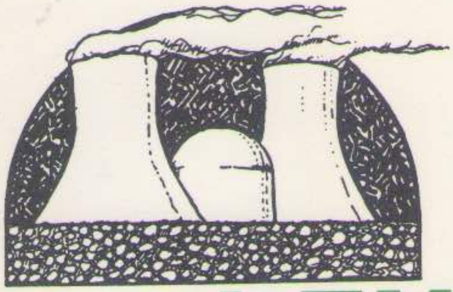
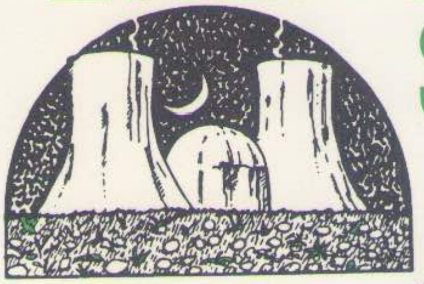
XI CONFERÈNCIA CATALANA PER UN FUTUR SENSE NUCLEARS I ENERGÈTICAMENT SOSTENIBLE



RESIDUS I ENERGIA



Dia 25 d'abril de 1997,

a les 17'30 hores

Sala d'Actes, Pati Manning del Centre d'Estudis i Recursos Culturals (CERC),

Montalegre, 7 · Barcelona

ORGANITZACIÓ: Grup de Científics i Tècnics per un Futur No Nuclear - GCTPFNN. Apartat de Correus 10095 · 08080 Barcelona

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ONZÈ ANIVERSARI DE LA CATÀSTROFE DE TXERNÒBIL

XI CONFERÈNCIA CATALANA PER UN FUTUR SENSE NUCLEARS I ENERGÈTICAMENT SOSTENIBLE

RESIDUS I ENERGIA

Barcelona, 25 d'Abril de 1997

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1.- Presentació.

Enguany iniciem la segona dècada de Conferències Catalanes per un Futur Sense Nuclears, que des de la novena edició tenen un afegit en el seu títol que fa referència a la Sostenibilitat Energètica. I la sostenibilitat energètica de les ciutats, de les comarques i dels països implica que s'aprofitin les fonts d'energia locals, especialment les fonts d'energia netes i renovables. En anteriors edicions s'han tractat diverses fonts d'energia netes i renovables, especialment el vent, però també el sol, l'aigua, etc.

En aquesta onzena edició hem cregut convenient tractar de forma monogràfica el tema dels residus municipals i la seva vessant energètica. Es parla molt de valoritzar els residus. També es parla de valoritzar-los energèticament, es a dir recuperant part del seu contingut energètic. Si be la idea pot semblar atractiva, i hi ha grups de pressió que estan capficats en dur a la pràctica una determinada forma de valorització: la incineració indiscriminada dels residus. Per una altra part, cal ser conscients que incinerar els residus municipals de forma indiscriminada pot ser, i a la pràctica és, una insensatesa ecològica, a més d'econòmica.

Per situar el debat al nivell que cal, hem convidat al Dr. Jeffrey Morris, de Sound Resouce Management, amb seu a Seattle, que té una gran experiència en fer valoracions comparatives des de'l punt de mira energètic, de les diverses opcions per a tractar els mal anomenats residus. I diem 'mal anomenats' perquè aquests materials no són altra cosa que materies primeres i recursos que cal recuperar.

Arreu del nostre país es produeix matèria orgànica residual que és exiliada cap als abocadors (que ara per fer-los més presentables, se'ls ha batejat amb el nom de 'controlats') o que és cremada en els forns crematoris de les incineradores, quan aquesta metèria orgànica està simplement formada per nutrients, que haurien de retornar al sòl per a mantenir la seva fertilitat i així poder oferir a la humanitat el servei que des de sempre el sòl li ha fet: produir aliments sans i saludables. Tancar el cicle de la matèria orgànica es pot fer mitjançant el compostatge (descomposició en presència d'aire) o amb la metanització (digestió anaeròbia). Aquesta segona via té l'avantatge que produeix un gas, anomenat biogas, que conté una gran proporció de metà (el gas natural fòssil que importem també és metà).

Produir energia i retornar els nutrients al sòl és un dels reptes que les nostres societats han d'afrontar si de debó volen fer via pel camí de la sostenibilitat. Per això hem convidat a l'associació SOLAGRO, amb seu a Tolosa de Llenguadoc, i a l'empresa STEINMÜLLER-VALORGA de Vendargues perquè són les entitats que a Europa tenen més experiència en la valorització energètico-ecològica dels residus orgànics.

La via del biogas ha estat massa amagada i massa marginada perquè continui essent desconeguda la seva realitat actual. També per això hem possibilitat la presentació a Barcelona de la veterana revista francesa dedicada a les energies renovables: SYSTEMES SOLAIRES, que ha dedicat recentment un número monogràfic a explicar la realitat d'aquest gas natural renovable que tenim a l'abast i no aprofitem, la qual cosa fa que tinguem problemes de contaminació greus. L'aplicació de la via biogas pot representar una ajuda a la transició des de la insostenible situació energètica actual cap a una situació on les energies netes i renovables siguin la base del funcionament de les nostres societats. I el metà renovable (a partir de tota mena de redidus orgànics, que avui són una font de problemes de contaminació) pot ajudar-nos a fer aquest camí.

Recycling Versus Incineration: An Energy Conservation Analysis

Prepared for:
Pollution Probe – Toronto, Ontario
Work on Waste USA – Canton, New York

September 1992

Sound Resource Management Group, Inc.

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EXECUTIVE SUMMARY

In Ontario Hydro's Twenty Five Year Demand-Supply Plan currently under adjudicatory review, the utility plans by the year 2000 to obtain over 90 Megawatts (MW) of generation capacity from incineration of at least 30% of Ontario's metropolitan area municipal solid waste (MSW) in large scale energy-from-waste (EFW) facilities. Ninety MW is an order of magnitude greater than municipal solid waste incineration capacity currently operating in the province. Ontario Hydro can use purchased power rate premiums and other incentives to encourage construction of new Non-Utility Generation (NUG) EFW facilities.

Waste that is incinerated cannot be reused or recycled. Furthermore, contractual arrangements between incinerator operators and local communities often require, either directly or indirectly, those communities to deliver guaranteed minimum amounts of waste, or pay for any shortfall. This practice, of course, financially restricts waste reduction and recycling that reduces a community's waste below the prescribed minimum tonnage.

Incinerator proponents may suggest that constraints on waste reduction and recycling can be justified by the electrical energy Ontario Hydro plans to obtain from NUG facilities that combust solid waste. Many of the materials in solid waste, e.g., paper and plastics, have substantial heating values. However, what we demonstrate in this report is that EFW is not an efficient source of electrical power. More energy can be conserved by recycling than can be generated by incinerating the various materials which make up Ontario's municipal solid waste. On average, we estimate that recycling saves three to five times as much energy as is produced by incinerating MSW.

Furthermore, energy conserved by manufacturing with recycled materials rather than virgin materials exceeds incineration energy by enough to pay the energy costs of shipping recycled materials to very distant markets. We estimate that on average recycled waste materials can be shipped over 12,000 kilometers (km) by truck, or 54,000 km by rail, before recycling's energy conservation savings are dissipated.

Based on a literature review, as well as our own primary research, Table E-1 provides estimates of energy conservation, in megajoules (MJ) per megagram (Mg)[1] , when 24 common MSW materials are substituted for virgin raw materials in manufacturing. For example, when ONP is substituted for wood pulp in producing newsprint, over 22,000 MJ are saved for each tonne of newsprint manufactured. Figure E-1 summarizes energy conservation for seven categories of waste, as well as an average for the entire waste stream.

These energy balances are based on primary energy used to extract, process and transport virgin raw materials, as well as full heat, light and power requirements of production processes for recycled- versus virgin-content products. Typically excluded from these calculations, however, is all energy required to make machinery or buildings, to feed production workers, and to manufacture all inputs used indirectly to produce the raw materials, intermediate goods and capital used directly to manufacture products. Because converting virgin materials is generally more capital intensive than converting secondary materials into final products, these energy conservation estimates are probably conservative.

Other complexities of calculating energy balances for recycled-content versus virgin-content products are discussed in detail in our report. But one important calculation should be mentioned in this summary. In some virgin manufacturing processes there is a substantial difference between total power requirements and externally purchased power, including fuels to generate power on site. The difference is explained by certain virgin material inputs, such as trees, which are purchased mainly to incorporate into products, say paper, but which also have substantial heating value and yield manufacturing byproducts and residues that can be combusted to generate on-site power. In this situation, external

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[1] MJ/Mg and kJ/kg are numerically equal measures for energy conservation or generation. Thus, MJ/Mg numbers for each waste material in Table E-1 of the summary and kJ/kg numbers in Table 1 of the report are the same.

energy purchases must be adjusted to get a true picture of the manufacturing process' total energy requirements.

