton |
| 4. | Waste paper consumed in the production of one ton of corrugated containerboard using 100% recycled fibres | 1.124 tons |
| 5. | Energy savings per ton of waste paper input** | $6.04 \times 10^6$ BTU/ton |

## Energy Associated with the Alternative Disposition of Waste Paper and Wood

| | | |
|---|---|---|
| 1. | Energy required for the collection and landfilling of one ton of waste paper | $0.25 \times 10^6$ BTU/ton |
| 2. | Energy associated with the collection and energy recovery of one ton of waste paper | $-11.03 \times 10^6$ BTU/ton |
| 3. | Energy associated with the harvesting and energy recovery of the trees made available by the recycling of one ton of waste paper | $-17.17 \times 10^6$ BTU/ton |

* The term 'maximum virgin fibre option' is employed rather than the term 'virgin fibre option', normally used, because the mill from which the energy data is taken uses about 19% waste paper in the manufacture of corrugating medium. The linerboard, however, is made from 100% virgin fibre. The amount of waste paper input is about .081 ton per ton of containerboard manufactured.

** The energy savings per ton of waste paper input were calculated by dividing the difference in energy utilization between the two options ($26.52 \times 10^6$ - $20.22 \times 10^6$) by the difference in waste paper (1.124-.081) used.

Table 16

ENERGY SAVINGS ATTRIBUTABLE TO RECYCLING ONE TON OF WASTE PAPER INTO CORRUGATED CONTAINERBOARD

| CASE | SAVINGS OF PURCHASED PRODUCTION ENERGY | ENERGY ASSOCIATED WITH THE ALTERNATIVE DISPOSITION OF: WASTE PAPER | | WOOD | ENERGY SAVINGS FROM RECYCLING |
|---|---|---|---|---|---|
| | | COLLECTION/ LANDFILL | COLLECTION/ ENERGY RECOVERY | HARVESTING/ ENERGY RECOVERY | |
| | $10^6$ BTU/Ton | | | | |
| 1 | 6.04 | 0.25 | - | - | 6.29 |
| 2a | 6.04 | - | -11.03 | - | -4.99 |
| 2b | 6.04 | 0.13 | - 5.51 | - | 0.66 |
| 3a | 6.04 | - | -11.03 | 17.17 | 12.18 |
| 3b | 6.04 | 0.13 | - 5.51 | 8.59 | 9.25 |
| 3c | 6.04 | - | -11.03 | 8.59 | 3.60 |

As mentioned previously, Table 15 shows the minor difference in the energy associated with the production of linerboard and corrugating medium with the separate collection and mechanical reclamation of corrugated containers. It also shows that 24% less purchased energy is associated with the production of recycled rather than virgin corrugated containerboard.

Table 16 indicates that energy savings are attributable to recycling in four of the six cases with negligible savings in one case and a net energy loss in another.

The potential energy savings attributable to recycling in this product category are particularly dependent upon the assumptions concerning waste paper or wood because the actual amount of purchased energy consumed in the options is not much greater than the energy that could be derived from burning either the waste paper or wood required to make the product. Thus, just as in the newsprint options, the selection of the relevant assumptions is particularly critical for corrugated containerboard.

Once again, it is useful to note that if the level of implementation of systems to recovery energy from solid waste is less than 56%, then energy savings can be attributable to recycling waste paper.

## 5. Summary of Associated Energy Savings

The following two tables summarize the purchased energy associated with paper production options and the energy savings attributable to recycling one ton of waste paper.

Table 17

SUMMARY OF THE PURCHASED ENERGY ASSOCIATED WITH PAPER PRODUCTION OPTIONS

| Paper Product | Input Composition | Purchased Energy | | Energy Savings From Recycling | | |
|---|---|---|---|---|---|---|
| | | GJ/ tonne | $10^6$ BTU/ ton | GJ/ tonne | $10^6$ BTU/ ton | % |
| PRINTING AND WRITING | 100% Virgin | 57.16 | 49.15 | - | - | - |
| | 34% Recycled | 51.15 | 43.98 | 6.01 | 5.17 | 11% |
| | 83% Recycled | 38.06 | 32.73 | 19.10 | 16.42 | 33% |
| NEWSPRINT | 100% Virgin | 34.67 | 29.81 | - | - | - |
| | 100% Recycled | 22.86 | 19.66 | 11.80 | 10.15 | 34% |
| TISSUE AND SANITARY | 100% Virgin | 56.84 | 48.87 | - | - | - |
| | 100% Recycled* | 26.09 | 22.43 | 30.75 | 26.44 | 54% |
| CORRUGATED CONTAINER BOARD | Maximum Virgin | 30.83 | 26.52 | - | - | - |
| | 100% Recycled | 23.52 | 20.22 | 7.31 | 6.29 | 24% |

Table 17 shows that from 11% to 54% less purchased energy is associated with producing the four types of paper products from recycled fibres than from virgin fibres.

* These energy savings are realizable only with a lower quality product.

Table 18 shows that in all but two instances there are energy savings attributable to recycling. As was noted earlier, the selection of the relevant case for analyzing the potential energy savings is particularly critical for the newsprint and corrugated containerboard production options.

Although the main focus of this analysis has been to evaluate the energy savings attributable to recycling waste paper, the figures in this chapter can also be used to compare the energy attributable to energy recovery and landfilling of waste paper. The predictable conclusion that energy savings can be attributed to energy recovery when compared to landfilling can be derived by substracting the energy associated with the collection and energy recovery of one ton of waste paper (-11.03 x $10^6$ BTU/year) from the energy associated with the collection and landfilling of one ton of waste paper (0.25 x $10^6$ BTU/ton). This yields an energy savings of 13.12 GJ/tonne (11.28 x $10^6$ BTU/ton) attributable to using waste paper as an energy source rather than merely landfilling it.

Table 18

SUMMARY OF THE ENERGY SAVINGS ATTRIBUTABLE TO RECYCLING ONE TON OF WASTE PAPER

| PAPER PRODUCT | CASE / INPUT COMPOSITION | 1 GJ/ tonne | 1 $10^6$ BTU/ ton | 2a GJ/ tonne | 2a $10^6$ BTU/ ton | 2b GJ/ tonne | 2b $10^6$ BTU/ ton | 3a GJ/ tonne | 3a $10^6$ BTU/ ton | 3b GJ/ tonne | 3b $10^6$ BTU/ ton | 3c GJ/ tonne | 3c $10^6$ BTU/ ton |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PRINTING AND WRITING | 34% Recycled | 18.08 | 15.55 | 4.97 | 4.27 | 11.54 | 9.92 | 26.74 | 22.99 | 22.42 | 19.28 | 15.85 | 13.68 |
| | 83% Recycled | 20.61 | 17.72 | 7.49 | 6.44 | 14.06 | 12.09 | 29.19 | 25.10 | 24.95 | 21.45 | 18.38 | 15.80 |
| NEWSPRINT | 100% Recycled | 10.83 | 9.31 | -2.29 | -1.97 | 4.28 | 3.68 | 11.13 | 9.57 | 10.99 | 9.45 | 4.42 | 3.80 |
| TISSUE AND SANITARY | 100% Recycled* | 27.84 | 23.94 | 14.72 | 12.66 | 21.29 | 18.31 | 37.58 | 32.31 | 32.72 | 28.13 | 26.16 | 22.49 |
| CORRUGATED CONTAINER BOARD | 100% Recycled | 7.32 | 6.29 | -5.80 | -4.99 | 0.77 | 0.66 | 14.17 | 12.18 | 10.76 | 9.25 | 4.19 | 3.60 |

* The energy savings are realizable only with a lower quality product.

## B. Environmental Impact

Tables 19, 20, 21 and 22 present the environmental impacts associated with the production of printing and writing paper, newprint, tissue and sanitary paper, and corrugated containerboard.

In all four cases, the air pollutants associated with the production from recycled fibres are less than those associated with the virgin production options; this is due to the emissions resulting from kraft or sulphite pulp mills.

Water pollution is also less severe for the recycling options, with the exception of the 34% recycled input mill (a relatively old mill). However, as was stated in the previous chapter, the figures for the 83% recycled printing and writing paper mill and for the deinking tissue and sanitary mill are those associated with an 'exemplary' deinking operation and thus represent a lower limit to the emissions that are to be expected. Thus, these figures should be interpreted as indicating that increased levels of recycling through deinking <u>need not</u> result in increased amounts of water pollution.

Table 19

ENVIRONMENTAL IMPACT ASSOCIATED WITH THE PRODUCTION OF PRINTING AND WRITING PAPER

| Associated Environmental Impact \ Input Composition | 100% Virgin | 34% Recycled | 83% Recycled |
|---|---|---|---|
| | lbs/ton | | |
| AIR POLLUTION | | | |
| Particulates | 31.48 | 19.44 | 9.31 |
| $SO_x$ | 94.02 | 59.96 | 44.06 |
| TRS | 8.02 | 5.28 | 1.51 |
| WATER POLLUTION | | | |
| $BOD_5$ | 96.00 | 176.00 | 28.00 |
| TSS | 81.00 | 76.00 | 44.00 |

Table 20

ENVIRONMENTAL IMPACTS ASSOCIATED WITH
THE PRODUCTION OF NEWSPRINT

| Associated Environmental Impact \ Input Composition | 100% Virgin | 100% Recycled |
|---|---|---|
| | lbs/ton | |
| AIR POLLUTION | | |
| Particulates | 6.46 | 3.31 |
| $SO_x$ | 88.28 | 20.75 |
| TRS | - | - |
| WATER POLLUTION | | |
| $BOD_5$ | 150.00 | 17.00 |
| TSS | 15.00 | 12.00 |

Table 21

ENVIRONMENTAL IMPACTS ASSOCIATED WITH
THE PRODUCTION OF TISSUE AND SANITARY PAPER

| Associated Environmental Impact \ Input Composition | 100% Virgin | 100% Recycled |
|---|---|---|
| | lbs/ton | |
| AIR POLLUTION | | |
| Particulates | 26.51 | 3.89 |
| $SO_x$ | 81.26 | 43.54 |
| TRS | 8.02 | - |
| WATER POLLUTION | | |
| $BOD_5$ | 41.00 | 20.00 |
| TSS | 71.00 | 33.00 |

Table 22

ENVIRONMENTAL IMPACTS ASSOCIATED WITH THE PRODUCTION OF CORRUGATED CONTAINERBOARD

| Associated Environmental Impact \ Input Composition | Maximum Virgin | 100% Recycled |
|---|---|---|
| | lbs/ton | |
| AIR POLLUTION | | |
| Particulates | 21.17 | 3.64 |
| $SO_x$ | 41.89 | 27.10 |
| TRS | 5.60 | - |
| WATER POLLUTION | | |
| $BOD_5$ | 39.00 | 18.00 |
| TSS | 12.00 | 12.00 |

Table 23

ENVIRONMENTAL IMPACTS ASSOCIATED WITH THE ALTERNATIVE DISPOSITION OF WASTE PAPER AND WOOD

| Associated Environmental Impact \ Input Composition | WASTE PAPER | | WOOD |
|---|---|---|---|
| | Collection/ Landfill | Collection/ Energy Recovery | Harvesting/ Energy Recovery |
| | lbs/ton | | |
| AIR POLLUTION | | | |
| Particulates | 0.03 | 1.52 | 4.02 |
| $SO_x$ | 0.07 | 1.55 | 0.81 |
| TRS | - | - | - |
| WATER POLLUTION | | | |
| $BOD_5$ | - | - | - |
| TSS | - | - | - |

Table 23 shows the environmental impacts associated with the alternative methods for the disposition of waste paper and wood. Of the three methods examined, only the burning of wood for energy would result in 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.

## V. ENERGY SAVINGS ATTRIBUTABLE TO REDUCTION AT SOURCE OPTIONS

The following 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 contained in Appendix F). Source reduction represents a qualitatively different way of managing the solid waste problem than either recycling or burning the waste; 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 proudction stage and thus the impact of source reduction is not restricted to one geographical area
- it can be introduced relatively quickly
- it, once introduced, 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 which have been reviewed in this report are:

- reducing the overall level of consumption of packaging
- replacing single-use products with multiple-use ones
- reducing the material intensity of packaging
- buying products in larger package sizes
- increasing product lifetime

Further discussion of source reduction can be found in other studies (3,10,48,49,50).

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, i.e. a policy aiming at source reduction. In fact, it turns out that there are other materials equally or even more susceptible to reduction at source 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.

It is intuitively obvious that each of these examples would, if implemented, reduce the amount of solid waste produced. There is thus an immediate 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 $55 \times 10^{12}$BTU ($58 \times 10^{6}$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.

TABLE 24

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 | - |

It should be noted that it is not possible to add together all the savings outlined in this table. A decision to adopt one measure can reduce the potential of another, e.g. energy savings from new lightweight soft drink containers will be offset by an increase in the market share of refillable bottles, where the potential savings due to materials reduction are lower.

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

# VI. CONCLUSIONS

In order to verify (or disprove) empirically the energy conservation claims made by advocates of various waste management strategies, this study has examined a series of generalized cases. In each of these cases, a ton of waste paper is directed either to landfill, energy recovery or recycling. The findings provide some indication of how solid waste management strategies can either further or run counter to energy conservation goals.

A direct comparison between the reduction at source option and the other three approaches was not possible because of the lack of Canadian data. An estimation of the order of magnitude of the potential energy savings has, however, been attempted.

Within the limitations of this study, seven questions have been answered.

1. Does a paper product containing secondary fibre require more or less energy to produce than its virgin equivalent?

   In all cases examined, analysis of primary data shows that recycled content products require less energy in their total production (including an allowance for reclamation of secondary fibre) than the products containing 100% virgin fibre. The difference on a per ton of output basis ranged from $5.17 \times 10^6$ BTU to $26.44 \times 10^6$ BTU.

   These differences are explained in large measure by the fact that the energy required for harvesting and pulping virgin fibre is consistently greater than that required to reclaim and pulp secondary fibre. The latter process is rendered far easier by the substantial energy investment earlier in the fibre lifetime at the virgin pulping stage.