For example, a recent report from International Paper estimated that "56 percent of the energy requirements in the average paper mill are met by wood residues and byproducts..."[2] The figures in Table E-1 for paper account for this internal energy generation by adjusting net energy requirements for recycled- versus virgin-content production with the energy value of trees not cut when recycled-content paper is produced. In making this adjustment, energy content of a tree is decreased to account for the harvest, chipping and transport of the tree wood to fuel markets. The fact that our study compares net energy conserved by recycling with energy generated by burning paper in an EFW facility allows us to count the energy value of the whole tree on the recycling side, because the energy value of the part of the tree actually converted into paper is taken into account by the energy yield when waste paper is burned in an EFW facility. This credits the virgin content and incineration side of the energy balance for that portion of the tree saved by burning paper to generate electricity.

As shown on Table E-1, energy conserved by producing recycled-content products ranges from a low of 582 MJ per tonne for recycled non-container glass used as a substitute for sand in construction aggregate, to a high exceeding 250,000 MJ per tonne for aluminum can sheet and other types of aluminum manufactured with recycled aluminum rather than virgin bauxite ore. As depicted on Figure E-1, energy conservation from recycling averages about 25,700 MJ per tonne for Ontario's residential waste stream.

Of course, energy is required to collect recyclable materials, prepare them for remanufacturing, and ship them to end users. Furthermore, energy generated from burning MSW at an EFW facility is not available when materials are recycled. On the other hand, recycling diverts materials from the refuse stream, thus saving some of the energy necessary to collect and dispose of MSW.

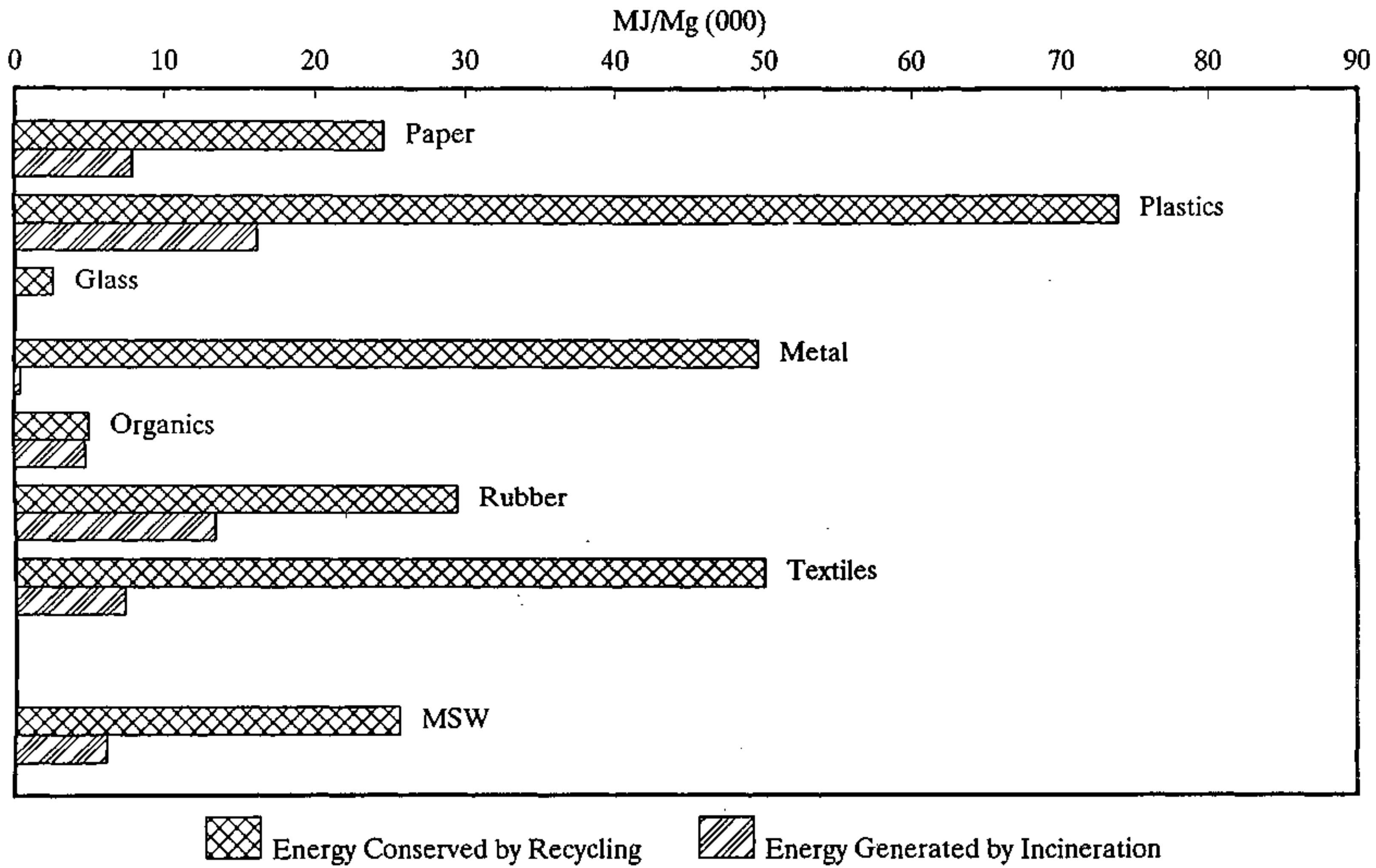
Table E-1 lists energy generated by incinerating the 24 different waste materials in mixed refuse, and Figure E-1 summarizes these estimates. Because landfilling would be less productive of energy than incineration, these data provide an upper estimate of energy available when MSW is disposed. Only for the organic components of MSW - food, yard and wood waste -- is energy generated from incineration close to or greater than energy conserved when waste materials are recycled.

Less than 200 MJ of incremental energy is required to collect and prepare the average tonne of recyclables for market. Shipping a tonne of recyclables one kilometer requires less than 2 MJ. Thus, even after deducting collection and processing energy, most waste materials can be shipped to markets across the ocean, and recycling still saves energy over simply collecting mixed refuse and disposing of it in an EFW facility. In fact, the date in Table E-1 conform quite well with customary practices in the recycling industry. Glass and compost, for example, are used close to the community in which waste glass or organic materials are generated. But paper, plastics, and aluminum cans are shipped to quite distant end-user markets.

[2] Wilfred Cote', *et al*, *Life-Cycle Assessment: Proceed with Caution.*

Table E-1 Energy Conserved in Recycled Content Manufacturing Compared with Energy from Waste Incineration

Waste Stream Materials	Energy Conserved By Substituting Secondary for Virgin Raw Materials	Energy Generated from MSW Incineration
	(MJ/Mg)	(MJ/Mg)
Paper		
Newspaper	22398	8444
Corrugated Cardboard	22887	7388
Office (Ledger & Computer Printout)	35242	8233
Other Recyclable Paper	21213	7600
Plastic		
PET	85888	21004
HDPE	74316	21004
Other Containers	62918	16782
Film/Packaging	75479	14566
Other Rigid	68878	16782
Glass		
Containers	3212	106
Other	582	106
Metal		
Aluminum Beverage Containers	256830	739
Other Aluminum	281231	317
Other Non-ferrous	116288	317
Tin and Bi-Metal Cans	22097	739
Other Ferrous	17857	317
Organics		
Food Waste	4215	2744
Yard Waste	3556	3166
Wood Waste	6422	7072
Rubber		
Tires	32531	14777
Other Rubber	25672	11505
Textile		
Cotton	42101	7283
Synthetic	58292	7283
Diapers	10962	10713



Averages based on Ontario residential waste composition.

Figure E-1 Energy from Recycling versus Incineration

I. Introduction

Ontario's electrical power utility, Ontario Hydro, proposes to use new Non-Utility Generation (NUG) sources to supply almost 13% of additional electrical power it projects needing in its twenty-five year demand/supply plan for the period 1989-2014. Incineration of municipal solid waste (MSW) in large scale energy-from-waste (EFW) facilities is expected to account for about 3% of NUG supply.[3]

In total, Ontario Hydro projects adding over 15,000 megawatts (MW) generation capacity through the year 2014. The utility projects over 200 megawatts potential power available from the province's MSW generation. Based on currently planned projects, and about 12 megawatts of in-service or committed MSW incineration capacity, Ontario Hydro expects over 90 megawatts to be installed by the year 2000.[4] At a rate of 45 tonnes per day (TPD) of MSW to provide 1 megawatt capacity,[5] 4050 TPD would need to be incinerated to provide up to 90 megawatts generation capacity.

Metropolitan Toronto and other large population centers in Ontario generate over 12,000 TPD of solid waste.[6] Thus adequate MSW is available from areas of high population density to make 90 megawatts mass burn incineration capacity practicable based on garbage collected from households and businesses, provided that waste reduction, reuse and recycling programs do not divert substantial amounts of waste away from the garbage truck. To encourage private development of MSW incineration capacity, Ontario Hydro has available subsidies, such as rate premiums paid for power purchases from NUG facilities and funds for consultant study assistance.

The issue we explore in this report is: Should Ontario Hydro be planning for and encouraging incineration of 30% or more of MSW from Ontario's metropolitan population centers?

In the analysis that follows we show that EFW is not an efficient source of electrical power, because energy expenditures can be conserved by recycling rather than incinerating the various materials that make up Ontario's municipal solid waste. In fact, for most waste materials, recycling can save many times more energy than is produced by incinerating mixed waste and recovering a portion of each waste material's heat value in the form of electrical energy. This is because burning garbage to generate steam and spin turbines in EFW facilities captures only about 15% of the burning materials' heat value. It is also because recycling these same waste materials saves substantial amounts of energy that would otherwise be expended in extracting virgin resources to make products that can be manufactured from recycled waste materials.

In sum, we estimate that recycling saves three to five times as much energy on average as is produced by incinerating MSW. Building or retrofitting manufacturing facilities in the province to use 720 to 1200 TPD of recycled (secondary) materials in place of virgin resources could eliminate Ontario Hydro's need to encourage construction of an additional 80 megawatts of EFW capacity to incinerate 3600 TPD of solid waste.

---

[3] NUG is electrical generation in Ontario owned and operated by electricity producers other than Ontario Hydro, such as private and municipal utilities and private power producers. Ontario Hydro expects an NUG mix of 18% hydraulic (i.e., hydropower), 74% natural gas cogeneration, 4.6% wood waste and 3.4% municipal solid waste incineration and/or landfill gas production. (*Providing the Balance of Power - Ontario Hydro's Plan to Serve Customers' Electricity Needs - Environmental Analysis*, p. 4-3.)

[4] *1990 Non-Utility Generation Plan*, Ontario Hydro, September 1990, pp. 2 and 7.

[5] Ontario Hydro, *Energy from Municipal Solid Waste Issues*, Mechanical and Engineering Department, December 1989, p. 30.

[6] Rawson, K.L., Ontario Hydro, *Energy from Waste - A Canadian Perspective*, Proceedings of the American Power Conference, 1990.

II. ENERGY BASED AND MARKET PRICE BASED THEORIES OF VALUE

A. The Perfect Market Price Yardstick

In an economist's perfect world, the most valuable use for any material would be determined by the market; and all costs and benefits of manufacturing products from virgin versus secondary (recycled) materials would be reflected in the relative prices for each type material. To understand how the economist's perfect world would work in the markets for, say, old newspaper (ONP), consider the following example:

Substituting ONP for timber as a raw material in making newsprint would eliminate many production costs that would be charged to newsprint producers in a perfect world: reforestation, repair of damage to soil and rivers from erosion, abatement of air and water effluent from pulping operations, etc. If using ONP to make newsprint did not entail significant increase in other production costs, then paper mills would be willing to pay more for ONP than they pay for timber, up to the amount of the benefit in lower production costs. If the cost of separating ONP from the solid waste stream were less than this benefit, then the ONP price would rise just to the point where it encouraged careful separation of ONP and delivery to paper producers. (Newsprint producers might even relocate plants nearer to the "urban forest," their new raw material supply source.)

In terms of incineration of MSW, we have to assume that, at some cost level, it is *possible* to fully avoid or abate air pollution and pollution from disposal of the ash. Then, the decision to leave ONP mixed in MSW, and use MSW as a fuel to generate electricity, would depend on the relative costs of pollution elimination when burning MSW versus burning fuels more traditionally used to generate electricity. On balance, in a perfect world whether ONP would be used as a fuel to produce energy or as a raw material in papermaking would be determined by the market, based on the price for recycled ONP in comparison with MSW incinerator tipping fees.

Unfortunately, in the real world some costs borne by society are external to the market system, not charged to the producer, and thus not reflected in prices producers charge for their products. For example, the full cost of managing wastes and abating pollutants associated with production is seldom charged to the producer, and *never* the cost of disposal after a product has served its useful purpose and become waste. In fact, it is only recently that garbage collection and/or disposal charges to consumers have even begun to reflect more of the true costs of disposal, thus encouraging consumers to pick products that generate less waste.

Until all environmental costs of production are fully charged to producers, the market pricing system will fail to reflect our need for a clean environment. As we clean up dead lakes and rivers, install scrubbers to reduce smog and acid rain, and deal with leachate, methane and other landfill problems, we have begun to understand some of these previously uncharged costs of industrial production and garbage disposal. Only when zero discharge becomes the standard[7], will we know the full cost of clean production.

But even then the question of resource depletion will persist -- how can we charge for cutting old growth forest? Its loss affects not only those who benefit from the timber produced, but also animals and future generations who do not share these benefits, and are not able to bid the price of uncut old growth forest land up. The market, thus, substantially underestimates the full cost of current cutting of old growth forest.

[7] Some industrial leaders such as Northrup Industries have already adopted zero discharge as an acceptable standard. It may be only attainable in the long run, but it is a fine benchmark.

In the absence of perfect markets and pricing, one typically resorts to other means to judge whether recycled content is preferable to virgin content, and recycling preferable to incineration. A first alternative often is to use current prices and then note where obvious adjustments need to be made. If recycling is cheaper than incineration in today's markets, and if an analysis of the environmental impacts of recycling shows it to be preferable to incineration, then one concludes that recycling is better, even when using the crooked yardstick yielded by the current price system. Or if recycling is more expensive, but one estimates that uncharged environmental impacts of incineration versus recycling are large enough to offset recycling's extra cost, then one promotes recycling anyway, despite what market prices might dictate.

B. The Energy Use Theory of Value

This report is an analysis of Ontario Hydro's plan to use EFW as a source of electrical power, so we decided to provide the analysis of recycling versus incineration in terms of a measure of value different than market price or economic cost. For an electrical power plan, energy is a particularly appealing yardstick (or numeraire). We computed energy produced by burning solid waste materials, and compared the results to net energy used or saved by recycling. The kilowatt hours (kWh) or kilojoules (kJ) dictated winners and losers.

However, just as there is no economically perfect monetary yardstick, there is no 100% accurate energy yardstick either. It is a detailed, but not impossible, task to compute energy inputs into a production process, say, how much oil, coal, natural gas and electricity is used to produce a tonne of newsprint from trees versus ONP. Given the amounts in kilojoules of oil or coal or natural gas that must be burned to produce a kilowatt of electricity, we can sum up energy use and compare relative energy costs in terms of fossil fuel equivalent kilojoules required to produce newsprint using trees versus ONP.[8]

But what about human labor inputs needed to produce that tonne of paper? Or the virgin tree inputs themselves, or logging equipment, or transportation equipment, or tree chipping and pulping equipment, not to mention the newsprint machine itself and chemicals used to control various aspects of the strength and brightness for the finished roll of newsprint? Then there are machines used to make machines, and those used to make machines that make machines....ad infinitum.

To deal with these complexities in computing energy usage, many analyses ignore all energy not used directly in the manufacturing process - e.g., energy required to mine, process and transport raw materials is left out. Furthermore, energy generated internally as part of the manufacturing operation may be ignored. Or sometimes only a specific type of energy input, for example, purchased electricity, is counted.[9]

Some analyses include energy used for raw material extraction, processing and transportation to the product manufacturing facility, but count only purchases of external energy inputs. Any energy generated within the process - for example, in papermaking by burning some of the tree instead of turning it all into pulp for paper - does not appear in the reported energy requirement for manufacturing

[8] Much of the literature we surveyed reported data in Btu's per pound or per ton. We have chosen to use kilojoules per kilogram (kJ/kg) as the energy yardstick or numeraire in this report to be consistent with metric system measurements reported in many Ontario-Hydro documents.

[9] This is the procedure Ontario Hydro used in comparing energy usage for producing newsprint from virgin versus secondary materials. In a report for Ontario Hydro, *The Ontario Newsprint Industry to the Year 2005 - Impact of Deinked Newsprint Trends*, prepared by Temanex Consulting (North Vancouver, B.C.), savings from using secondary fiber to manufacture newsprint are estimated to be from 3600 to 3960 kJ/kg of finished newsprint versus virgin stone groundwood production, and 6840 kJ/kg versus virgin thermomechanical pulp (TMP) production. These energy savings estimates are based on usage of purchased electricity by pulp and newsprint manufacturers. Any energy used in harvesting and transporting trees to the pulp mill, any non-electrical energy inputs to the pulping and newsprint making operation, and any energy generated internally from tree residues is ignored in these estimates.

the product.