   In only one case, tissue and sanitary paper, is the recycled content product of a significantly lower quality.

2. Can energy savings still be attributed to recycling if it is assumed that the waste paper can be used as an energy source?

Whether energy savings can be realized under this assumption depends on the type of product being manufactured and on the percentage of waste paper which can be assumed to be dedicated to energy recovery.

Even when compared to the extreme case (which assumes energy recovery of 100% of the waste paper), energy savings continue to be associated with the production of printing and writing paper and tissue and sanitary paper from recycled fibres.

The production of 100% recycled newsprint and corrugated containerboard does not, however, exhibit similar energy savings compared to the 100% energy recovery/virgin production alternative.* No conclusions can be drawn from this analysis concerning the use of waste newsprint or corrugated in the manufacture of other products such as boxboard.

It should be noted, however, that if 83% or less of the hypothetical ton of waste paper is subjected to energy recovery in the region from which the supply is being drawn, the newsprint recycling option does produce energy savings.

Similarly, in the recycled corrugated containerboard case, energy savings can be expected at energy recovery levels of 56% and under.

* For newsprint and corrugated containerboard, the inherent energy in waste paper is almost as large as the purchased production energy per ton of output.

3. Does recycling the waste paper yield energy savings if it is assumed that both the ton of waste paper and the trees saved in the forest by the recycling option are used for energy production?

In all cases, energy savings are associated with the recycling option. Their magnitude depends on how much of the waste paper or the wood is assumed to be actually used to produce energy.

In the predicted era of energy scarcity, this may be the most realistic question to ask. It is likely that the fibre in the forest will be regarded not only as a potential source of input to the paper industry but also as a possible source of food, chemicals and energy.

4. Under what conditions does energy recovery make energy sense?

Energy recovery, which makes energy available to the community, is clearly superior in this regard to landfill and incineration (without energy recovery) of solid waste, both of which, in effect, spend energy to destroy energy potential.

Furthermore, it is generally true that energy recovery also makes energy sense for all paper fibre (and other solid waste combustibles) which cannot be separated out for recycling.

Under certain assumptions, energy recovery also makes energy sense when compared to two particular recycling options - the manufacture of 100% recycled newsprint and corrugated.

Energy recovery systems, therefore, form a logical and important part of an energy-conscious solid waste management program.

5. To what extent do the long distances which often exist between sources of secondary fibre and recycling capacity mitigate against recycling?

Even over long distances in excess of 1000 miles, transportation of fibre does not appear to require quantities of energy large enough to significantly reduce the energy savings attributable to the recycling options.

6. Does the achievement of energy savings through recycling waste paper result in a net increase in environmental impact?

Estimates of the air and water pollution indicators examined in this study (particulate matter, $SO_x$, TRS, $BOD_5$ and TSS) suggests that recycling, and in particular the establishment of new capacity in Canada, may well bring a decrease in air and water pollution per ton of product output.

A review of current technology for the deinking process, for example, suggests that serious problems can be avoided.

7. What order of magnitude of energy savings may conceivably be expected from a combination of reduction at source measures?

As stated earlier, reduction at source has not been compared directly to the other solid waste management options. A qualitatively different approach, it 'manages' solid waste by not producing it in the first place. Thus, reduction at source is in many ways incomensurable with the other management strategies.

Secondly, very little rigorous investigation has been conducted in Canada to estimate the energy savings which may be achieved through the various solid waste reduction measures proposed to date.

It is worthwhile, however, to attempt a rough estimate using prior U.S. studies adjusted by Canadian population and packaging production data.

Based on an estimate of the energy savings that would be associated with a number of source reduction options (principally a return to 1958 levels of packaging and the advent of a 100,000 mile auto tire), something in the order of $55 \times 10^{12}$ BTU or $58 \times 10^{6}$ GJ could be saved per year across Canada. This represents a savings of about 2.6% of the total industrial energy demand in Canada in 1975.

The findings and conclusions of this study should be placed carefully in context. Although the energy (and environmental impacts) associated with different solid waste management options constitutes a very important consideration in the planning stage, energy conservation will not be the sole criterion for making significant investment decisions.

General and particular economic conditions, practical feasibility, social and political implications and resource availability* will all play a role in decision-making.

* A previous study for the Canadian government (51) concluded that expansions in the pulp and paper industry beyond 1990 would be severely limited with wood supplies acting as the major restraint. Thus, in the long term, the impetus for increased levels of recycling may be stronger from the fibre shortage perspective than from energy conservation programs.

## VII. 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 analyzed rigorously to identify energy and resource as well as social and economic costs and benefits which may accure 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.

LIST OF APPENDICES

# APPENDIX A

## WOOD AS A POTENTIAL SOURCE OF ENERGY

Concern over the price and availability of traditional forms of energy has recently prompted the search for sources of renewable forms of energy. This appendix briefly describes the possibility of using wood as a source of energy.

The solar energy captured by plant material (biomass) through photosynthesis has served as man's oldest fuel. In 1970, 48per cent of the roundwood harvested in the world was used as a fuel (51) with most of this use occurring in Asia and Africa.

A number of studies have recently been conducted which examined the possibility of using wood as a major source of energy in North America. Although, as previously noted in this report, some wood wastes from pulp mills (bark,black liquors) are currently being used as a source of energy, existing forest resources and even energy plantations are now being considered as sustainable sources of energy.

The energy inherent in wood can be utilized by burning the harvested wood in conventional steam boilers(turbine generators producing electricity). All technology, including cultivation and harvesting techniques and boiler arrangements for steam production,is currently available. In addition to direct combustion for power generation, wood from energy plantations can be converted to useful fuels by pyrolysis or hydrogasification.

The feasibility of energy plantations has been explored by previous studies (52,53, 54 ). It has been estimated that, for hybrid poplar, a cultivation area of 245 square miles would be required to fuel a 400 MW generating station at 34 per cent thermal efficiency and 55 per cent load factor (55). In comparison , it has been estimated a 1,000 ton per day pulp mill would require an area of about 350 square miles to keep it perpetually supplied with wood (52). Hence the plantation area requirement would not be revolutionary. A recent study in Vermont has estimated that all the state's heating requirements could, theoritically, be provided by the surplus unmerchantable wood growing in the state (56).

A number of studies have commented on the economic viability of energy plantations ( 52) and there is a general concensus in the literature that, despite higher delivery costs, biomass from energy plantations is at least within reach of economic viability.

It would thus appear that wood and energy plantations warrant consideration as a future energy source. The present study analyses the energy associated with each paper production option with and without wood considered as a potential energy source.

Certain problems could arise in the implemention of energy plantations since severe competition could arise with other potential uses of the land for agriculture, forestry , recreation and urban development. Questions regarding this approach include the availability of appropriate high yield crops in Canada, the cost of collection and delivery of the wood, the environmental impact (especially in terms of soil nutrient depletion) of bringing large land areas under prolonged monoculture cultivation, the vulnerability of monocultures to disease and annual variations in climate, and the threat to security of supply faced by fire and other natural occurrences. However, many of these adverse implications could likely be avoided with careful management of the forestry resources.

## APPENDIX B

## TRANSPORTATION REQUIREMENTS FOR DIFFERENT PAPER PRODUCTION OPTIONS

Transportation can pose a particularly significant problem in a country as large as Canada. It is for this reason that this appendix lays out in some detail the transportation implications of the different paper production options considered in this study.

Table 23 includes the following transportation stages: wood and waste paper to pulp or paper mill; market pulp to paper mill; paper product from paper mill to a centre for further distribution and/or conversion (assumed to be Toronto for this analysis).

Three types of recycling mills examined in this study did not exist in Ontario and, therefore, mills from the United States and Quebec were used. For the purposes of this study, it was assumed that these three mills were situated within 100 miles of Toronto.

Table 25 indicates that transportation generally represents about 5% of the total purchased energy associated with the various paper production options, varying from 2.2 to 6.6%. For all product options except the last (corrugated containerboard), the recycling options generally appears to require less absolute transportation energy; however, this represents a higher percentage contribution to the total purchased energy. For corrugated linerboard, both the absolute amount and percent of energy due to transportation are lower than for the virgin option.

One interesting result of this transportation analysis is the slightly reduced amount of transportation energy required if the 5% recycled (non-deinked) newsprint mill is located in northern Ontario where the roundwood used by the southern Ontario mill originates. This can be attributed to the fact that the roundwood transported to the southern Ontario mill undergoes a major fibre and moisture loss when it is made into newsprint after it has been shipped. However, when newsprint is produced in northern Ontario and then shipped south, these losses occur prior to the shipment.

Table 26 calculates the maximum average distance that the waste paper could travel in each recycling option before the energy savings from recycling disappear. This maximum distance has been calculated for two cases: Case 2a (a likely short-term possibility and the worst case with respect to energy savings from recycling) and Case 3c (the most likely medium- to long-term case).

Table 25

TRANSPORTATION REQUIREMENTS FOR DIFFERENT PAPER MANUFACTURING OPTIONS

| PRODUCT | COMPOSITION | LOCATION OF MILL | TRANS-PORTATION ENERGY | % OF ASSOCIATED PURCHASED PRODUCTION ENERGY (Case 1) | COMMENTS |
|---|---|---|---|---|---|
| | | | $10^6$ BTU/ Ton | | |
| PRINTING AND WRITING PAPER | 100% Virgin | southern Ontario | 2.14 | 4.3% | 60% Integrated mill |
| | 34% Recycled | southern Ontario | 2.25 | 5.1% | Non-integrated mill |
| | 83% Recycled | United States | 1.98 | 5.7% | Mill assumed to be within 100 miles of Toronto |
| NEWSPRINT | 100% Virgin | northern Ontario | 1.44 | 4.8% | Integrated mill |
| | 5% Recycled (non-deinked) | southern Ontario | 2.39 | 6.7% | Integrated mill |
| | 5% Recycled (non-deinked) | northern Ontario | 2.03 | 5.7% | Same mill as above except assumed to be where that mill gets its roundwood from in northern Ontario |
| | 100% Recycled | United States | 1.26 | 6.4% | Mill assumed to be within 100 miles of Toronto |
| TISSUE AND SANITARY | 100% Virgin | southern Ontario | 2.11 | 4.3% | Non-integrated mill |
| | 100% Recycled | Quebec | 1.39 | 6.2% | Mill assumed to be within 100 miles of Toronto |
| CORRUGATED CONTAINER BOARD | 100% Virgin Linerboard<br>73% Virgin Medium | northern Ontario<br>southern Ontario | 1.56 | 5.9% | Products mixed in the ratio necessary to make complete corrugated cartons |
| | 100% Recycled | southern Ontario | 0.45 | 2.2% | Produces both linerboard and medium. |

Table 26

MAXIMUM WASTE PAPER TRANSPORTATION DISTANCES

| RECYCLING OPTION | ENERGY FOR WASTE PAPER TRANSPORTATION | CASE 2A: ENERGY SAVINGS FROM RECYCLING (Case 2a) | CASE 2A: MAXIMUM WASTE PAPER TRANSPORTATION DISTANCE | CASE 3C: ENERGY SAVINGS FROM RECYCLING (Case 3c) | CASE 3C: MAXIMUM WASTE PAPER TRANSPORTATION DISTANCE |
|---|---|---|---|---|---|
| | $10^6$ BTU/ ton-mile | $10^6$ BTU/ton | miles | $10^6$ BTU/ton | miles |
| PRINTING AND WRITING PAPER | | | | | |
| 34% Recycled | 0.0040 | 4.27 | 1168 | 13.63 | 3508 |
| 83% Recycled | 0.0040 | 6.44 | 1710 | 15.80 | 4050 |
| NEWSPRINT | | | | | |
| 100% Recycled | 0.0040 | -1.97 | - | 3.80 | 1050 |
| TISSUE AND SANITARY PAPER | | | | | |
| 100% Recycled | 0.0040 | 12.66 | 3265 | 22.49 | 5723 |
| CORRUGATED CONTAINERBOARD | | | | | |
| 100% Recycled | 0.0040 | -4.99 | - | 3.60 | 1000 |

For the two recycling options in Case 2a, where there is an energy loss attributable to recycling (newspring and containerboard), there is no maximum distance. However, in the majority of options considered, the maximum distance over which the waste paper could travel is quite large. It is significant to note here that all transportation of the waste paper has been assumed to be by truck; if this transportation were by rail, the maximum distances would be even larger.

It can thus be concluded that even if waste paper were drawn from a radius of over 1000 miles from a paper recycling mill, energy savings would still be attributable to recycling in six of the eight cases considered. The two exceptions to this general rule are not relevant if very likely medium-term assumptions are made concerning the energy recovery from waste paper to wood (Case 3c).

# APPENDIX C

## ENERGY RECOVERY FROM SOLID WASTE

This Appendix reviews the thermodynamics of various energy recovery systems currently in full-scale operation or demonstration stage. Critical commentary on both the thermodynamic and technical aspects of each system is offered where it has been considered relevant.

## A. DATA ACQUISITION AND QUALITY

### 1. General

The information presented here is based on the best data that could be obtained. Full co-operation was obtained from the majority of individuals and companies consulted.

### 2. Uncertainties

#### a. Refuse Heating Value

The heating value of the solid waste as received by the processing facility has been assigned different values by different studies. Although $9 \times 10^6$ BTU/ton is a commonly used figure by the U.S. Environmental Protection Agency, operating experience at the Montreal incinerator indicates that this figure is about $10 \times 10^6$ BTU/ton. Experience at the Quebec incinerator indicates that $12 \times 10^6$ BTU/ton is a more typical figure.

No data was generated by this study on the heating value of refuse. The problems of obtaining a truly representative sample for calorimetric evaluation, as well as seasonal variations, hamper accurate measures. A value of $10 \times 10^6$ BTU/ton was used throughout this study as a representative value. The higher heating value, defined as the gross heat of combustion of a substance including the heat contained in the post-combustion products, is used in this study.

#### b. Refuse Flow Rate

Flow rates of refuse into the process are frequently best estimates. The majority of installations visited had on-going difficulty with weighing equipment and most were content to charge by the truck visit rather than by recorded weight. The capacity of many systems, particularly incinerators, are often designed to take down time due to maintenance into account.

c. Other Flow Rates

Flows of steam, condensate, product gases, etc. were usually estimated from averaged data. The refuse composition is constantly changing and so the heating value of the refuse feed varies continuously.

### 3. Quality

All data used in this study on energy recovery systems were supplied by manufacturers and/or promoters of the equipment being examined. No responsibility can therefore be taken by the authors of this report for the absolute accuracy of the information. Consistency is, however, to be hoped for since a standard questionnaire was used to obtain this data.

## B. SYSTEMS EVALUATED

The five systems listed under the headings 'Incineration with Steam Recovery' and 'Refuse Derived Fuel' are full-scale, totally operational systems. Of those included under 'Other Systems' (which are in various stages of development), some are operating demonstration plants which have been closed for various reasons and others are in varying stages of development. For each system, the name of the organization involved (if relevant), the name of the process , and the location is given.

### 1. Incineration with Steam Recovery

Three examples were visited. Because of the many similarities among them, they are presented together.

a. Incinérateur Municipal No. 3 (Rue Des Carrières), Montreal
b. Incinérateur C.U.Q. (Communauté Urbaine de Quebec), Quebec City
c. Refuse Energy Systems Company, Boston North Shore System, Saugus, Massachusetts

The Montreal incinerator has been in operation since 1970 and produces steam. No reliable market has been found, however, and thus most of its production is condensed.

The Quebec City incinerator has been operational since 1974 producing steam for use in a nearby paper mill. The mill requires a steady steam flow and, as a result, a large condensate accumulator and auxiliary oil burners were installed in the main boilers in order to guarantee continuous performance.

Montreal and Quebec both use von Roll type grates with the entire system manufactured by Dominion Bridge Company.

Saugus, Massachusetts became operational in late 1975 and provides steam for a heavy manufacturing plant nearby. The customer needed a reliable steam supply and so oil-fired boilers of equal capacity to the refuse-fired boilers were installed.

Saugus is a von Roll installation engineered by Wheelabrator-Frye of Hampton, Massachusetts.

Although the above plants are similar, their differences should be made clear. In particular, different ratios between drying, burning and finishing grates have been used at each installation. In addition to experiments being conducted on the metallurgy of the grate steels, different lining refractories are being tried - all in an attempt to reduce maintenance requirements.

The general performance of these plants suggests that they are not experimental installations. They are based on proven European technology using North American expertise.

It should be noted that no processing of the refuse is required between the packer truck and the combustion process. All plants are equipped with electrostatic precipitators; however, some questions remain regarding the possible emission of heavy metals in the stack gases. Stack gas sampling techniques will require improvement before this question can be accurately resolved.

Ash removal at each installation is accomplished by an automatic, continuous process with ferrous metals being separated before the ash is landfilled. In addition, a "bright" metal slag accumulating under the first grate is manually removed every month. This slag is apparently a mechanical mixture of lead, tin and aluminum.

The unpredictable variation in heating value of the refuse as well as the seasonal variation in supply has required that some overlapping (or peaking capacity) by conventional fuel be provided in order to match supply with demand. The Quebec City incinerator has experienced a continued high heating value of their input refuse; based on their output of steam, they estimate an average heating value of $12 \times 10^6$ BTU/ton for their refuse.

The processing energy ranges from 30 to 40 kwh/ton. The energy efficiency of conversion from refuse to steam in all these plants runs at about 65%.

## 2. Refuse-Derived Fuel (RDF) Systems

### a. Canadian Industries Ltd. (CIL) Solid Waste Reduction Unit (SWARU), Hamilton

This system produces a refuse-derived fuel by shredding the solid waste and removing the ferrous scrap. The RDF is then burned on-site in specially built semi-suspension fired steam generators.

The shredding operation is atypical with the incoming refuse being shredded only to a 4" nominal size prior to ferrous material removal. The shredded refuse is then conveyed to the boiler where it is semi-suspension fired. In this process, some of the fuel is burned while falling through the boiler with the final burnout being completed on a grate.

This suspension burning process offers advantages in that the amount of excess air required for the combustion process is reduced compared to a grate burning system. This reduction in air requirements means that physically smaller equipment and buildings will accomodate a similar daily tonnage thus reducing capital costs. The smaller quantity of stack gases produced as a result of lower air requirements reduce the size of the electrostatic precipitator required to meet air emission standards.

The ash produced by this system can be handled dry, thus reducing the plant water requirements and eliminating waste water treatment facilities. Less maintenance is to be expected because the grate temperatures are lower.

The semi-suspension firing, with its lower excess air requirements and better heat transfer within the steam generator, can be expected to yield higher combustion efficiencies than on-grate burning.

Process energy requirements for the SWARU system run at 52 kwh/ton. The energy efficiency of conversion of refuse to steam at SWARU is 66%.

No market has been found for the steam produced by this system and so it is being condensed. Studies are currently underway to remedy materials flow problems which have been hampering the efficient operation of the combustion unit.

b. Ames Solid Waste Recovery System, Ames, Iowa

This relatively new (October, 1975) dry fuel preparation operation processes 100 tons per day and eventually will handle 200 TPD after shakedown of plant equipment. It was patterned after and relies heavily on experience gained in a similar plant in St. Louis (Union Electric). The Ames operation shreds to 6", removes ferrous material, shreds again to 2" size, air classifies, removes aluminum from the heavy residue and transports the light fraction to the nearby thermal power plant. The fuel is stored in a live bottom bin and pneumatically conveyed to the boiler where it is suspension-fired with the pulverized coal input (at 10-15% by weight RDF).

The Ames system is on-line and operating well. Problems relating to handling of the milled refuse, slight mismatch between shredders and conveyors and the abrasive nature of the fuel have resulted in high maintenance costs for the piping systems in the power plant. Also, the large particle size produced has resulted in combustion difficulties. The large particles go through the flame and do not complete their combustion before landing on the ash quench water surface. Similar problems have been encountered with wood waste boilers. Some improvement has been obtained by introducing additional underfire air and the Ames boiler is being so modified.

The processing operation requires about 100-125 kwh per ton of waste processed. Considering material losses and removals, 1 mass unit of waste will produce .8 units of fuel. This process yields a recovery efficiency of 71%. When this wet (25-30% moisture) fuel is introduced into an existing pulverized coal boiler, a loss of 10% in boiler efficiency is to be expected. Thus, the overall conversion of refuse to steam is accomplished at an energy efficiency of 55%.

3. Other Processes

Various other processes supplied data on their operations for this study.

a. Union Electric Solid Waste Utilization System, St. Louis, Missouri

The Union Electric system, which uses shredded solid waste as a supplementary fuel to generate electricity, is presently converting from a pilot/demonstration operation to a much larger scale. Data was used from the St. Louis system (upon which the Ames Iowa plant is based) to predict performance at Ames.

b. Monsanto Enviro-Chem LANDGARD System, Baltimore, Maryland

The LANDGARD is a pyrolysis system producing a gas which is then burnt to produce steam. It is currently suffering from a variety of problems resulting in a plant shutdown for an indefinite period. Litigation is pending regarding financial responsibility for repairs and modifications required.

Baltimore is an example of one large processing line rather than several small ones of equal or greater total capacity. There is no margin of error in the large line and no easy way of performing maintenance without interrupting the flow. Published data on the system show an energy efficiency of 51% from refuse to steam.

c. Andco-Torrax ANDCO-TORRAX PROCESS, Orchard Park, N.Y.

This process is normally referred to as slagging pyrolysis. The end products are heat and a glassy frit. It produces the maximum reduction in volume of the refuse and no pre-treatment is required. An exceptionally complete treatment of the process operation and anticipated performance appear in a previous report (17).

The anticipated heat and mass balance for this system is reproduced below:

| | HEAT | MASS |
|---|---|---|
| **Input** | $10^6$ BTU/ hour | tons/ hour |
| Refuse | 79.3 | 8.00 |
| Auxiliary Fuel | 2.2 | 0.04 |
| Combustion Air | 1.0 | 46.37 |
| Feed Water | 12.3 | 22.19 |
| | 94.8 | 76.60 |
| **Output** | | |
| Steam | 67.0 | 22.19 |
| Losses | 11.5 | - |
| Slag | 2.0 | 1.99 |
| Exhaust Gases | 14.3 | 52.42 |
| | 94.8 | 76.60 |

Steam Production: 2.77 lb. steam/lb. refuse

Basis: Refuse at 9 x $10^6$ BTU/ton (Higher Heating Value)

This gives an energy efficiency of 68% from refuse to steam. The process energy required is expected to be 70 kwh/ton of refuse.

d. Union Carbide PUROX, South Charleston, West Virginia

The PUROX process is normally referred to as pyrolysis, although it does not fit into the general definition since oxygen is supplied to the thermal decomposition reaction. The product is a fuel gas with a typical higher heating value of 370 BTU/cubic foot.

Typical gas composition by volume is as follows:

| | |
|---|---|
| Hydrogen | 24% |
| Carbon Monoxide | 40% |
| Carbon Dioxide | 25% |
| Methane | 5.6% |
| Acetylene, Ethane, etc. | 5.4% |

Minimal shredding and ferrous recovery is performed on the solid waste prior to thermal decomposition. The process energy required, according to Union Carbide, is about 5-6 kwh/ton processed. Approximately 60% of this is required for the cryogenic oxygen producer. Fuel recovery efficiency is guaranteed by the company at 70% with demonstration runs yielding 75-80%.

Assuming a reduction in gas boiler optimum efficiency from 83% to 75% because of the nature of the fuel, the energy efficiency from refuse to steam would be 56%. This is lower than the figure for some of the other pyrolysis systems because the gas produced is cooled and refined prior to its end use, whereas the gas from some of the other systems (such as the Andco Torrax system) is burned immediately on-site while it is still relatively hot and unrefined. The 200 TPD demonstration facility in South Charleston, West Virginia is shut down at present. This process is among the most highly regarded of all processes examined. It is to be hoped that a large-scale commercial system will be in operation soon to demonstrate viability. Good detailed descriptions are to be found in other studies (17, 18).

e. Syngas Recycling SYNGAS PROCESS, Columbus, Ohio

The SYNGAS PROCESS, which produces a high BTU synthetic gas, emerged from studies conducted by the Energy Research Centre of the U.S. Bureau of Mines in Pittsburgh. Based on a pilot plant at the Battelle Columbus Laboratories, the two reactor system is reported to be able to produce a gas with a heating value of 1020 BTU/cubic foot, which can be pumped directly into a gas pipeline system. The fuel recovery efficiency is estimated to be 66% and thus the energy efficiency from refuse to steam would be 55% using a gas boiler efficiency of 83%. However, using this gas to produce steam does not represent the most efficient use of this pipeline quality gas.

f. Occidental Research FLASH PYROLYSIS, San Diego County, California

Occidental Research (formerly Garrett Research and Development) are now constructing a 200 TPD plant in San Diego County. Their proprietary FLASH PYROLYSIS process converts the organic portion of the refuse into about one U.S. barrel of low sulphur liquid fuel from each ton of raw refuse.

The fuel recovery efficiency is about 39% and thus the energy efficiency from refuse to steam would be 33%.

The oil is a difficult fuel to handle and store due to its viscosity and acidity. It remains to be seen whether a market will evolve for this fuel.

g. Combustion Equipment Associates/Arthur D. Little, ECO FUEL II, Cambridge, Massachusetts

ECO FUEL II is a dry, finely shredded fuel produced from the paper-organic fraction of processed solid waste. Combustion Equipment Associates have contracted Arthur D. Little exclusively for fifteen years to do R & D on resource recovery systems. ECO FUEL II is the trademark applied to a fuel which has evolved from the ADL work.

The process developed to produce ECO FUEL II differs from the Ames-St. Louis system in several ways: these differences combine to reduce its process energy requirements to about 50 kwh/ton of waste. This is accomplished by using a flail mill as the primary shredder, and the use of a heated ball mill for the final fine grinding of the fuel product. The heat required for the ball mill is provided by burning some of the solid waste being processed. The power requirements are further reduced by the addition of an inorganic chemical embrittling agent to the light "paper" fraction before milling.

This chemical is the subject of patent proceedings at the present time and cannot be disclosed. Assurance has been received that it is a chemical currently in common industrial usage, that it poses no threat to the safety of workers using it and that its effect on stack emissions will be negligible. It is effective in low concentrations when combined with the correct heat in the ball mill.

The end product fuel is denser and drier than shredded fuel. It is easier to burn, has a higher heating value and is self sustaining in a combustion process. The table below summarizes a comparison Combustion Equipments Associates made between their fuel with the expected properties of other shredded fuels.

Table 27

PROPERTIES OF REFUSE-DERIVED FUELS

| | ECO FUEL II | SHREDDED FUEL | |
|---|---|---|---|
| | | Dried | Undried |
| Combustibles (% by weight) | 88.6 | 77 | 50-60 |
| Ash (% by weight) | 9.4 | 13 | 20 |
| Moisture (% by weight) | 2.0 | 10 | 20-30 |
| | 100.0 | 100 | 100 |
| Higher Heating Value (BTU/lb) | 7800 | 6800 | 5000 |
| Average Particle Size (inches) | 0.006 | 0.75 | 2-3 |
| Bulk Density (lb /cu ft ) | 30-35 | 3.50 | 4-6 |
| Storage Life | indefinite | indefinite | 2-3 days maximum |

The fuel recovery efficiency of the ECO FUEL II production system is 72%. When the fuel is used to produce steam in a boiler, the efficiency loss (relative to boiler efficiency for conversion from coal to steam) will be much less than the 10% experienced with the co-combustion of shredded fuel. Assuming a 3% loss from the peak achieved with coal firing, the energy efficiency to produce steam from refuse using the ECO FUEL II process would be 61%.

h. American Can AMERICOLOGY System, Milwaukee, Wisconsin

All data available on this dry fuel production unit are based on prototype performance and may vary with the full-size operation. A 1200 ton per day facility is currently being built in Milwaukee, Wisconsin. A shredding operation followed by sophisticated air separation allows rapid separation into a light paper and fibre fraction.