In this study we attempted to include all energy used to extract, process and transport the major raw materials used to manufacture Ontario's basic waste stream categories (e.g., newsprint, corrugated cardboard, HDPE plastic containers, tires, or cotton textiles), and as well, to include production process heat, light and power requirements. Also, if a virgin raw material, such as a tree, has significant energy value and is only partly consumed as a raw material in making products, while the remainder is consumed to provide process energy or ends up as a waste residue, then we counted that amount of the raw material as part of the total energy consumed to manufacture the product from virgin raw materials. When recycled materials are substituted for virgin resources, this methodology gives due credit to recycling for both the lower energy intensity of material extraction and manufacturing processes that use recycled materials, as well as for the virgin material resources that are left undisturbed for future use.

For non-energy inputs, we ignored the energy used to make machine's and buildings, as well as energy required to support the lifestyles of humans providing labor inputs.[10] Typically, energy used to produce purchased materials used in the manufacturing process, other than virgin raw materials, is not counted either.

Where we used secondary information sources, we attempted to adjust their estimates when we detected that a source's methodology violated these specifications. For example, we often encountered the practice of counting only external energy inputs when a raw material could be used as a fuel as well as a material input. That is, say, in virgin kraft paperboard manufacturing, the virgin kraft (sulfate) chemical pulping process yields about 50% of input wood chips as output pulp product.[11] Much of the tree is not turned into pulp, and wood residues and black liquor from the chemical pulping process are used as fuels to run the pulping process itself. As a result, some comparisons of purchased energy for virgin kraft versus recycled linerboard show that more energy is required for recycling.[12] However, these comparisons ignore the energy value of the tree that is not cut when recycled content linerboard is produced. Adding this energy value to the recycling side puts recycling ahead of virgin kraft linerboard production.

To summarize, in this study we present comparative energy figures that include energy required to extract raw materials, as well as production process energy consumed. For production process energy, we added up the amounts of purchased energy and, in addition, added in any internal energy generation to determine total energy used to produce each particular material. We also attempted to present data for 100% virgin versus 100% recycled content production. We note in the text below where we have had to deviate significantly from this methodology.

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[10] Love, Peter, "Energy Savings from Solid Waste Management Options," *Resources Policy*, March 1978, P. 57, states, "...capital-related energy consumed by...newsprint...operations is less than 5% of the total energy consumed in the production of a ton of paper, and that capital-related energy consumption for energy recovery systems is about 1% of the fossil fuel equivalent energy produced. This order of magnitude has no substantial effect on the outcome of the comparison, especially since a large part of the capital for the two options is the same...

To the extent that the 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."

[11] Ince, P., and Klungness, J., "Economics of Increasing the Use of Recycled Fiber in Linerboard," *Tappi Journal*, Vol. 67, No. 8, August 1984, p. 62.

[12] For example, see Gunn, Timothy L., and Hannon, Bruce, "Energy Conservation and Recycling in the Paper Industry, *Resources and Energy*, September 1983.

C. Additional Notes on Methodology and Report Organization

In terms of transportation energy and energy consumed to produce a product, we have made additional simplifying assumptions appropriate to the scale and budget for this project. First, we have only examined the energy necessary to produce each basic waste stream material. We did not examine the additional energy required to produce the multitude of products that come from the basic material. For example, kraft paperboard is converted into everything from polycoated paper milk cartons to cardboard box linerboard. We focused our analysis on energy required to produce the kraft paperboard versus that required to produce recycled paperboard.

Second, we also had to include energy, say, required to harvest trees and transport them to the kraft pulping mill on the virgin side of the calculation. We included energy required to pulp trees on the virgin side, and energy required to pulp recycled corrugated cardboard on the recycled content side. But because we wanted to compare energy produced by incineration with energy saved by recycling, we compare the collection, processing and transportation energy for recovering corrugated from waste generators and delivering it in suitable condition for use in the recycled content paperboard mill, with energy required to collect, process and transport cardboard as a component of garbage to the incinerator. Those transportation energy expenditures are summarized in Table 2 which reports relative energy usages to collect and transport garbage versus collect and transport recyclables.

Thus our production side comparison table,Table 1, includes energy to transport virgin materials to the kraft pulp mill, but does not include energy to collect and transport recycled cardboard to the recycled content paperboard mill. Energy usage in transporting recycled cardboard is accounted for in Table 2. Transportation energy usages are all there, however, they have been divided between production and solid waste management. The movement of recycled materials to market was more appropriately included in the latter category, to facilitate comparison with the transport of garbage.

D. Conversion Factors

To add up energy used in production processes we had to convert oil, gas, coal, electrical, garbage, and other fuel inputs into a common energy denominator. The conversion factors we used are explained in this section. Various energy sources are converted from their original units (for example, short tons or tons, metric tonnes or tonnes, cubic feet, barrels, kilowatt hours) to a common thermal equivalent in kilojoules.

The conversion factors we used to convert to kJ are, as follows:[13]

- Petroleum products: 6115 thousand kJ per barrel.
- Coal: 21,028 thousand kJ per tonne.
- Fossil fuel-steam electric power: 10,807 kJ per kWh.
- Solid waste-steam electric power: 23,820 kJ per kWh.

The fossil fuel and solid waste to electricity conversion factors require some explanation. A 100% efficient conversion into electricity of heating value from a fuel would take place at the rate of 3596 kJ input fuel heating value per output kWh. However, any thermal process loses some heating value in the form of waste heat, e.g., turbines are not 100% efficient at turning steam into electricity. There are other factors, as well, that limit the efficiency with which a fuel can be burned to generate electricity. The 10,807 kJ on average required to yield a kWh in a fossil fuel boiler producing steam to turn a turbine and generate electricity is based on this type process having an average efficiency of just 3596/10807 = 33.3%.

Converting garbage into electricity is even less efficient than converting fossil fuels into electrical energy. Some waste stream materials, for example, wood waste or plastics, have higher kJ values that could be converted to electrical energy more efficiently were they to be burned separately.

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[13] The petroleum product, coal and fossil fuel-steam electric power conversion factors are based on Section 19, "Energy," *1990 Statistical Abstract of the United States*.

However, Ontario Hydro proposes to purchase electricity from mass burn incinerators which burn mixed waste (garbage). Here the seasonally changing, heterogeneous, and often wet mass of mixed solid waste materials is injected into the furnace apparatus; auxiliary fuels are sometimes required even to maintain an effective burn. The result is that only about 507 kWh's of electricity are produced for each tonne of garbage burned.

This electrical energy output is based on solid waste having an input heating value of about 12,100 kJ/kg. Thus, (12,100 kJ/kg x 1000 kg/tonne =) 12.1 million kJ input heating value is required to produce (507 kWh/tonne x 3596 kJ/kWh =) 1.8 million kJ output electrical energy per tonne of waste. This is an input/output efficiency of just 15%.[14] [15] In other words, almost 2 kilograms of waste, or 23,820 kJ of input heating value from MSW, is necessary to generate one kWh.

To take into account the inefficiencies in burning solid waste to generate electricity versus burning a fossil fuel to generate electricity for a production process, we adjusted the heating values of the various waste stream materials down by the ratio 10807/23820 = 45%. This yields heating values for incinerating solid waste to produce electricity that are comparable to heating values for fossil fuel inputs saved by manufacturing processes that use 100% secondary (recycled) materials instead of 100% virgin resources. The adjustment accounts for the relative inefficiency with which EFW facilities turn waste materials into electrical energy versus the greater efficiency with which conventional fossil fuel facilities generate electrical or production process energy.

To summarize, then, this report compares energy generated by incinerating solid waste with energy saved by recycling the various materials found in solid waste. Just as prices can be expressed in 1991 dollars, 1980 dollars, U.S. dollars, Canadian dollars, or Russian rubles, energy usage can be reported on a variety of bases -- e.g., kilojoules per kilogram or kWh per tonne. Most production process power and most electricity in North America is still generated by fossil fuels, so fossil fuel equivalent input heating values in kJ/kg is an appropriate numeraire for this study. Electricity generated from fossil fuels requires an estimated 10,807 kJ of heating value per kilowatt generated. EFW electrical generation is less efficient than fossil fuel powered electricity generation. Thus, the kJ heating value of MSW fuel must be decreased accordingly. Then comparisons can be made between energy produced by incineration and energy saved by recycling in terms of fossil fuel equivalent input heating values.[16]

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[14] In Camp, Dresser & McKee's *Draft Environmental Impact Statement* for the proposed Town of Oyster Bay, NY, EFW facility, net electricity generation for sale per tonne of processible solid waste was projected to be 507 Kwh. A 17 of Oyster Bay's processible waste was projected to have a heating value of 12, 095 kJ/kg, or 12.1 million kJ per tonne. Thus, a 15% efficiency factor is specified in the engineering design of this particular EFW facility. (See Camp, Dresser & McKee, *Town of Oyster Bay Draft Environmental Impact Statement for a Proposed Resource Recovery Facility*, March 1988, pp. 4-125.) A United States Environmental Protection Agency publication, "Reusable News," calculated that EFW generates only about 475 kWh per tonne (EPA/530-SW-91-022, Fall 1991, p. 5). For calculations in this report we used the higher figure of 507 kWh per tonne.