The facility will recover ferrous material and aluminum. Processing energy is projected to be 32 kwh/ton. Projected fuel recovery efficiency of the process is 58% with final conversion to steam in an off-site power plant yielding an energy efficiency of 45%.

i. Black Clawson HYDRASPOSAL/FIBRECLAIM System, Franklin, Ohio

No energy data were provided by the company on this wet separation process which recovers paper fibre from the waste. This fibre can be either used in paper mills or burned as RDF. Considerable commercial/promotional literature is available but no energy data could be obtained.

j. Combustion Power Company CPU-400, Menlo Park, California

Development work is still proceeding on this system which is attempting to burn the light fraction of solid waste in a fluidized bed as part of a gas turbine cycle.

The problems experienced relate to the difficulty of achieving high flow, high pressure, and high efficiency filtration with low pressure drop of the combustion gases prior to the turbine.

k. Other Canadian Systems

A number of other Canadian systems, although not included in this analysis, could be promising in the future.

Tricil Waste Management are constructing a pilot plant size gasifier at their Kingston Reclamation Plant. Energy data on this operation is not available at the present.

The Watts from Waste project, to use solid waste as a supplementary fuel in the Lakeview Power Generating Station in Toronto, can be expected to be very similar to the Ames and St. Louis operations.

An approach which may warrant special attention is the use of solid waste as an energy source in cement kilns. The Ontario Research Foundation have studied the feasibility of this application and have estimated its potential energy efficiency (4).

Two other systems also of interest are the wood waste gasifiers currently being promoted by Power Gas Division (formerly Moore Dry Kiln) and Alberta Industrial Development.

1. Other Systems Contacted

The following organizations were also contacted but were not included in this analysis because data were not received, or the data received were inadequate or the project had been cancelled: IBW Martin, Tecnican Industries, Raytheon, Browning-Ferris, Engineered Waste Control System, Systems Associates, Sira International and Battelle Pacific Northwest.

## C. CONCLUSION

The results of this Appendix are summarized and used in Chapter III of the main report and are used to derive an average net energy efficiency figure based on operating experience and best estimates of future performance.

## APPENDIX D

## EFFECT OF PAPER RECLAMATION ON THE RECOVERY OF ENERGY FROM SOLID WASTE

In the debate over whether waste paper should be reclaimed from solid waste for recycling or burned for energy along with the rest of solid waste, attention has been focused on the effect that increased amounts of paper reclamation would have on energy recovery systems. A number of previous studies have investigated this question (3,5,17,57).

The removal of waste paper from solid waste for recycling will have three effects on energy recovery systems:

- a smaller absolute amount of material will be available for energy recovery

- the heating value of a ton of solid waste will be reduced since the heating value 'as generated' waste paper ($16 \times 10^6$BTU/ton) is higher than that for solid waste generally ($10 \times 10^6$BTU/ton)

- the average moisture content of a ton of solid waste will be increased when the waste paper is reclaimed before entering the solid waste stream, since the moisture content of 'as generated' waste paper (8%) is lower than the moisture content of solid waste (25%)

Each of these three effects will be discussed separately.

The first effect could be decisive in areas able to justify one energy recovery plant (or one additional plant). The minimum size for most energy recovery systems is usually in the order of 200 tons per day. This is not of concern in most of Canada at the present time where there is currently enough solid waste to warrant the construction of many energy recovery facilities.

The following table estimates the percentage of solid waste that would be unavailable for burning if the maximum amount of waste paper assumed to be potentially reclaimable was reclaimed.

Table 28

PAPER COMPONENT OF SOLID WASTE POTENTIALLY RECLAIMABLE

| Grade of Waste Paper | Source | % Composition of Solid Waste ('as generated') | Maximum Reclamation Rate (%) | % of Solid Waste Reclaimed |
|---|---|---|---|---|
| Newspaper | Homes | 6 | 50 | 3.0 |
| Deinking | Offices | 4 | 25 | 1.0 |
| Corrugated | Commercial | 9 | 30 (separate collection) | 3.0 |
| | | | 60 (mechanical recovery of remainder) | 4.2 |
| | | | Total | 11.2 |

Source: EPA, Third Report to Congress; Resource Recovery and Waste Reduction (4)

The maximum reclamation rates in Table 26 represent the maximum rates believed to be physically and technically possible. These reclaimed amounts are in addition to what is now collected for recycling. These rates would be achievable without significant increases in the energy required to reclaim a ton of waste paper. The two reclamation systems for waste corrugated containerboards, separate collection, and mechanical recovery, are considered to be possible simultaneously: 30% is collected separately and 60% of the remaining 70% is reclaimed by mechanical recovery.

The 11.2% reduction in solid waste represents a 34% reduction in the amount of waste paper in solid waste.

The second effect is the most important as far as the viability of energy recovery system is concerned. The following formula was derived to estimate this effect of removing a portion of the paper from solid waste:

$$H_{sw-x} = \frac{H_{sw} - (x \cdot H_p)}{1 - x}$$

Where $H_{sw}$ is the higher heating value of solid waste
$H_p$ is the higher heating value of paper ('as generated')
$x$ is the fraction of the solid waste stream removed by paper reclamation
$H_{sw-x}$ is the higher heating value of solid waste with x removed

Thus, with $H_{sw}$ = 5000 BTU/lb
$H_p$ = 8000 BTU/lb
$x$ = 0.112
$H_{sw-x}$ = 4622 BTU/lb

This represents an 8% reduction in the heating value of a ton of solid waste. The magnitude of the reduction in heating value is less than the normal variation in the heating value as a result of seasonal or climatic changes.

This reduction in heating value resulting from recycling paper would, to some extent, counteract the tendency for the heating value to increase due mainly to the projected increase in amounts of plastic in waste.

This lowered heating content of solid waste will have some effect on the energy efficiency of energy recovery systems. Although a numerical calculation of this effect was not possible, it can be expected to be small.

The third effect concerns the moisture content of the remaining solid waste. The moisture content of a ton of solid waste (generally about 25%) would increase if some of the paper(which has a moisture content of 8% when it is discarded) formerly added to the solid waste stream was collected separately. Although some work has been done on the moisture content of the various components of solid waste and on the transfer of moisture from the wet components (food and yard waste) to the dry components (paper) an estimation of the effect of removing some paper was beyond the scope of this study. Since this can be expected to have a significant impact on the energy efficiency of energy recovery systems , it represents an area where further work appears to be warranted.

Thus, increased levels of paper reclamation will have an absolute effect on the amount of solid waste that is available for energy recovery and on the energy that can be extracted from one ton of solid waste. Although this study could not make a numerical estimation of the second effect, the analysis performed does indicate that energy recovery from solid waste will be feasible even if up to one third of the paper formerly entering the solid waste stream is reclaimed. This suggests that both paper reclamation and energy recovery can be employed simultaneously as solid waste management options.

# APPENDIX E

## MARKET PULP PRODUCED FROM WASTE PAPER

A recycling option that may be of particular interest in the Canadian context is the production of market pulp from waste paper. The two main advantages of this operation are the economies of scale that can be realized and the concentration of expertise in the procurement, handling and pulping of the waste paper. The only disadvantage , from an energy perspective, is the increased amount of energy required either to ship it as slush pulp or to dry the market pulp and then ship it.

Two U.S. mills are currently producing market pulp from waste paper. Both mechanically thicken the pulp to approximately 50% moisture and then ship it to nearby paper mills. Because both mills are situated in the vicinity of a number of paper mills, long distance transportation of the pulp is not required. This would minimize the one disadvantage of the market pulp system compared to an integrated paper mill using waste paper directly. It is also significant to note that this study has not found transportation to be a major energy factor (see Appendix B).

Although the limitations of this study did not allow a full energy and environmental analysis of these two mills compared to virgin market pulp mills, some comments on the direct energy consumed by each mill can be offered. The U.S. mill producing market pulp from poly coated waste paper consumes approximately $2.5 \times 10^6$ BTU/ton of air dry pulp; this mill does not require a deinking process for the grades of paper stock used. The U.S. mill producing market pulp from deinked waste paper consumes approximately $4.8 \times 10^6$ BTU/ton of air dry pulp; the increase in energy use over the first mill is due to the deinking required. For comparison purposes, the bleached kraft pulp mill analysed in this study consumes approximately $17.0 \times 10^6$ BTU/ton of air dry pulp. It must be noted that although all three figures are expressed in terms of air dry pulp, the product from the two pulp mills producing market pulp from waste paper in fact have a 50% moisture content.

Since the energy required to transform mechanically thickened pulp (50% moisture) to air dry pulp (8% moisture) is approximately $10 \times 10^6$ BTU/ton (air dry) , the energy consumed by the virgin pulp mill (excluding the drying energy) is still greater than that for the mills producing market pulp from waste paper. It must be noted however, that virgin market pulp is dried to reduce the expense of long distance transportation often required between virgin market pulp mills and the non-integrated paper mills that use this pulp.

Thus, although the scope of this study did not permit a complete analysis of the energy and environmental impacts associated with producing market pulp from waste paper instead of from wood, it appears that less energy is consumed by the waste paper pulp mills. This is an option which may well deserve additional attention.

## APPENDIX F

## ENERGY SAVINGS ATTRIBUTABLE TO REDUCTION AT SOURCE OPTIONS

This Appendix has been divided into four sub-sections. The first two examine the present energy (and to a lesser extent, solid waste) implications of the various products and packaging systems which have been chosen for this analysis. The selection of examples is illustrative rather than exhaustive and depends upon previously published work.

The remaining two sections look at the energy savings that result from applying various reduction options to these products and packages.

### A. PACKAGING

Packaging is a major consumer of raw materials as shown below (50):

| | |
|---|---|
| Paper | 47% |
| Plastic | 29% |

Although packaging may spend a comparatively long time protecting a product on its journey from the manufacturer to the retailer and thereafter displaying the product on the retailer's shelf, it has a very short lifetime once it and the product it protects are purchased by the consumer. Ninety percent of all packaging becomes garbage within one year of purchase (58), and most much sooner than that. This is despite the fact that the value of the package in many cases exceeds the value of the product it protects (Table 29).

Table 29

PACKAGING COSTS AS A PERCENT OF TOTAL MATERIALS AND SUPPLIES COSTS (BY INDUSTRY)

| | | | |
|---|---|---|---|
| Toilet Preparations | 60% | Pharmaceuticals/Medicine | 24% |
| Fruit/Vegetable Canners | 41% | Flour/Breakfast Cereals | 8% |
| Soft Drink Manufacturers | 48% | Motor Vehicle Parts | 1% |
| Breweries | 52% | | |

Source: Maclean-Hunter, Canada's Packaging Market (59)

The inevitable result of these factors is that packaging is a major component of solid waste, as shown in Table 30.

Table 30

PACKAGING MATERIALS AS A PERCENT OF TOTAL MUNICIPAL SOLID WASTE

| | |
|---|---|
| Paper | 16.3% |
| Glass | 8.9% |
| Metal | 4.9% |
| Plastic | 2.0% |
| Wood | 1.4% |
| Total | 33.5% |

Source: U.S. EPA, Second Report to Congress: Resource Recovery and Source Reduction (50)

These figures are for municipal solid waste, which includes residential, commercial and retail wastes. An examination of solid waste from households in London, Ontario produced similar results, although they refer to residential solid waste only (Table 31).

Table 31

PACKAGING MATERIALS AS A PERCENT OF RESIDENTIAL SOLID WASTE

| | | % | Total % |
|---|---|---|---|
| Paper: | Printed Packaging | 6.3 | |
| | Paper Bags | 4.0 | 12.3 |
| | Corrugated Boxes | 2.0 | |
| Cans: | Food Cans | 4.4 | |
| | Soft Drink | 2.0 | 7.6 |
| | All Other | 1.2 | |
| Glass: | Food Bottles | 4.4 | |
| | Soft Drink | 2.0 | |
| | Beer | 0.3 | 9.0 |
| | Wine | 2.1 | |
| Plastic: | | 2.5 | 2.5 |
| | Total Packaging | 31.4 | 31.4 |

Source: James F. MacLaren, Packaging Component of Solid Waste (60)

1. The Packaging Industry in Canada

Packaging is a major industry in Canada with an output valued at over $2 billion in 1974. Table 32 shows the growth in this industry over the past decade. "Apparent Domestic Supply" is equal to domestic production plus imports minus exports and is presumably equal to the total consumption of packaging by all users in any given year.

Table 32

GROWTH IN APPARENT DOMESTIC SUPPLY
IN CANADA'S PACKAGING INDUSTRY

(000's of Dollars)

| | |
|---|---|
| 1964 - $1,111,070 | 1970 - $1,621,263 |
| 1965 - 1,196,311 | 1971 - 1,751,565 |
| 1966 - 1,279,008 | 1972 - 1,910,241 |
| 1967 - 1,366,471 | 1973 - 1,994,089 |
| 1968 - 1,482,467 | 1974 - 2,279,022 |
| 1969 - 1,597,972 | |

Source: Maclean-Hunter, Canada's Packaging Market (59)

Table 33

PACKAGING CONSUMED BY MANUFACTURING INDUSTRIES

| | ALL INDUSTRIES | FOOD AND BEVERAGE INDUSTRIES | ALL OTHER INDUSTRIES | FOOD/BEVERAGE AS % OF ALL INDUSTRIES |
|---|---|---|---|---|
| | 000's of Dollars | | | |
| 1967 | 987,120 | 553,921 | 433,199 | 56.0% |
| 1968 | 1,062,348 | 553,321 | 469,977 | 55.9% |
| 1969 | 1,145,884 | 637,589 | 508,295 | 55.6% |
| 1970 | 1,204,135 | 686,189 | 517,946 | 57.0% |
| 1971 | 1,285,227 | 731,000 | 554,227 | 56.9% |
| 1972 | 1,383,452 | 781,393 | 602,059 | 56.5% |
| 1973 | 1,623,000 | 930,000 | 693,000 | 57.3% |
| 1974 | 1,873,000 | 1,060,000 | 813,000 | 56.6% |

Sources: Maclean Hunter Research Bureau, Canada's Packaging Market (59), and Statistics Canada, Consumption of Containers and Other Packaging Supplies by the Manufacturing Industries (61)

The difference between apparent domestic supply and the amount consumed by the manufacturing industries is the packaging used by the retail trade. It comprises a surprisingly high percentage of all packaging as shown below.