[15] Shalaby, Amir, Ontario Hydro System Planning Division, "Role of Alternative Generation Sources in Ontario," paper presented at IEEE Power Engineering Society 1986 winter meeting in New York, NY, estimates that heating value of waste in urban areas is about 11,000 kJ/kg.

Pai, V., Ontario Hydro Mechanical and Equipment Engineering Department, "Energy From Municipal Solid Waste Issues," December 1989, p. 4, states, "The higher heating value of MSW, as received with typically 25 percent moisture is approximately 10,500 kJ/kg." Table 1 below shows Ontario's residential MSW to have an estimated average heating value of about 13,500 kJ/kg. This estimate does not adjust for the 25% moisture content of mixed garbage, which would lower the heating value of materials when they are mixed and moist.

[16] Alternatively, one could compare energy generation versus conservation in output kWh per input kg or tonne of waste material. We chose to use input heating values because it is not just electrical energy that is saved when recycled materials replace virgin resources in manufacturing products.

III. PRODUCTION PROCESS ENERGY SAVED BY USING SECONDARY MATERIALS

Table 1 lists the thirty-one waste stream categories we used to analyze energy generated by burning waste versus energy conserved by recycling waste. The categories include the materials that are most commonly recycled as distinct commodities. However, there are a number of less commonly recycled materials that are grouped together in some of the categories. For example, "Other Recyclable Paper" includes, among other paper products, telephone books, boxboard, junk mail and catalogs, all of which are sometimes recycled as separate commodities. Similarly, the "Other Non-Ferrous" and "Other Ferrous" metals categories include many metals that have well developed recycling collection and marketing infrastructures.

The main reasons for grouping some materials were lack of composition data, lack of specific data on energy savings, and lack of time and budget to develop the analysis for many more than thirty-one waste stream materials. Still, our analysis provides substantial new information based on primary research into energy saved by recycling some major waste stream components, such as yard, food and wood wastes. For the remaining waste stream materials we relied on secondary sources for estimates of energy conservation through recycling. We summarize this secondary information in our report by providing in Table 1 both the lowest and highest estimates we found in the literature for energy savings from recycling each specific waste material.

Table 1 also lists estimated waste composition percentages for Ontario for the 31 waste categories. These estimates are based on recently available composition data for major components of Ontario's residential and industrial/commercial/institutional (ICI) wastes, as well as on more detailed composition information on residential waste available from Volume I of the Ontario Waste Composition Study. We used the residential waste composition percentages given in the second column of Table 1 to compute the average energy generation and conservation estimates reported at the bottom of Table 1.[17]

The columns of Table 1 labeled "Mass Burn Incineration Energy from Waste" give energy content in kilojoules per kilogram for each waste stream category, excluding the five material categories that are not processible or not processed in mass burn EFW facilities. The "Heating Value" column's values reflect heat content for a kilogram of each waste material. These numbers can be compared to the heat content of a kilogram of such fossil fuels as coal or oil.

However, as discussed in Section I, a waste material's energy value is compromised when the material is incinerated with mixed waste in a mass burn EFW facility to generate electricity. In general, an MSW fired EFW facility is only 45% as efficient as a fossil fuel fired electric power plant. Thus, the kJ/kg values reported in the column of Table 1 labeled "Fossil Fuel Equivalent" are 45% of the values shown in the "Heating Value" column. These reduced energy content numbers represent estimates of the fossil fuel equivalent value of each waste material when it is incinerated in an EFW plant.[18]

As shown at the bottom of the "Fossil Fuel Equivalent" column of Table 1, Ontario's residential MSW has an average electrical energy productivity of over 6100 kJ per kilogram incinerated. The various materials range from a high of about 21000 kJ/kg for PET and HDPE plastics, to a low of about 100 kJ/kg for basically incombustible glass.

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[17] Volume II of the Ontario Waste Composition Study-*Commercial Waste Composition Study* was completed July 1991. Energy generation and conservation averages based on Ontario's ICI waste composition percentages rather than residential percentages would not alter any conclusion reached in this report.

[18] The 45% adjustment factor is derived in Section II. It was determined by a comparison of input kilojoules versus output electricity when fossil fuels are burned to generate power, with input kilojoules versus output electrical power when solid waste is burned at a mass burn incinerator.

Table 1 Energy Generated By Mass Burn Incineration versus Energy Conserved By Recycling

Waste Stream Materials	Ontario Provincial Waste Composition (1)	(2)	Mass Burn Incineration Energy from Waste: Heating Value(3) (kJ/kg)	Fossil Fuel Equivlnt(4) (kJ/kg)	Energy Saved When Recycled Into(5): Same Material/Use(6) Low Est. (kJ/kg)	High Est. (kJ/kg)	Other Materials (kJ/kg)
Paper	19.5% (7)						
Newspaper		10.3%	18608	8444	21450 (a)	23346 (b)	38600
Corrugated Cardboard	13.8% (8)	14.6%	16282	7388	13665 (c)	32108 (d)	38600
Office (Ledger & Computer Printout)		5.7%	18143	8233	34699 (a)	35786 (a)	38600
Other Recyclable Paper		4.8%	16747	7600	10318 (e)	32108 (d)	38600
Metallic, Plastic or Wax Coated		0.5%	17910	8127			38600
Total		35.8%	17331	7865	18863	30264 (f)	
Plastic							
PET		0.3%	46287	21004	60825 (g)	110950	
HDPE		0.9%	46287	21004	66058	82573	
Other Containers		0.2%	36983	16782	61639	64198 (h)	
Film/Packaging		4.3%	32099	14566	66058	84899	
Other Rigid		1.8%	36983	16782	41868	95887 (i)	
Total		7.5%	35669	16186	59934	87877	
Glass	3.0% (9)						
Containers		5.7%	233	106	907 (j)	5517	582 (k)
Other		2.1%	233	106			582 (k)
Total		7.8%	233	106	907	4209 (l)	
Metal							
Aluminum Beverage Containers		0.4%	1628	739	201562 (m)	312098 (m)	
Other Aluminum		1.1%	698	317	201562 (m)	360900 (n)	
Other Non-ferrous		0.1%	698	317	110148 (o)	122429 (p)	
Tin and Bi-Metal Cans		3.1%	1628	739	7094 (m)	37100 (m)	
Other Ferrous		7.7%	698	317	14496 (n)	21218 (n)	
Vehicular Batteries		0.5%	NP	NP	NP	NP	NP
Household Batteries		0.1%	NP	NP	NP	NP	NP
White Goods	1.0%	1.0%	NP	NP	NP	NP	NP
Total		14.0%	889	403	35150	64155	
Organics	16.0%	16.0%					
Food Waste			6048	2744			4215 (q)
Yard Waste			6978	3166			3556 (r)
Memo: MSW Compost							5548 (s)
Wood Waste	11.9%	11.9%	15584	7072	6422 (t)	6422 (t)	
Leather		0.1%	16747	7600	ND	ND	ND
Rubber							
Tires		0.9%	32564	14777	16265 (u)	48796 (u)	147800 (v)
Other Rubber		0.7%	25353	11505	25672 (o)	25672 (o)	
Textile		2.6%	16049	7283			
Cotton							42101 (w)
Synthetic					58292 (x)	58292 (x)	
Diapers	1.1%	1.1%	23609	10713	6801 (y)	15124 (z)	
Construction & Demolition Debris	0.6%	0.6%	NP	NP	NP	NP	NP
Small Quantity Hazardous		1.0%	NP	NP	NP	NP	NP
Total/Average		100.0%	13514	6132	20060	31270 (A)	

NP = not processible and/or not processed in mass burn EFW facility; ND = no data available.