Table 34

PACKAGING CONSUMED BY RETAIL TRADE

(000's of Dollars)

| YEAR | CONSUMED BY RETAIL | PERCENTAGE OF TOTAL PACKAGING |
|---|---|---|
| 1967 | 379,351 | 27.8% |
| 1968 | 420,119 | 28.3 |
| 1969 | 453,088 | 28.3 |
| 1970 | 417,128 | 25.7 |
| 1971 | 466,338 | 28.8 |
| 1972 | 526,789 | 27.6 |
| 1973 | 371,089 | 18.6 (Estimates) |
| 1974 | 406,822 | 17.8 (Estimates) |

Source: Maclean-Hunter Research Bureau, Canada's Packaging Market (59)

The four packaging items with the largest consumption in Canada are:

Corrugated Cardboard Boxes and Cartons
Metal Cans
Folding and Set-up Boxes and Paperboard
Glass Bottles and Carboys

Together these four categories make up 49% of all packaging consumed in Canada (Table 35)

The food and beverage industries use 29.8% of all packaging consumed in Canada, and the soft drink industry alone uses 4% of all packaging, in the form of bottles and cans.

Table 35

FOUR MAJOR PACKAGING GROUPS AS A PERCENTAGE OF ALL PACKAGING

| | Consumed by All Industries | Consumed by Food and Beverage Industry |
|---|---|---|
| Corrugated Boxes | 17.8% | 12.3% |
| Folding Boxes Cartons | 9.6% | |
| Metal Cans | 12.7% | 10.6% |
| Glass Bottles/Carboys | 8.9% | 6.9% |
| Total 4 Major Groups | 49.0% | 29.8% |

Source: Statistics Canada, Consumption of Containers and other Packaging Supplies by the Manufacturing Industries (61)

2. Soft Drink Containers

Soft drink production in Canada is outlined in Table 36.

Table 36

SOFT DRINK PRODUCTION IN CANADA 1965-1973 IN GALLONS *

| | | |
|---|---|---|
| 1965 | 204,999,398 | (100.0%) |
| 1966 | 231,869,426 | (113.1%) |
| 1967 | 249,310,547 | (121.6%) |
| 1968 | 259,926,963 | (126.8%) |
| 1969 | 269,738,539 | (131.6%) |
| 1970 | 266,877,845 | (130.2%) |
| 1971 | 276,656,961 | (135.0%) |
| 1972 | 280,520,987 | (136.8%) |
| 1973 | 303,727,256 | (148.2%) |

Source: Statistics Canada, Soft Drink Manufacturers (62)

The 1973 total represents a consumption of 42 10-ounce servings a year for every man, woman and child in Canada.

* Note: All liquid volumes used in this report are imperial gallons unless otherwise specified.

Figure 2 shows the historical growth of soft drink sales against the growth in packaging expenditures by soft drink manufacturers on different types of container material. While soft drink sales have increased by 31% from 1966-1973, the value of packaging has increased by 192%, and of metal cans by 565%. The relative market share of refillable bottles has declined at the expense of one-way glass bottles and cans. This naturally has the effect of increasing the solid waste produced by soft drink containers; and it also affects the amount of energy consumed. Table 37 shows the energy required to deliver 240,000 ounces of soft drink for each container type and size.

Table 37

ENERGY USED BY VARIOUS SOFT DRINK CONTAINERS PER 240,000 OUNCES SOLD

| 10 Ounce Size | Energy ($10^6$ BTU) |
|---|---|
| Refillable Bottle (10 trip) | 62.1 |
| One-Way Bottle | 136.8 |
| Metal Can | 100.7 |
| **16 Ounce Size** | |
| Refillable Bottle (15 trip) | 50.6 |
| One-Way Bottle | 122.5 |
| Refillable Bottle (15 trip) (3 trip carrier) | 22.5 |
| **26 Ounce Size** | |
| Refillable (15 trip) (1 trip carrier) | 44.2 |
| One-Way Bottle | 120.3 |
| **40 Ounce Size** | |
| Refillable (15 trip) | 42.6 |
| One-Way Bottle | 119.4 |

Sources: Solid Waste Task Force, General Report of the Solid Waste Task Force to the Ontario Minister of the Environment (63), Hunt, et al, Resource and Environmental Profile Analysis of Nine Beverage Container Alternatives (64), Hannon, Systems Energy and Recycling: A Study of the Beverage Industry (65)

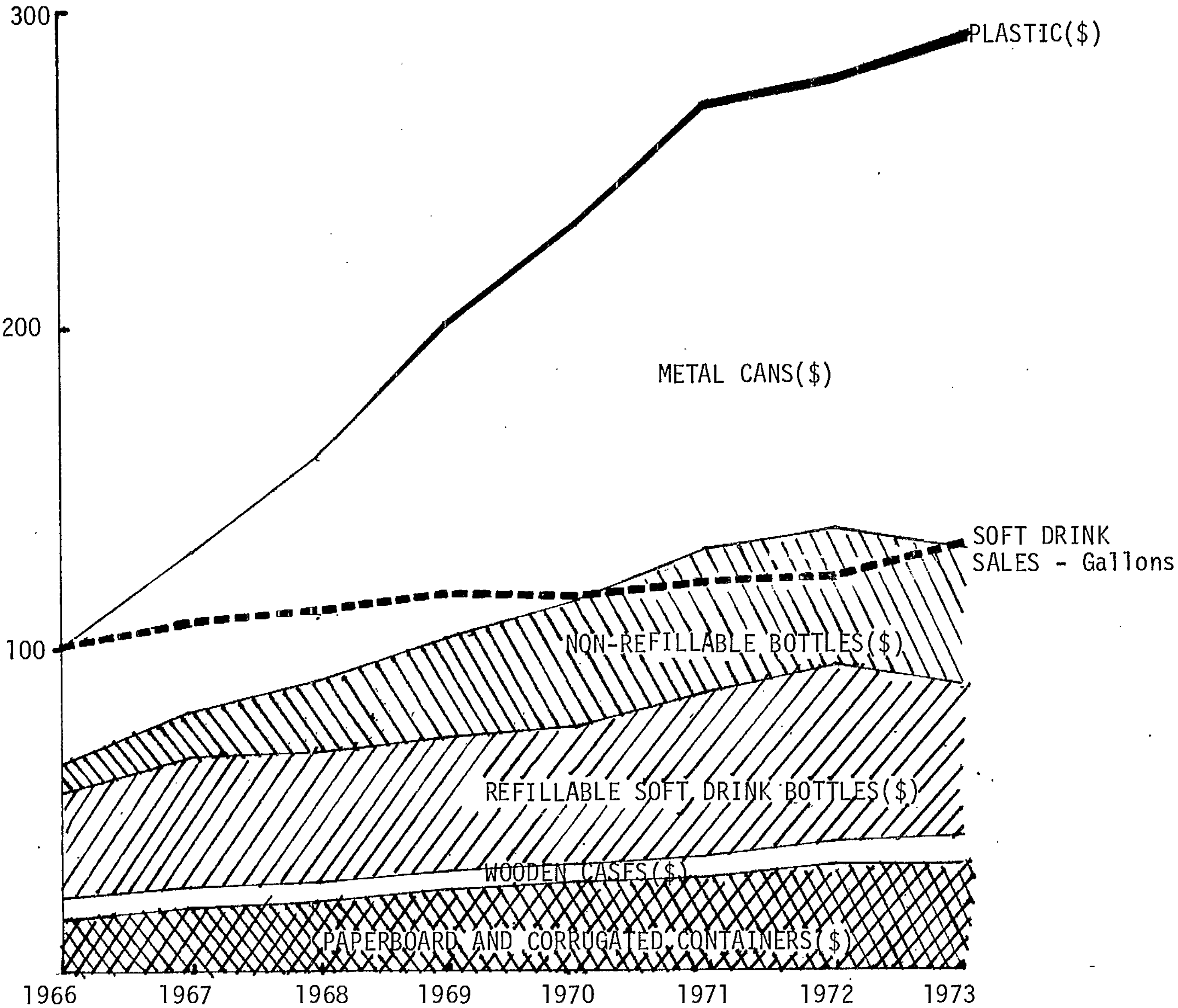



Figure 2 : GROWTH IN SOFT DRINK SALES AND PACKAGING VALUE
1966 - 1973

Sources: Statistics Canada, Consumption of Containers and Other Packaging Supplies by the Manufacturing Industries (61) and Statistics Canada, Soft Drink Manufacturers (62)

Two factors emerge from this comparison:

- For the same container size, the disposable system uses considerably more energy than the refillable. The gap widens as the number of trips made by the refillable bottle (and its paperboard carrier) increases.

- The energy per ounce of soft drink delivered decreases as the size of the container increases.

This suggests four ways in which the energy for soft drink containers can be reduced:

- Use refillable bottles
- Use reusable paperboard carriers
- Increase the trip rate of refillable bottles
- Increase the market share of large size containers

The energy savings from each of these measures will be examined in Section C of this appendix. The soft drink volumes and container types used in these calculations are outlined in Table 38.

## 3. Milk Containers

Milk sales in Canada have remained fairly constant recently, increasing by only 8% over the past eight years. Consumption in 1974 was equivalent to 117 quarts per person per year. In the same period, expenditures on packaging by milk producers and dairies have increased 165% in constant 1965 dollars. (The increase in current dollars is 215%.) This is shown graphically in Figure 3. Projected milk sales for 1975, together with the percentage market share of each container type, and the energy used per 3,000 quarts of milk delivered, are shown in Table 39.

Three points emerge from the figures in Table 39:

- The larger the pack, the less the energy required per quart of milk delivered.
- Package design can reduce energy use for the same package size (Ecopak compared with regular 1/2 pint container)
- Refillable glass bottles use more energy than the paperboard packages of the same size, but the refillable plastic jug uses just one-third of the energy required by the disposable pouch.

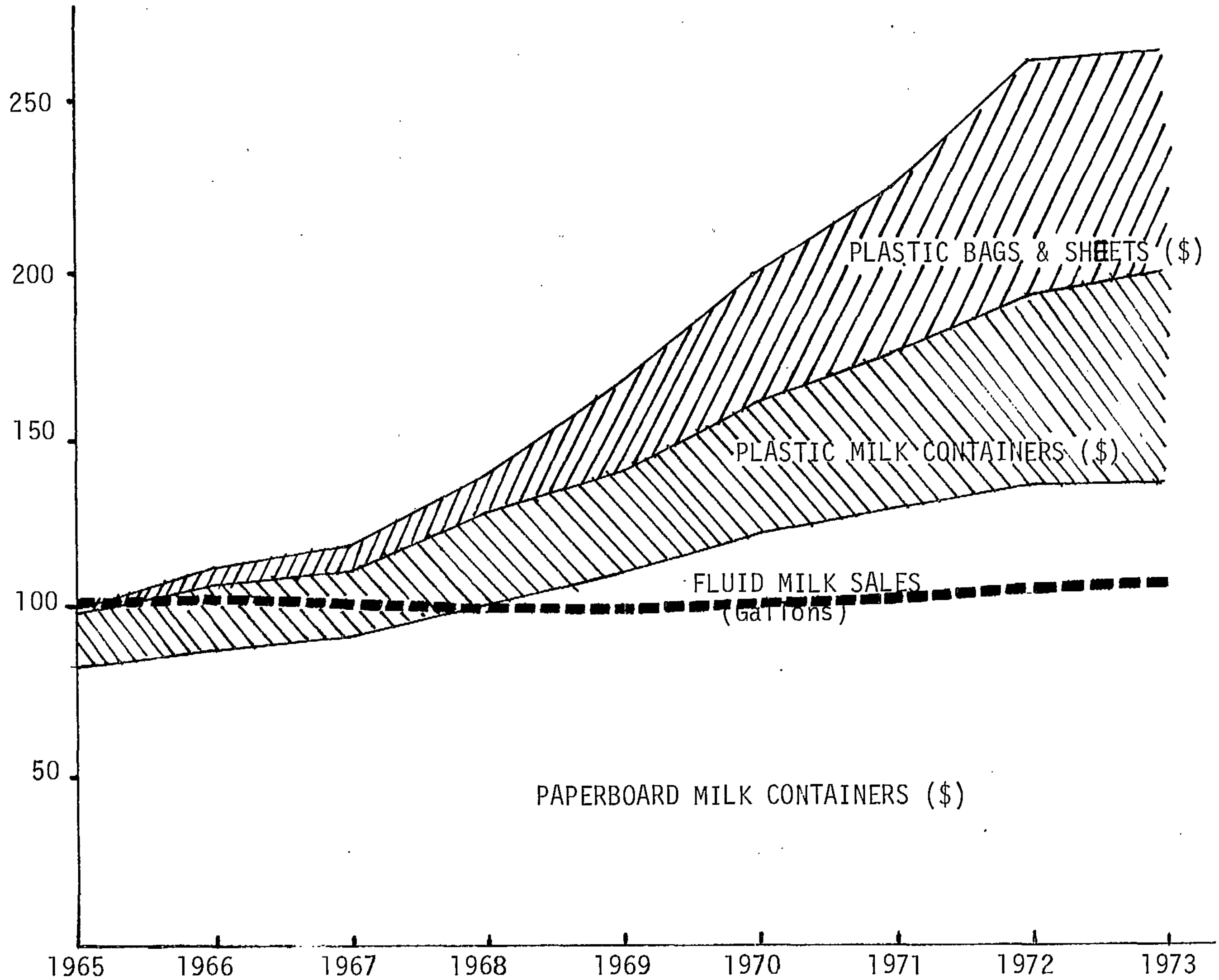



Figure 3: GROWTH IN MILK SALES AND PACKAGING VALUE, 1965 - 1973. (PACKAGING VALUES IN CONSTANT 1965 $.)