Footnotes for TABLE 1

Notes: (1) Source: Ontario Ministry of the Environment, "Ontario's Waste Reduction Action Plan: Backgrounder," 02/21/91.
(2) Sources: "Residential Waste Composition Study, Volume 1 of the Ontario Waste Composition Study," and Ontario Ministry of the Environment, Ibid.
(3) Source: "Residential Waste Composition Study, Volume 1 of the Ontario Waste Composition Study," except tires heating value from phone conversation with Stuart Natof, U.S. Department of Energy.
(4) A new mass burn incinerator generates 507 kWh per tonne at 12095 kJ/kg, or 1825 kJ of output energy (at 3600 kJ/kWh) per kg of input waste. Thus, almost 2 kg of waste are required to produce 1 kWh, an input kJ to output kWh conversion rate of about 23,800 kJ of input waste per kWh of electrical energy produced. The kJ/kWh conversion factor for thermal power generation is typically 10,800. To put waste material heating values on a fossil fuel equivalent basis we adjusted heating values down by 10800/23800= 45.4%.
(5) Based on Office of Technology Assessment, "Facing America's Trash," 1989 unless otherwise indicated. Energy savings for recycling into other materials are based on most productive use. E.g., tissue and toweling papers are made from all types of recycled paper, so that 45,450 kJ/kg energy savings for 100% recycled content tissue paper versus 100% virgin wood content tissue is available for all types of recycled paper. Adjusting for 85% tissue output to waste paper input gives about 38,600 kJ saved per kilogram of waste paper input.
(6) These columns report the low and high estimates obtained from primary and secondary data sources.
(7) All paper types excluding corrugated cardboard and non-corrugated cardboard (boxboard).
(8) Commercial and institutional sector corrugated cardboard only.
(9) Commercial and institutional sector glass only.
(a) Peter Love, "Energy Savings from Solid Waste Management Options," Resources Policy, March 1978. Estimates include Love's calculation of the fossil fuel equivalent of trees not cut.
(b) Kunz, Regis D., and Mark R. Emmerson, "Energy Analysis of Secondary Material Use in Product Manufacture," CA Solid Waste Management Board, Nov.1979. Estimate of 5800 kJ/kg adjusted to include fossil fuel equivalent of 2.18 tonnes of trees not cut per tonne 100% recycled content newsprint, and old newspaper yield of 85% in remanufacturing newsprint (Gunn & Hannon, "Energy Conservation and Recycling in the Paper Industry," Resources and Energy, Vol.5, 1983, p.251,Table 4-Total Energy, Wood and Scrap Required...by Type of Paper&PaperBoard).
(c) Tellus Institute, "Inventory of Material and Energy Use & Air and Water Emissions from the Production of Packaging Materials," Draft October 1990.
(d) OTA estimate (from Gunn and Hannon, op.cit.) of 1093 kJ/kg adjusted to include the fossil fuel equivalent of trees saved by recycling. According to Gunn & Hannon, 3.64 tonnes of tree wood are required to produce one tonne of linerboard or food service board; 1.18 tonnes of recycled corrugated are necessary to make a tonne of linerboard. The fossil fuel value of wood is 9.5 million kJ/tonne.
(e) OTA estimate (from Gunn and Hannon) of 11,950 additional kJ to produce recycled boxboard adjusted to include fossil fuel equivalent of trees saved by recycling. According to Gunn & Hannon, 2.53 tonnes of tree wood versus 1.08 tonnes of recycled paper are required to produce a tonne of boxboard.
(f) Includes use of metallic, plastic or wax coated papers in tissue making.
(g) Jonathon Kimmelman, Natural Resources Defense Council.
(h) Based on 65% PVC, 25% polypropylene and 10% LDPE.
(i) Based on 25% each polystyrene, ABS, nylon, and polycarbonate. Production energy for latter three types from Martin Grayson (ed.), Recycling, Fuel and Resource Recovery: Economic and Environmental Factors, New York: John Wiley, 1984. Energy savings from recycling estimated at 90%.
(j) Stauffer, Roberta Forsell, "Energy Savings from Recycling," Resource Recycling, January-February 1989.
(k) Based on estimate by OTA, op. cit., p. 152, of energy required to obtain sand raw material for glass making.
(l) Includes use of other glass as construction aggregate.
(m) Center for the Biology of Natural Systems, "Development and Pilot Test of an Intensive Municipal Solid Waste Recycling System for the Town of East Hampton," Flushing, NY: Queens College, CUNY.
(n) Reid, George W., and Chan Hung Khuong, "Energy Conservation Through Source Reduction," Cincinnati, OH: Municipal Environmental Research Laboratory, U.S. EPA, EPA-600/8-78-015, November 1978.
(o) Leonard, LaVerne, "Specifying Metals for Recycling," Materials Engineering, September 1985.
(p) Energy savings for recycling copper: Reid, op. cit.
(q) Based on substituting an anaerobically produced soil amendment for peat. Estimates based on conversations in January and July of 1992 with Robert Legrand and David Chynoweth.
(r) Based on substituting an anaerobically produced soil amendment for peat. Estimates based on conversations in January and July of 1992 with Robert Legrand and David Cnynoweth.
(s) Based on substituting an anaerobically produced soil amendment for peat. Sources: R. Legrand, et al, "A Systems Analysis of the Biological Gasification of MSW and an Assessment of Proven Technologies," p.18, and updated estimates provided by Robert Legrand via telephone conversations in January & July of 1992.

Footnotes for TABLE 1 (continued)

(t) Reflects energy saved by using recycled wood in manufacture of particleboard. Sources: C. Boyd, P. Koch, et al, "Highlights from Wood for Structural and Architectural Purposes," Forest Products Journal, Feb. 1977; and conversations with wood recyclers and particleboard manufacturer.
(u) Based on 5 to 6 gallons fossil fuel energy to produce one tire, 3 to 4 gallons to retread, and an average tire weight of: 9.1 kilograms.
(v) Based on 70,000 to 233,000 kJ/kg to produce polyurethane, and substitution of tire rubber for polyurethane in composite at an energy cost of 3700 kJ/kg to recycle tires into surface treated rubber.
(w) Based on cotton rags used in manufacture of writing paper, and energy savings for recycled content writing paper as reported by Peter Love, op.cit.
(x) Reid and Khuong, op. cit., p. 32, average energy consumed in manufacture of four synthetic textiles (polyester, nylon, acrylic modacrylic, and olefin). Energy savings is for use of synthetics as rags versus using new synthetic textiles as rags.
(y) Energy to recycle disposable diapers in hypothetical facility reclaiming 4.5 tons per day of unbleached kraft pulp, which could be used again in disposable diapers or in a variety of paper products, from A. Little, Inc., "Report on Disposable Diaper Recycling Pilot Program," April 1991.
(z) Based on substituting reusable cloth diapers (at 167 uses per diaper) for disposable diapers (Lehrburger,C., "Diapers: Environmental Impacts and Lifecycle Analysis," January 1991). Assumes that cloth remaining at end of reusable diaper's life (approximately 50% of the original fiber)is recycled into cotton rags which are then used to manufacture writing paper.
(A) Includes energy savings from "Other Materials" column whenever "Same Material/Use" energy savings estimates are unavailable.

The last three columns of Table 1, labeled "Energy Saved When Recycled Into," provide estimates of energy saved when each waste material replaces appropriate virgin raw materials in manufacturing processes. Many waste materials can be recycled into a wide variety of new products. For example, ONP can be recycled into a variety of other products besides newsprint, such as paperboard, gypsum wallboard backing or cellulosic insulation. To account for this fact, the columns with the subheading "Same Material/Use" indicate energy saved when the product being manufactured is the same as the waste product being recycled, or can be used to fulfill the same final consumption need. For example, these columns give low and high estimates of energy saved by remanufacturing newsprint from ONP rather than trees.

We provide both low and high energy savings estimates, because the literature we surveyed, as well as our own primary research, yielded estimates of energy consumption for both virgin and secondary content manufacturing processes that varied quite widely. Reported and actual energy usage are both dependent on a wide variety of factors. For example, the specific type of manufacturing equipment used, the age of the production facility, the accuracy of records kept on energy inputs, the extent to which machinery substitutes for human labor, and relative prices for various energy resources, to name a few important variables, can have substantial impacts on energy usage and corresponding estimates of energy savings from recycling.

We did attempt to count both energy required to pull raw materials from on or below the planet's surface, as well as energy used directly in running the manufacturing process. We also attempted to adjust for process energy provided by using a portion of the input raw materials for fuel rather than material inputs. But estimates of energy savings from recycling remained widely disparate, so we give both low and high end estimates in Table 1.[19]

The last column of Table 1, subheaded "Other Materials," acknowledges the fact that some waste materials can be recycled into other products. For example, many recycled content paper or paperboard products are produced using a wide mixture of recycled paper and paperboard materials to produce the input pulp fibers. Similarly, ceramics and other non-container glass items, as well as mixed-color broken glass can be recycled into asphalt. Tires can be recycled to replace a portion of polyurethane and produce a rubber-polyurethane composite material. Cotton textiles can be recycled into writing paper. Synthetic textiles can be reused as rags. Diapers can be processed to separate the various materials used in their manufacture, and those materials remanufactured into new products.