Sources: Statistics Canada, Consumption of Containers and Other Packaging Supplies by the Manufacturing Industries (61) and Statistics Canada, Dairy Products Industry (67)

Table 38

SOFT DRINK SALES BY CONTAINER TYPE 1965, 1973 AND 1975 (ESTIMATED)

| Container | 1965 | % | 1973 | % | 1975 | % |
|---|---|---|---|---|---|---|
| Refillable 10 ounce (10-trip) | 133,249,000 | 65.0 | 84,740,000 | 27.9 | 92,870,000 | 28.0 |
| One-Way Glass - 10 ounce | 6,149,000 | 3.0 | 20,046,000 | 66.0 | 21,559,000 | 65.0 |
| Metal Can | 13,120,000 | 6.4 | 87,170,000 | 28.7 | 92,870,000 | 28.0 |
| Refillable - Family Size | 4,100,000 | 2.0 | 18,831,000 | 6.2 | 23,217,000 | 7.0 |
| One-Way Glass - Family Size | 40,999,000 | 20.0 | 79,880,000 | 26.3 | 86,236,000 | 27.0 |
| Bulk Sales | 7,380,000 | 3.6 | 13,060,000 | 4.3 | 14,925,000 | 45.0 |
| Total | 204,999,000 | 100.0 | 303,727,000 | 100.0 | 331,677,000 | 100.0 |

Sources: Statistics Canada, Soft Drink Manufacturers (62) and Quebec Soft Drink Bottlers Association, Brief to the Quebec Minister of the Environment (66)

Table 39

1975 MILK SALES BY CONTAINER TYPE

| Container | Gallons | % | $10^6$ BTU per 3,000 Quarts |
|---|---|---|---|
| 5 Gallon | 28,746,000 | 5.0 | 1.86 |
| 3 Quart Plastic Jug (200 trip) | 201,221,000 | 35.0 | 0.20 |
| 3 Quart Plastic Pouch | 160,977,000 | 28.0 | 0.57 |
| 2 Quart Paper Board | 68,990,000 | 12.0 | 1.92 |
| 2 Quart Glass (20 trip) | 11,498,000 | 2.0 | 2.13 |
| 1 Quart Paper Board | 80,488,000 | 14.0 | 1.93 |
| 1 Quart Glass (20 trip) | 8,624,000 | 1.5 | 2.76 |
| 1 Pint Paper Board | 5,749,000 | 1.0 | 2.52 |
| 1/2 Pint Paper Board | 8,624,000 | 1.5 | 3.27 |
| 1/2 Pink Ecopak | - | - | 2.55 |
| Total | 574,918,000 | 100.0 | |

Sources: Solid Waste Task Force, General Report of the Solid Waste Task Force to the Ontario Minister of the Environment (63), Statistics Canada, Dairy Products Industry (67) and EPA, Tnird Report to Congress: Resource Recoverv and Waste Reduction (3)

Energy use for milk containers may thus be reduced in three ways:

- Increase the market share of large size containers
- Redesign packages to minimize energy and materials use
- Increase the market share of high trip rate refillable plastic jugs

The energy savings that result from these measures are examined in Section C of this appendix.

## 4. Reusable Paperboard Containers

The food and beverage industry uses 45% of all corrugated and 52% of all paperboard containers produced in Canada. Consumption of corrugating material is 115.7 pounds per person per year (36), making a total of 1,330,550 tons per year. In the food industry, these containers are used primarily for two purposes:

Shipment of glass and metal containers from the manufacturer to the food processor

Shipment of filled containers to the wholesaler and retailer

In the beverage industry, paperboard containers are used primarily for three purposes:

Shipment of bottles and cans from the manufacturer to the bottler

Shipment of filled containers from the bottler to the retailer or commercial user

Transportation of filled containers from the retailer to the consumer's home

The majority of these shipments are made in single-use paperboard containers. However, some of the shipments in the last two catagories for the beverage industry are made in reusable containers. The breweries ship beer to commercial customers (hotels and bars) in reusable corrugated boxes, which make between seven and twelve trips before discard (average; nine). The containers used by the breweries for the retail trade are also reused. Refillable soft drink bottles are sold in reusable paperboard carriers which make three or four trips. Table 40 shows the energy required by different soft drink container systems, and the reductions due to reusable carriers.

Table 40

ENERGY USED BY SOFT DRINK CONTAINERS
PER 240,000 OUNCES DELIVERED

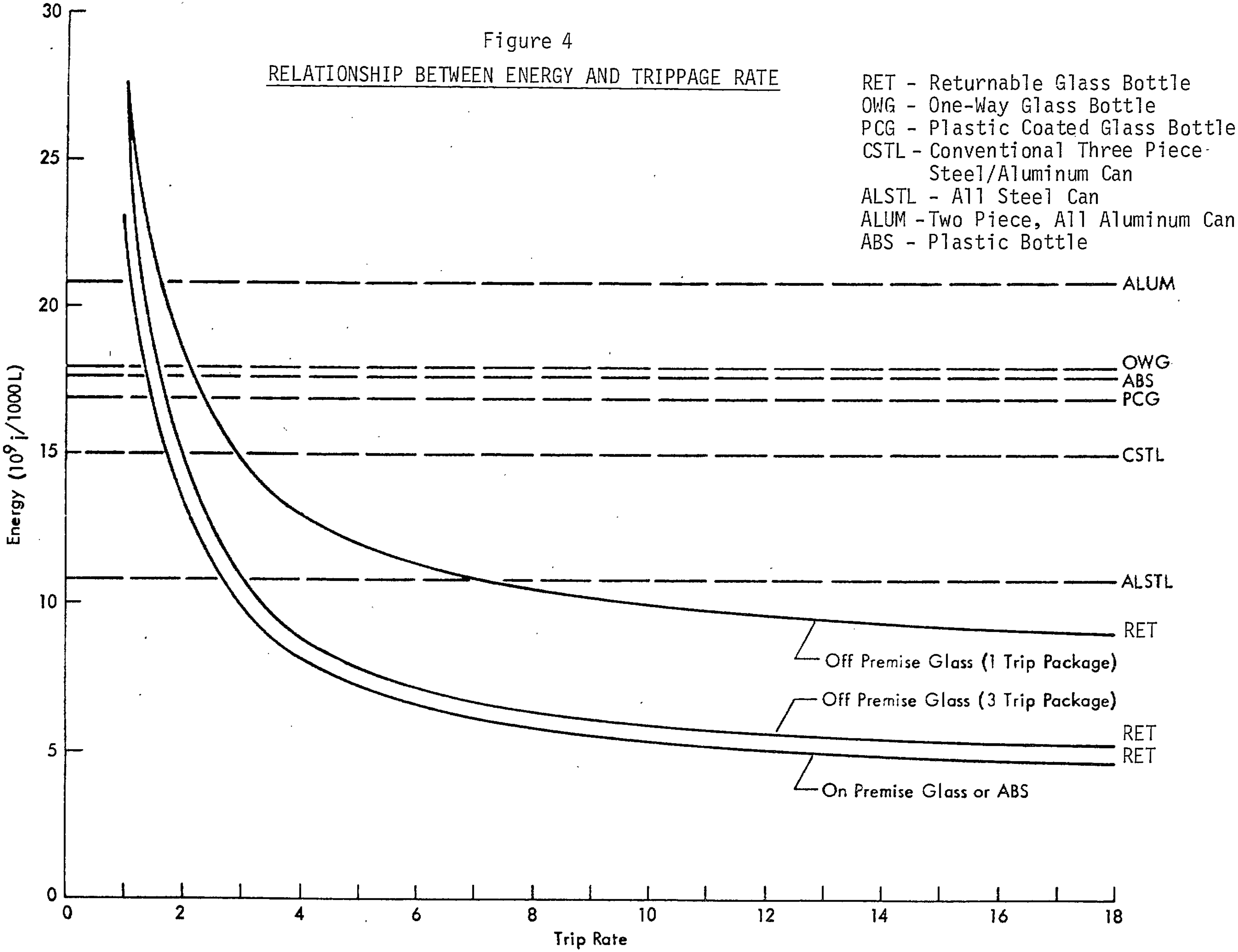
| 10 Ounce Size | $10^6$ BTU |
|---|---|
| 10 Trip Bottle - 1 Trip Carrier | 62.1 |
| 10 Trip Bottle - 3 Trip Carrier | 52.9 |
| One-Way Glass Bottle | 136.8 |
| **40 Ounce Size** | |
| 15 Trip Bottle - 1 Trip Carrier | 42.6 |
| 15 Trip Bottle - 3 Trip Carrier | 36.1 |
| One-Way Glass Bottle | 119.5 |

Source: Solid Waste Task Force, General Report of the Solid Waste Task Force to the Ontario Minister of the Environment (63)

Figure 4 compares the effects of increasing the trip rate of the bottle with substituting a reusable carrier for the disposable one. It shows that much more energy is saved with a reusable carrier, once the trip rate of the bottle is four or more. The energy saved by using reusable corrugated containers elsewhere in the food and beverage industries will be examined later in Section C.

Figure 4

RELATIONSHIP BETWEEN ENERGY AND TRIPPAGE RATE




Source: Hunt et al., Resource and Environmental Profile Analysis of Nine Beverage Container Alternatives (64)

## B. PRODUCTS

Products can be broken down into two categories: Durable Goods and Non-Durable Goods. The composition of durable and non-durable goods entering the solid waste stream is shown in Table 41.

Table 41

COMPOSITION OF DURABLE AND NON-DURABLE GOODS IN SOLID WASTE (1973)

| | | |
|---|---|---|
| Durable Goods | 11% | |
| Major Appliances | | 2% |
| Furniture, Furnishings | | 3 |
| Rubber Tires | | 1 |
| Misc. Durables | | 5 |
| Non-Durable Goods except Food | 18% | |
| Newspapers, Books, Magazines & | | 13% |
| Tissue Paper | | 2 |
| Other Non-Packaging Paper | | 1 |
| Clothing, Footwear | | 1 |
| Misc. Non-Durables | | 1 |

Source: EPA, Third Report to Congress: Resource Recovery and Waste Reduction (3)

There are two trends which are tending to increase the amount of products in solid waste:

- The substitution of disposable or non-durable items for their durable counterparts; e.g. paper plates for china, plastic or earthenware
- "Built in obsolescence" - the fact that products are not built to last as long as they could

## 1. Disposables Versus Durables

People buy disposable products because they are thought to be more convenient. It is, for example, easier to throw a paper plate into the garbage than to wash a reusable one, or to use a paper towel and throw it out than to wash a cloth one.

While the convenience of the disposable is not easily measured, the energy required by the two systems, one disposable, one durable is summarised below.

### a. Paper Versus Cloth Towel

A comparison of the energy used by paper towels with that used by cloth towels is complicated by the fact that cloth towels are washed in a wide variety of ways, each of which requires different amounts of energy. The variables include how often the towel is washed; machine or handwashing; water heating by gas or electricity; hot or cold rinse cycle; and whether or not a dryer is used, and what energy source it uses.

The following estimations were made by one study (68 ). The energy used for one roll (170 sheets) of paper towel is 37,100 BTU; the energy used by a comparable number of cloth towels, assuming that they are washed after doing the work of 10 sheets of paper towel, ranges from 27,000 BTU to 85,000 BTU. The other variables are so significant that it is very hard to say which system uses the most energy.

### b. Disposable Versus Cloth Diapers

The same comments apply to a comparison of the energy used by a gauze, prefolded cloth diaper with that used by a disposable paper one. It is only slightly simplified by the fact that for every disposable diaper used, the cloth diaper must be washed. The number of washing variables remain the same, and the conclusion is still that it is impossible to say that one system uses more energy than the other. The energy for the disposable system is 2,700 BTU per change; for the washable diaper it ranges from 1,600 to 4,900 BTU per change (68 ).

### c. Paper Dishes Versus Earthenware

A comparison of paper with earthenware dishes yields more positive results. Comparisons are made between: (i) earthenware plate and cup (washed in a domestic machine) with a sturdy, plastic-coated paper plate and cup (68) and (ii) glass plate (washed in a commercial dishwasher) with a solid bleached sulphate (SBS) paper plate (69).

The energy required by these four systems are given below:

| | |
|---|---|
| Disposable Plastic-Coated Plate and Cup | 4,000 BTU/Serving |
| Disposable SBS Plate | 599 BTU/Serving |
| Earthenware Plate and Cup | 1,400 BTU/Serving |
| Glass Plate | 129 BTU/Serving |

Disposable plates and cups are not used on an everyday basis in most homes. They are mainly used for parties, picnics, and when people are away from home. The largest use of paper plates and cups is by institutions and fast food chains. It is estimated (70) that in the United States, 2.5% of all paper packaging in the solid waste stream comes from fast food outlets. Not all of this is plates and cups; it is assumed here that 1% of all paper solid waste is disposable plates and cups.

One percent of all paper solid waste in the U.S. is 520,000 tons (68). One thousand 9" standard paper plates weigh between 24 and 29 pounds (69). It is assumed that the average weight for all paper plates and cups is 27.5 pounds per 1000. Thus, in 1973, $3.78 \times 10^{10}$ paper plates and cups were used in the United States, or 180 per person per year.

This gives a total for Canada (in 1975) of $4.16 \times 10^{9}$ paper plates and cups, assuming U.S. and Canadian consumption is equivalent.

## 2. Product Lifetime

The energy used by a reusable product like an earthenware cup is the sum of the energy used in making it and the energy required for "operating" - in the case of a plate, for washing it. Since a plate can be used many times before it is worn out or broken, the manufacturing energy must be spread over the total number of times it is used in its lifetime. For example, the earthenware plate and cup required 73,000 BTU for manufacture. If they last for two years at two uses per day (1460 washings), the manufacturing energy component is only 50 BTU per washing, compared with an operating energy per use of 1300 to 2300 BTU. Manufacturing energy is only between 2% and 4% of the total.

The effect of lengthening the lifetime to five years would be only to decrease the total energy use by between 1.3% and 2.2%.

It is generally true that where the operating energy is large, extending the lifetime of the product makes an insignificantly small difference to the total energy use. A much greater saving results from reducing the operating energy requirement. In the case of the earthenware plate and cup, switching from electric to gas water heating would save $3.65 \times 10^6$ BTU per plate and cup over five years, while extending the lifetime from two years to five would save only $0.11 \times 10^6$ BTU, just 3% of the other.

Herendeen (68) has designated the ratio:

$$Q = \frac{\text{Manufacturing Energy + Maintenance Energy + Disposal Energy}}{\text{Annual Operating Energy}}$$

He concludes:

> "Appliances which produce heating or cooling tend to have low Q's (e.g., Q = 1 for a kitchen range) while those which produce only mechanical motion have higher Q's (e.g., Q = 7 for an electric mixer). For high Q appliances, total annual energy use is quite sensitive to changes in lifetime. For low Q, it is not. Thus, prolonging the lifetime of low Q appliances through increased durability will effect relatively little energy savings" (68).

It is unfortunately also true that increasing the lifetime of high Q appliances will effect little energy saving, since they use very little energy in the first place. There are potential energy savings through increased lifetime with only two classes of products:

- Products with no operating energy
- Products with a high Q, where individually the savings are small, but whose large number makes the total saving significant

Automobile tires satisfy both of these requirements.

a. Automobile Tires

There are three basic types of automobile tires: Bias, Belted Bias, and Radial, and they last about 15,000, 26,000 and 38,000 miles respectively (71). The more durable tires are also the more expensive. Sales of the different tire types are outlined in Table 42.

Table 42

MARKET SHARE OF PASSENGER CAR TIRES

| | 1972 | 1973 | 1974 | 1975 |
|---|---|---|---|---|
| Replacements (70%) | | | | |
| Bias | 54 | 45 | 42 | 38 |
| Belted Bias | 38 | 42 | 39 | 38 |
| Radial | 8 | 13 | 19 | 24 |
| Total | 100 | 100 | 100 | 100 |
| Original Equipment (30%) | | | | |
| Bias | 16 | 18 | 13 | 9 |
| Belted Bias | 78 | 64 | 46 | 30 |
| Radial | 6 | 18 | 41 | 61 |
| Total | 100 | 100 | 100 | 100 |

Source: EPA, Third Report to Congress: Resource Recovery and Waste Reduction (3)

Passenger car tire sales in Canada were 17,305,365 (72) units in 1972, and an estimated 18,000,000 in 1975.

It is assumed that it is technically possible to build a 100,000 mile tire (71) that would last the present average lifetime of the North American car. Automobiles presently use an average of 6.6 sets of bias tires, 3.6 sets of bias belted tires or 2.6 sets of radial tires.

The 100,000 mile tire would have a considerable impact on solid waste. If, starting in 1978, all new cars are fitted with 100,000 mile tires, and all replacements are 27,000 mile retreads, the annual volume of tire discards will have declined by 58% by 1990 (73).

The composition of the average tire is taken as 23 pounds (74) of Styrene Butadiene Rubber, making a total consumption of 207,000 tons in 1975. The energy required to produce this material is 133.63 x $10^6$ BTU per ton (12). Thus, the total energy used for automobile tire manufacture in 1975 was 27 x $10^{12}$ BTU in Canada.

## C. ENERGY SAVINGS FROM PACKAGING REDUCTION

### 1. General Reduction in Packaging

The rapid increase in packaging consumption is due to three factors:

Increasing population
Increasing per capita consumption of durable and non-durable goods
Increased packaging per product

Concern about over-packaging tends to focus on the last of these.

A general reduction in packaging could be achieved by eliminating increased packaging per product, or by returning to a previous per capita level of packaging. The Environmental Protection Agency has calculated the reduction in materials consumption that would be achieved through a return to 1958 per capita levels of packaging. (see Table 43 on next page)

This table shows the problems of assuming a return to a previous level of packaging without taking account of the changing composition of packaging. It may be possible to reduce packaging to 1958 per capita levels; but it is not possible to return to the materials and technologies of 1958. New materials (particularly plastic and aluminum) will continue to be adopted. The composition figures below reflect changes in packaging technology (Table 44).

Table 44

PACKAGING COMPOSITIONS

| | 1975 | 1958 |
|---|---|---|
| Paper | 67.5 | 60.3 |
| Glass | 11.75 | 18.5 |
| Steel | 11.5 | 19.5 |
| Aluminum | 0.75 | 0.4 |
| Plastic | 8.5 | 1.3 |
| Total | 100.0 | 100.0 |

Table 43

CONSUMPTION OF PACKAGING MATERIALS

(000's Tons)

| | ACTUAL AND PROJECTED | | | | | | AT 1958 PACKAGING LEVELS | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1958 | % | 1971 | % | 1980 | % | 1971 | % | 1980 | % |
| Paper | 16,552 | ( 60.3) | 27,700 | ( 67.6) | 39,068 | ( 67.4) | 21,137 | ( 60.3) | 25,043 | ( 60.3) |
| Glass | 5,063 | ( 18.5) | 4,900 | ( 12.0) | 6,608 | ( 11.4) | 6,465 | ( 18.5) | 7,660 | ( 18.5) |
| Steel | 5,340 | ( 19.5) | 5,235 | ( 12.8) | 6,168 | ( 10.6) | 6,819 | ( 19.5) | 8,079 | ( 19.5) |
| Aluminum | 97 | ( 0.4) | 212 | ( 0.5) | 507 | ( 0.9) | 124 | ( 0.4) | 147 | ( 0.4) |
| Plastics | 368 | ( 1.3) | 2,900 | ( 7.1) | 5,607 | ( 9.7) | 470 | ( 1.3) | 577 | ( 1.3) |
| Total | 27,420 | (100.0) | 40,947 | (100.0) | 57,947 | (100.0) | 35,015 | (100.0) | 41,468 | (100.0) |

Source: Lowe, Robert, Energy Conservation Through Improved Solid Waste Management (5)

It is assumed that the weight of packaging could be reduced to the per capita levels of 1958. This gives a total packaging weight of 3,503,000 tons for Canada in 1975 (Table 45).

Table 45

PACKAGING CONSUMPTION

| | Total (000's Tons) | Per Capita (Pounds) |
|---|---|---|
| Actual U.S.A. 1958 | 27,420 | 304.6 |
| Estimated Canada - 1975 | 4,591 | 399.2 |
| Canada in 1975 @ 1958 Per Capita Levels | 3,503 | 304.6 |

Source: Projected from EPA, Third Report to Congress: Resource Recovery and Waste Reduction(3)

Some of the increase in consumption due to higher per capita consumption of durable and non-durable goods will still be able to take place, because, although the per capita weight of packaging remains at 1958 levels, new lighter materials and lightweighting processes introduced since then will allow more packaging to be produced from the same total weight.

The energy savings that could be achieved by adopting 1958 per capita (in the United States) levels of packaging in Canada in 1975 are shown in Table 46.

2. Returning to Returnables

a. Soft Drink Containers

Table 47 calculates the energy savings from increased use of returnable soft drink bottles, assuming that:

- all sales in one-way glass are diverted to refillables
- can sales are reduced to 10% of the market; the rest are diverted to refillables.

Table 46

1975 ENERGY SAVINGS IN CANADA FROM A RETURN TO 1958 PER CAPITA PACKAGING LEVELS

| | Amount of Packaging | | | Associated Energy | |
|---|---|---|---|---|---|
| | Estimated 1975 | @ 1958 Per Capita Levels | Reduction | Production Per Ton ($10^6$ BTU) | Annual Saving ($10^{12}$ BTU) |
| | tons | | | | |
| Paper | 3,098,000 | 2,365,000 | 733,000 | 40.8 | 29.9 |
| Steel | 528,000 | 403,000 | 125,000 | 29.6 | 3.7 |
| Aluminum | 35,000 | 26,000 | 9,000 | 196.6 | 1.77 |
| Plastics | 390,000 | 297,000 | 93,000 | 36.0 | 3.35 |
| Glass | 540,000 | 412,000 | 128,000 | 15.3 | 1.96 |
| Total | 4,591,000 | 3,503,000 | 1,088,000 | | 40.68 |

Source: Lowe, Energy Conservation Through Improved Solid Waste Management (5)

Table 47

ENERGY SAVINGS FROM INCREASED USE OF REFILLABLE SOFT DRINK CONTAINERS

| | Soft Drink Sales | | | Associated Energy | |
|---|---|---|---|---|---|
| | 1975 Estimated (Gallons) | 1975 Proposed (Gallons) | Reduction or (Increase) (Gallons) | Per Gallon ($10^3$ BTU) | Annual Saving ($10^{12}$ BTU) |
| Refillable 10 Ounce | 92,870,000 | 174,130,000 | (81,260,000) | 41.4 | (3.36) |
| One-Way Glass 10 Ounce | 21,559,000 | - | 21,559,000 | 91.2 | 1.97 |
| Metal Can | 92,870,000 | 33,168,000 | 59,702,000 | 67.1 | 4.01 |
| Refillable Family Size | 23,217,000 | 109,453,000 | (86,236,000) | 28.4 | (2.45) |
| One-Way Glass Family | 86,236,000 | - | 86,236,000 | 79.6 | 6.86 |
| Bulk Sales | 14,925,000 | 14,925,000 | - | - | - |
| Total | 331,677,000 | 331,677,000 | | | 7.03 |

b. Soft Drink Carriers

Additional energy savings could be realized if all refillable bottles were sold in reusable, 3-trip carriers. These savings are outlined in Table 48 and amount to 1.53 x $10^{12}$ BTU per year.

Table 48

ENERGY SAVINGS FROM USING REUSABLE CARRIERS FOR SOFT DRINK BOTTLES

| | Proposed 1975 Sales | Energy Saving With 3-Trip Carrier | |
|---|---|---|---|
| | (000's gal.) | ($10^3$ BTU per gal.) | ($10^{12}$ BTU per year) |
| 10 Ounce Size - 10 Trip Returnable | 174,130 | 6.1 | 1.06 |
| Family Size - 15 Trip Returnable | 109,453 | 4.3 | 0.47 |
| Total | 283,583 | 10.4 | 1.53 |

c. Milk Containers

In calculating the energy savings from using refillable milk containers, the following assumptions are made:

- The 3-quart plastic pouch retains 5% of the market, the rest of its market share goes to the refillable 3-quart jug.
- All sales presently made in 2-quart glass bottles are diverted to the 3-quart jug.
- Half the sales presently made in 2-quart paperboard containers are diverted to the jug.
- One-quarter of the sales in the 1-quart paper and one-half of those in the 1-quart glass are diverted to the jug.

The energy saved by these measures are shown in Table 49. They amount to 0.234 x $10^{12}$ BTU per year.

Table 49

ENERGY SAVINGS FROM INCREASED USE OF REFILLABLE MILK CONTAINERS

| | Milk Sales | | | Associated Energy | |
|---|---|---|---|---|---|
| | 1975 (000's gallons) | Proposed 1975 (000's gallons) | Reduction or (Increase) (000's gallons) | Per Gallon Delivered ($10^3$ BTU) | Annual Saving ($10^{10}$ BTU) |
| 5 Gallon | 28,746 | 28,746 | - | 2.48 | - |
| 3 Quart Jug | 201,221 | 403,880 | (202,659) | 0.27 | (5.47) |
| 3 Quart Pouch | 160,977 | 28,746 | 132,231 | 0.76 | 10.01 |
| 2 Quart Paper | 68,990 | 34,495 | 34,495 | 2.56 | 8.83 |
| 2 Quart Glass | 11,498 | - | 11,498 | 2.84 | 3.27 |
| 1 Quart Paper | 80,488 | 60,366 | 20,122 | 2.57 | 5.17 |
| 1 Quart Glass | 8,624 | 4,372 | 4,312 | 3.68 | 1.59 |
| 1 Pint Paper | 5,749 | 5,749 | - | 3.86 | |
| 1/2 Pint Paper | 8,624 | 8,624 | - | 4.36 | |
| Total | 574,918 | 574,918 | | | 23.4 |

d. Reusable Corrugated Containers

The main potential for reuse of corrugated containers lies in the industrial and commercial sector for shipments from the can and bottle manufacturers to the food processors and bottlers. The food and beverage industry uses an estimated 695,000 tons of corrugated containers per year (36,61).

Different assumptions are made about the percentage of all trips that could be served by reusable containers making three trips and the energy savings that would be realized are outlined in Table 50. (Energy for one ton of corrugated containers has been previously estimated to be $40.8 \times 10^6$ BTU (12).

These energy savings could only be attributed to reusable corrugated containers that would be returned "free" in an empty truck that would otherwise have returned to the packing plant empty. It has been assumed, for the purpose of this study, that 10% of the trips made by corrugated containers could have been made in reusable containers.

Table 50

ENERGY SAVINGS FROM USE OF REUSABLE CORRUGATED CONTAINERS IN THE FOOD AND BEVERAGE INDUSTRIES

| % of Trips Made by Reusable Containers | Reduction in Corrugated Boxes (Tons/Year) | Annual Energy Savings ($10^{12}$ BTU) |
|---|---|---|
| 10 | 69,500 | 2.83 |
| 25 | 173,750 | 7.09 |
| 50 | 347,500 | 14.18 |

3. Packaging Redesign

a. Milk Containers

The "Ecopak" is a new half-pint container, taller and narrower than the conventional squat 1/2 pint pack. It is 2¼" square on the base instead of 3/4". It uses 31% less paper, 16% less plastic and 22% less energy than the squat pack. The Ecopak has been adopted by the Wells Dairy of Lemars, Iowa, primarily for use in the local schools (75).

If all milk now solid in 1/2 pint packs in Canada were to be diverted to the Ecopak, there would be a saving of $\underline{8.19 \times 10^9}$ BTU a year.

b. Soft Drink Cans

New lightweighting processes have (or will soon) reduced the energy requirements for soft drink (and beer) can manufacturing, as well as glass manufacturing (76).