Just as the economic value of a resource typically should be represented by the price paid for its highest and best use, so should the energy value of a waste material be represented by kilojoules saved when the material is used as a secondary input in the manufacturing process in which it yields maximum energy savings. Where we have estimates of energy savings for waste materials remanufactured into more than one product, we reported savings for that product in which energy conservation is highest. For example, recycled tissue and toweling saves more energy, 38,600 kJ/kg, versus its virgin content counterpart, than does any other major recycled content paper type for which we found energy savings data. All categories of waste paper shown on Table 1 can be recycled into some type of tissue or toweling. Thus, we report the 38,600 kJ/kg savings for tissue and toweling in the "Other Materials" column opposite all five waste paper categories in Ontario's MSW.

We now turn to a material by material review of energy produced by incinerating a material as part of mixed waste versus energy saved by recycling each material. The results of this review, however, are foreshadowed by noting that according to the averages for Ontario's residential waste given at the bottom of Table 1, recycling on average saves from three to five times the energy produced by burning mixed solid waste in an EFW facility.

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[19] For an example of a study, based solely on secondary sources, in which the author chose to list a point estimate for energy savings from using secondary materials in manufacturing, see David C. Wilson, "Energy Conservation Through Recycling," *Energy Research*, Vol. 3, 1979, pp. 307-323. Wilson's energy conservation estimates for recycled paper, glass and aluminum fall within the low-high ranges given in Table 1.

1. Newspaper

Newspapers traditionally have been used to make recycled paperboard and, to a lesser extent, to remanufacture newsprint. However, that is changing as more newspaper publishers in North America are beginning to order recycled content newsprint to help meet the solid waste diversion goals of the cities in which their papers are published.

The energy saved when old newspapers (ONP) are recycled into new newsprint is between 21,450 and 23,346 kJ/kg. The energy saved when old newspapers are recycled into tissue and toweling papers is 38,600 kJ/kg . This compares with an energy value of less than 8450 kJ/kg when newspapers are incinerated along with other mixed wastes in an EFW facility.

The high energy savings estimate of 23,346 for 100% recycled content newsprint is based on a study by Kunz and Emmerson, but it includes the fossil fuel equivalent of the 2.18 kg of trees not cut when newsprint is made from ONP rather than trees.[20] Kunz and Emmerson calculated that there was no energy expenditure to harvest trees for newsprint because the wood chips would come from sawmill residues. They estimated that raw material transport and manufacturing energy savings would total 5800 kJ/kg of recycled content newsprint.[21] To this estimate we added the fossil fuel equivalent of the 2.13 kg of trees not cut for every kilogram of recycled newsprint produced, after adjusting for an estimated 85% yield in transforming ONP into newsprint.

2. Corrugated Cardboard

Old corrugated cardboard (OCC) is extensively used to make recycled paperboard products, especially recycled corrugating medium (the corrugated middle layer in the common cardboard box). It also is used to make recycled content packaging papers, such as brown paper grocery sacks.

The energy saved when OCC is recycled into new corrugated cardboard is between 13,665 and 32,108 kJ/kg recovered. OCC can also be used to make certain industrial strength toweling papers at an energy savings of 38,600 kilojoules per kilogram of OCC substituted for virgin kraft wood pulp. At about 7400 kJ/kg generated through mass burning, recycling OCC saves between two and five times as much energy as incinerating OCC with mixed waste.

The Office of Technology Assessment (OTA) used a study by Gunn and Hannon[22] to estimate that the energy savings from recycling corrugated paperboard was only 1093 kJ/kg.[23] However, that estimate did not account for the trees saved when linerboard is made from OCC. As discussed in Section I, adding in the fossil fuel equivalent of trees saved by recycling increases estimated energy savings considerably. At a fossil fuel equivalent of about 9500 kJ/kg, and 3.64 kilograms of wood per kg of linerboard produced, this savings in trees has an energy value of over 31,000 kJ/kg OCC recycled, after adjusting for the 90% yield of OCC in remanufacturing linerboard.[24]

3. Office Papers

Office papers are often remanufactured into tissue and toweling papers. Only recently have many paper producers begun to experiment with recycled content printing and writing papers.

The energy produced by incinerating office papers, for example, white ledger or computer

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[20] See discussion of energy savings for corrugated cardboard for source of estimate for the fossil fuel equivalent of wood.

[21] Kunz, Regis D., and Emmerson, Mark R., "Energy Analysis of Secondary Material Use in Product Manufacture," Resource Conservation and Recovery Division, State of California Solid Waste Management Board, November 1979.

[22] Gunn, Timothy L., and Hannon, Bruce, "Energy Conservation and Recycling in the Paper Industry," *Resources and Energy*, Vol. 5, September 1983.

[23] Office of Technology Assessment, *Facing America's Trash: What's Next for Municipal Solid Waste?*, 1989, p. 144.

[24] Gunn and Hannon, *op. cit.*, p. 245 and Table 4, p. 251.

printout, is above 8200 kJ/kg when they are burned with mixed waste at an EFW plant. This compares with about 35,000 kilojoules saved per kilogram when office papers are recycled to make new printing paper, and 38,600 kJ/kg when office papers are made into tissue papers. Recycling office papers thus conserves more than four times the energy incinerating them produces.

4. Other Recyclable Paper

The category "Other Recyclable Paper" includes boxboard (non-corrugated cardboard, e.g., cereal boxes), telephone books, catalogs, magazines, junk mail and other used paper types that are not coated or lined with metallic, plastic or wax. Recycling mixed paper saves from 10,318 to 32,108 kJ/kg when recycled content boxboard is manufactured. In the past recycled board has been the major market for mixed waste paper. However, recycled content tissue and toweling mills are beginning to be an important market for mixed paper. When mixed papers are used to manufacture recycled content tissue and toweling papers, 38,600 kilojoules are conserved per kilogram recycled. This compares with 8127 kJ/kg produced by mass burn incineration.

OTA reported an estimate from Gunn and Hannon of 5,140 additional kJ/kg to produce recycled boxboard compared with 100% virgin wood pulp boxboard.[25] However, adjusting for the 2.53 kg of wood needed for each kg of virgin boxboard, adds about 24,000 kJ/kg to the recycling side of the energy balance equation. After adjusting for the 93% yield of mixed paper in producing recycled boxboard, counting the energy value of trees saved swings the net energy comparison to favor recycling, even when starting with the Gunn and Hannon estimate that recycled content boxboard requires more energy than virgin boxboard.

5. Metal, Plastic or Wax Coated Papers

Although paper materials such as polycoated paper milk cartons are not recycled to any major extent yet, there are a number of pilot projects in North America involving recovery of these multi-material paper wastes. For example, Edmonton, Alberta has a recycling program that includes coated paper milk cartons, which are baled and shipped to a Korean mill. There they are pulped, the coating materials separated from the bleached kraft fibers, and the paper pulp manufactured into tissue papers and bristol board.

As a second example, in the U.S. Northwest, Weyerhaueser and Tetra Pak have been conducting a pilot project to recycle milk, juice and paperboard containers for other liquids. Weyerhaueser repulps "gable-top" and other containers in its hydrapulper, separates plastic and aluminum from the paper fiber, uses the secondary fiber in its Longview, WA corrugating medium facility, and sells the plastic and aluminum to other recyclers.

A similar pilot program is underway in three Connecticut towns for 60,000 households. Drink boxes and milk cartons are included in regularly scheduled curbside pick-ups. Approximately three tons of these mixed material paper cartons are being recovered each week from these households.[26]

To account for the possibility of recycling these coated papers into tissue we have included the 38,600 kJ/kg savings for recycled content tissue papers in the "Other Materials" column of Table 1 opposite the metallic, plastic or wax coated paper category.

6. PET Plastics

Unlike paper and metals, which have been recycled by their respective industries for some time, plastics recycling is relatively new. The two most prominent plastics currently being collected for recycling are polyethylene terephthalate (PET) and high-density polyethylene (HDPE). Plastics recyclers function much like virgin plastic resin producers - each supplies plastic products manufacturers with the raw materials necessary to manufacture products.

Reprocessed resin from PET beverage containers is recycled into a variety of plastic products

[25] OTA, *op. cit.*, p. 144.

[26] *Recycling Times*, September 24, 1991, Vol. 3, No. 19, p. 7.

such as carpet fibers, rope, fiberfill, strapping, parking space bumpers, paint brushes and other plastic products. Like the other plastic solid waste categories listed on Table 1, PET beverage containers presently are not recycled back into beverage containers. But Eastman Kodak has recently obtained U.S. Food and Drug Administration approval to recycle PET for food packaging.[27] Also, products using recycled PET could use virgin PET resins in the manufacturing process, unlike tissue paper which cannot be made from used tissue papers.