Table 51

ENERGY FOR SOFT DRINK CONTAINERS
($10^3$ BTU Per Gallon)

| Container (12 Ounce) | 1975 Actual | 1980 Projected | Reduction |
|---|---|---|---|
| 10-Trip Refillable | 17.5 | 16.0 | 1.5 |
| One-Way Glass | 138.6 | 49.6 | 89.0 |
| All Steel Can | 49.2 | 39.8 | 9.4 |
| Aluminum Can | 76.7 | 54.3 | 17.4 |

Source: Bingham, T.H., et.al: Energy and Economic Impacts of Mandatory Deposits (76)

Had these energy reductions been achieved in 1975, the energy saved in soft drink deliveries would have been as outlined in Table 52 .

Table 52

ENERGY SAVINGS FROM SOFT DRINK CONTAINER REDESIGN

| | 1975 Sales (Estimated) (Gallons) | Energy Reduction ($10^3$ BTU per gal.) | Energy Savings ($10^{12}$ BTU per yr.) |
|---|---|---|---|
| 10-Trip Refillable | 92,870,000 | 1.5 | 0.14 |
| One-Way Glass | 21,559,000 | 89.0 | 1.92 |
| All Steel Can | 87,298,000 | 9.4 | 0.82 |
| Aluminum Can | 5,572,000 | 17.4 | 0.10 |
| Total | 331,677,000 | | 2.35 |

## 4. Larger Package Size

### a. Soft Drink Containers

In calculating the energy savings from increasing the average size of soft drink containers, the following assumptions are made:

- Half the sales in 10-ounce bottles are diverted to the family size.
- One-quarter of the sales in cans are diverted to family size, one-way glass bottles.

The savings that would be realized in this way are outlined in Table 53 and amount to $0.43 \times 10^{12}$ BTU per year. They would have been greater had there been no diversion of sales from cans to family size one-way glass, since the glass bottle, even though larger, uses more energy than the small can.

### b. Milk Containers

Since the three-quart plastic jug is both large and refillable, the energy savings resulting from using larger milk containers have already been calculated. They amount to $.234 \times 10^{12}$ BTU per year.

Table 53

ENERGY SAVINGS FROM A MOVE TO LARGER SOFT DRINK CONTAINERS

| | Sales | | | Associated Energy | |
|---|---|---|---|---|---|
| | 1975 Estimate (000's Gal.) | 1975 Proposed (000's Gal.) | Reduction or (Increase) (000's Gal.) | Per Gallon Delivered ($10^3$ BTU) | Annual Savings ($10^{12}$ BTU) |
| 10 OUNCE | | | | | |
| Refillable - 10 trips | 92,870 | 46,435 | 46,435 | 41.4 | 1.92 |
| One-Way Glass - 10 Ounce | 21,559 | 10,780 | 10,779 | 91.2 | 0.98 |
| Metal Can | 92,870 | 69,652 | 23,218 | 67.2 | 1.56 |
| 40 OUNCE | | | | | |
| Refillable - 15 trips | 23,217 | 69,652 | (46,435) | 28.4 | (1.32) |
| One-Way Glass - Family Sjze | 86,236 | 120,233 | - | | |
| BULK | | | | | |
| Bulk Sales | 14,925 | 14,925 | - | | |
| | 331,677 | 331,677 | - | | 0.43 |

## D. PRODUCT REDUCTION

### 1. Passenger Car Tires

If a 100,000 mile tire were fitted as standard equipment on all new cars, and all replacement tires were 27,000 mile retreads, tire production would decline 58% within 12 years (74). If the 100,000 mile tire had been introduced in Canada in 1963, the energy savings in 1975 would have been $15.12 \times 10^{12}$ BTU/year. Had the tire been introduced in 1970, the savings in 1975 would have been $7.56 \times 10^{12}$ BTU/year.

### 2. Durable Plates

There are $4.16 \times 10^{9}$ paper dishes used in Canada each year. The energy saving per use as a result of a switch from paper to a durable plate is between 500 and 1300 BTU. Assuming that the average saving is 900 BTU, the total energy that could be saved in Canada by switching various percentages of present paper plate users to durable crockery may be as outlined below:

| Users Switching to Durable (%) | Energy Saved ($10^{12}$ BTU/Year) |
|---|---|
| 5 | .187 |
| 10 | .374 |
| 25 | .936 |
| 50 | 1.872 |

### 3. Washable Diapers

Energy savings are only realized by switching from disposable paper to washable cloth diapers if the cloth diaper is washed in water heated by gas, and dried in a gas drier.

It is unlikely that there are any savings to be made in Canada, where electricity is widely used for water heating, and even more extensively for clothes drying.

## 4. Washable Kitchen Towels

Whether or not there are energy savings from using washable cloth towels depends entirely on how often they are washed - or, put another way, on how many sheets of paper towel are needed to do the work of one cloth towel. If a cloth towel can do the mopping and drying work of 24 sheets of paper towel, then there will be energy savings from using cloth towels, but how large these savings will be is complicated to estimate, since it depends on the washing and drying machines used.

Peter Middleton and Associates Limited
*environmental consultants*

## NET ENERGY SAVINGS FROM SOLID WASTE MANAGEMENT OPTIONS

Information Required from Selected Pulp and Paper Mills

A. MILL LOCATION ____________________

NAME OF COMPANY ____________________

ADDRESS ____________________

____________________

LIAISON OFFICER ____________________ TELEPHONE ____________

B. GENERAL PROCESS DESCRIPTION

Indicate by circling those processes utilized at your mill:

debarking, chipping, pulping (mechanical, kraft, sulphite, semichemical), bleaching (semi, full), deinking, black liquor recovery furnace, hog fuel burner, electricity generating system, paper production, paperboard production, conversion to final product, chemical byproducts, other - (specifiy) ____________, ____________

____________, ____________, ____________

C. RAW MATERIAL INPUTS TO THE MILL

Roundwood ____________

Wood Chips ____________

Wood Residue ____________
(from plywood, veneer or saw mill operations)

Chemicals (specify)

____________

____________

____________

Waste Paper ____________

Virgin Market Pulp ____________

Other Fibres ____________

____________

____________

____________

____________

NOTE: All quantities reported in this questionnaire should be expressed on either a yearly or per ton of finished product basis.

D. ENERGY INPUTS

Oil ______________________ Grade ______________________

Natural Gas ______________________

Coal ______________________ Grade ______________________

Electricity - Purchased __________

-Self-generated __________ Specify source (hydro, steam from ______________________)

Steam - Purchased __________

- Self generated:

Recovery Boiler __________

Hog Fuel Burner __________

E. MATERIAL OUTPUTS

Market Pulp ______________________

Paper Products (Specify)

______________________ ______________________

______________________ ______________________

______________________ ______________________

______________________ ______________________

Paperboard Products (Specify)

______________________ ______________________

______________________ ______________________

______________________ ______________________

______________________ ______________________

Secondary Outputs (Chemicals, Etc.)

______________________ ______________________

______________________ ______________________

______________________ ______________________

______________________ ______________________

PLEASE RETURN THIS QUESTIONNAIRE TO:

Peter Middleton & Associates, Limited
6 Crescent Road, Suite 2B
Toronto, Ontario M4W 1T3 CANADA

Attention: Peter F. Love



December, 1975

Peter
Middleton
and
Associates
Limited
*environmental
consultants*

NET ENERGY SAVINGS FROM SOLID WASTE MANAGEMENT OPTIONS

Energy Recovery Systems Questionnaire

1. NAME OF COMPANY ____________________

ADDRESS ____________________

____________________

LIAISON OFFICER ____________ TELEPHONE ____________

2. GENERAL DESCRIPTION OF PROCESS
(May be provided by press release or standard brochure, supplemented by comments, if desired.)

____________________

____________________

____________________

Anticipated or Actual Operating Times ____________________

Maintenance Time - Scheduled ____________________

- Unscheduled ____________________

3. SYSTEM INPUTS

Prime

. Solid Waste (Describe the treatment of the waste before processing in recovery unit unless covered in #2.)

____________________

____________________

Flow Rate into process ____________________

(If additional space is required for comments, use the backs of these sheets or additional sheets, if necessary.)

Prime continued

Heating Value ____________________

Basis ____________________

Proximate Analysis - Moisture __________ %

- Volatiles __________ %

- Fixed Carbon __________ %

- Inert __________ %

Installed Horsepower of Front End Equipment:

By Item ____________________

____________________

____________________

Conveyors ____________________

Driven by Electricity or ____________________ ?

Other Inputs

Purchased Electricity __________ Kwh/Month or Kwh/Ton Waste

Auxiliary Fuel 1) Burner Rate ____________________

Type ____________________

HV ____________________

2) Handling Equipment (Dozers, Loaders, etc.)

Rate ____________________

Type ____________________

HV ____________________

Process Water: Rate __________ Gallon/Day or Gallon/Ton Waste

Temperature ____________________

Other Inputs continued

Process Gases: Oxygen - Rate ______________________

Air - Rate ______________________

Other? - Rate ______________________

4. SYSTEMS OUTPUTS
(that actually leave or could leave the premises)

Principal Output

Steam _____, Electricity _____, Fuel _____, Materials _____
(Choose One)

Describe all outputs:

Steam: _____ °F _____ psig ______________ condition

Rate _______ lb/hr or ____________ lb/ton of waste

Electricity: _________ kw _________ volts

Fuel: Type __________________ Rate __________________

Heating Value ______________________________

Other Specifications ___________________________

______________________________________________

Anticipated or Actual Use ______________________

______________________________________________

Materials: (Indicate Rate)

Iron _________ Aluminum _________ Glass _________

Char _________ Paper _________ Ash _________

Other ______________________________________________

Comments: (Include markets if possible)

______________________________________________

______________________________________________

______________________________________________

______________________________________________

Other Outputs:

Stack Gases: Temperature ______

Flow Rate ______

Analysis ______

______

Dust Content ______

Water: Temperature (if above intake) ______

Flow Rate ______

Disposal Location ______
(Sanitary Sewer, Natural Water, Etc.)

Analysis ______

______

______

PLEASE RETURN THIS QUESTIONNAIRE IN THE ENCLOSED,
SELF-ADDRESSED ENVELOPE TO:

Peter Middleton & Associates, Limited
6 Crescent Road, Suite 2B
Toronto, Ontario M4W 1T3

Attention: Grant Slinn

APPENDIX H

CONVERSION FACTORS AND BASE DATA

Metric - British Units Conversion Factors

| | | |
|---|---|---|
| 1 gigajoule (GJ) | = | 0.9479 x $10^6$ BTU (British Thermal Unit) |
| 1 x $10^6$ BTU | = | 1.055 GJ |
| 1 tonne (metric) | = | 1.1023 tons |
| 1 ton | = | 0.9072 tonne |
| 1 GJ/tonne | = | 0.8599 x $10^6$ BTU/ton |
| 1 x $10^6$ BTU/ton | = | 1.163 GJ/tonne |
| 1 mile | = | 1.609 km. (kilometres) |
| 1 km. | = | 0.6215 miles |
| 1 imperial gallon | = | 4.545 litres |
| 1 litre | = | 0.22 imperial gallon |

Table 54

FUEL AND ENERGY FACTORS

Fossil Fuel Energy

| | DISTILLATE OIL INDUSTRIAL HEATING 1000 Imperial gallons | | | RESIDUAL OIL INDUSTRIAL HEATING 1000 Imperial gallons | | | NATURAL GAS INDUSTRIAL HEATING 1000 cu. ft. | | | COAL INDUSTRIAL HEATING 1000 lb. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Pre-combustion | Combustion | Total | Pre-combustion | Combustion | Total | Pre-combustion | Combustion | Total | Pre-combustion | Combustion | Total |
| Energy - $10^6$ BTU | 23.88 | 166.80 | 190.68 | 23.88 | 180.80 | 204.68 | .056 | 1.000 | 1.056 | .2 | 13.0 | 13.2 |
| Atmospheric Emissions - lb. | | | | | | | | | | | | |
| Particulates | 5.04 | 18.00 | 23.04 | 5.04 | 27.60 | 32.64 | .003 | .018 | .021 | 2.0 | 21.0 | 23.0 |
| Sulfur Oxides | 38.04 | 170.40 | 208.44 | 38.04 | 300.00 | 338.04 | .012 | - | .012 | 1.5 | 42.0 | 43.5 |

| | GASOLINE IN TRUCKS 1000 Imperial gallons | | | DIESEL IN TRUCKS 1000 Imperial gallons | | | DIESEL IN RAIL 1000 Imperial gallons | | |
|---|---|---|---|---|---|---|---|---|---|
| | Pre-combustion | Combustion | Total | Pre-combustion | Combustion | Total | Pre-combustion | Combustion | Total |
| Energy - $10^6$ BTU | 23.88 | 149.70 | 173.58 | 23.88 | 166.80 | 190.68 | 23.88 | 166.80 | 190.68 |
| Atmospheric Emissions - lb. | | | | | | | | | |
| Particulates | 5.04 | 13.20 | 18.24 | 5.04 | 15.60 | 20.64 | 5.04 | 30.00 | 35.04 |
| Sulfur Oxides | 38.04 | 7.20 | 45.24 | 38.04 | 32.40 | 70.44 | 38.04 | 68.40 | 106.44 |

Table 54 (continued)

FUEL AND ENERGY FACTORS

ELECTRICITY FROM COAL

1000 kwh

| | Pre-combustion | Combustion | Total |
|---|---|---|---|
| Energy - $10^6$ BTU | - | - | 10.50* |
| Atmospheric Emissions - lb. | | | |
| Particulates | 1.62 | .72 | 2.34 |
| Sulfur Oxides | 1.21 | 32.00 | 33.21 |

* includes 10% transmission and distribution losses

Non-Fossil Fuel Energy

| | BARK (50% moisture) 1000 pounds | WOOD (50% moisture) 1000 pounds | SOLID WASTE 1000 pounds |
|---|---|---|---|
| Energy - $10^6$ BTU | 5.25 | 4.50 | 5.00 |
| Atmospheric Emissions - lb. | | | |
| Particulates | 7.50 | 4.00 | 0.75 |
| Sulfur Oxides | 0.75 | 0.75 | 0.75 |

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