For these reasons, we listed energy savings for plastic in the "Same Material/Use" columns of Table 1 and provide the minimum and maximum estimates of energy savings that we were able to glean from secondary literature. Recycled PET resins are estimated to save between 60,825 and 110,950 kJ/kg as substitutes for virgin PET resins. These energy savings are from three to over five times greater than the energy produced from PET plastics in a mass burn incinerator burning mixed garbage.

7. HDPE Plastics

HDPE plastic containers (food and non-food) are recycled into drain pipe, traffic barrier cones, flower pots, base cups for soft drink bottles, kitchen drain boards, milk bottle crates and other plastic products. Generally speaking, post-consumer HDPE resin is used to make lower grade products with less stringent performance and aesthetic specifications than products made from virgin HDPE resins.[28]

As shown in Table 1, recycled HDPE resins save between 66,000 and 83,000 kJ/kg reclaimed. This is three to almost four times the energy produced by burning HDPE in mixed waste at an EFW facility.

8. Other Plastic Containers

Other food and non-food plastic containers are made from polyvinyl chloride (PVC), polypropylene (PP) and low-density polyethylene (LDPE). At present there is not much post-consumer PVC recycling. However, PVC is considered environmentally unfriendly, so that major PVC resin suppliers all have projects under way to stimulate the recycling of this material.

Polypropylene is recovered from vehicle battery casings and about 40% of reclaimed polypropylene is remanufactured into new battery cases. The remaining recycled polypropylene is used in the manufacture of such consumer products as lawn mowers and flower pots.[29]

Virgin resin LDPE is used to manufacture grocery and dry cleaner bags to a much greater extent than it is used in container manufacturing. Other than collection programs for plastic bags and plastic lids at some retail stores, very little recycling of LDPE is currently underway. The LDPE that is collected is used to remanufacture polyethylene resin for general use, as well as for recycled content plastic bags.

The energy savings reported in Table 1 for container plastics are based on a 65% PVC, 25% PP and 10% LDPE mix for plastic resins used to manufacture containers that are not made from PET or HDPE. Energy saved by recycling is from 61,639 to 64,198 kJ/kg, compared with about 16,800 kilojoules generated by incinerating a kilogram of these type of plastic containers mixed in with garbage. Recycling is thus almost four times as productive of energy as is incineration for this waste stream material.

9. Film/Packaging Plastics

LDPE probably accounts for more disposed plastics than any other resin type. In its use for bags, sacks, films, wraps, coatings for paperboard containers (e.g., paper milk cartons), and box or sack liner, LDPE also probably accounts for more of the disposable film/packaging plastics than any other resins.

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[27] "Integrated Waste Management," October 2, 1991, pp. 2-3.

[28] New York State Department of Economic Development Secondary Materials Program, Technical Assistance Bulletin No. 3, *1990 Status of the Markets Report for: Paper, Metals, Glass, Plastics and Used Oil*, March 1991, p. 63.

[29] *Plastics Recycling Update*, Vol. 3, No. 9, September 1990, p. 5.

However, film and packaging plastics are also made from HDPE (bags and grocery sacks), PP (films and sheets), polystyrene (PS) (oriented film and sheet), PVC (film, sheet, blister packs) and PET (blister packs and coatings for ovenable paperboard). The fact that packaging plastics are so diverse and indistinguishable to most eyes requires that film/packaging plastics be recycled as mixed resins, unless they are collected through retail outlets which use a single resin type for their bags and sacks. Mixed film/packaging plastics are recycled into such products as plastic lumber, car stops and traffic barriers. There is technology to produce high-quality resin from mixed plastics; this resin cannot be used for film or bags but is suitable for making bottles.[30]

As shown in Table 1, film/packaging plastics are estimated to save between 66,058 and 84,899 kJ for every kilogram used in remanufacturing. This is four to six times the energy generated by incinerating these plastics in MSW.

10. Other Rigid Plastics

The energy savings reported in Table 1 for other rigid plastics are based on a mix of 25% each for polystyrene, ABS, nylon and polycarbonate. Recovery of each of these polymers is minimal at present, although polystyrene recovery is being aggressively promoted by polystyrene manufacturers. When these plastics are recycled, about 90% of energy used in their production from virgin raw materials is avoided.

11. Glass Containers

Container glass can be easily recycled as long as at is separated by color - flint, amber and green. Once chipped into cullet, container glass is simply substituted for silica sand, natural soda ash and other raw material inputs in making new glass containers.

Energy saved when container glass is remanufactured into new containers is estimated to be between 907 and 5517 kJ per kilogram of recycled content glass containers. Because most glass is manufactured using some recycled cullet, and because glass is apparently difficult to make using only recycled cullet, these energy savings estimates do not compare 100% virgin glass versus 100% secondary glass containers. Nevertheless, glass is virtually non-combustible, and recycling saves up to fifty times the energy produced by incinerating glass in mixed garbage.

12. Other Glass

Glass products (e.g., ceramics and window glass) other than glass containers can be used in road surfacing (glasphalt) and road bed materials. It is also being tried, along with mixed color container glass, as a substitute for construction aggregate.

Based on estimated energy needed to produce sand, all types of glass products yield energy savings of 582 kJ/kg when recycled as a construction aggregate. This is a savings of over five times the amount of energy produced by burning glass in mixed waste at an EFW facility.

13. Aluminum

Aluminum beverage containers and other aluminum scrap are extremely energy intensive products when manufactured from raw bauxite and other virgin raw materials. However, aluminum cans and aluminum scrap metal are rather easily resmelted into, respectively, new aluminum sheet for cans and ingot for other products. Energy savings are huge -- between 201,562 and 360,900 kJ/kg recycled. Although aluminum cans are somewhat more combustible than heavier aluminum products, they still yield less than 750 kJ/kg when burned as part of MSW. Recycling aluminum cans thus saves 275 to 425 times the energy generated by incinerating aluminum cans in mixed refuse.

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[30] Brewer, G., "European Plastics Recycling, Part 4," *Resource Recycling,* Vol. 6, No. 6, November/December 1987.

14. Other Non-Ferrous Metals

Non-ferrous metals other than aluminum are also readily recycled via resmelting and remanufacturing into the same types of products in which virgin ores appear. We use copper as a surrogate for the vast array of non-ferrous metals. Energy savings from recycling copper are estimated to be between 110,148 and 122,429 kJ/kg. Energy produced from incinerating non-ferrous metals is insignificant.

15. Tin Cans

Tin cans have traditionally been recycled at de-tinning plants where their tin coating is separated from their steel body content. More recently the capacity of electric arc furnaces and steel-making technology to handle tin contaminants has increased, so that tin cans are sometimes recycled directly into new steel.

Energy savings are estimated to be between 7,094 and 37,100 kJ/kg. As with glassmaking, in practice most steel contains recycled material so that comparing 100% virgin to 100% recycled steel is essentially impossible. Nevertheless, energy savings from increasing average recycled content in steel are still quite large because ferrous metals are virtually non-combustible.

16. Other Ferrous

Other ferrous metals (e.g., cast iron) also have a long tradition of being remanufactured into iron and steel products. Energy savings are estimated to be between 14,496 and 21,218 kJ/kg.

17. Organic Wastes

The organic fraction of solid waste can be broken down biologically and transformed into compost. Composting is a major recycling alternative to EFW for organic waste materials. Composting programs take several forms which vary depending on the types of materials composted and the level and stage at which compostable materials are separated from non-compostable materials, as well as from each other.

MSW composting facilities take in mixed solid waste, and then separate compostables from non-compostables at the facility. Often, municipal sewage sludge or high-nitrogen fertilizer is mixed with the compostables before composting.

Yard waste composting systems utilize yard wastes which have been source separated and collected separately from other wastes. Food waste composting programs often compost food waste along with yard waste or wood waste. In some cases, yard waste is collected along with, and in the same container, as the food waste; in other cases it is not.[31] (In most food waste composting systems, food waste must be combined with other material. Yard and wood wastes are good materials to co-compost with food waste since they facilitate aeration and provide the structural material needed to balance the high moisture content of food waste.)

Composting is a more common waste management strategy in Europe than in North America, though communities in the U.S. and Canada are building large-scale composting systems to manage their waste. In addition, numerous jurisdictions in Ontario provide financial incentives for individuals to purchase food waste and/or yard waste home composters.

MSW and yard waste composting operations are more abundant than food waste composting programs, especially in the U.S. While several studies have been published on the energy consumed to produce MSW compost, less research has been done on the energy needed to compost food and yard waste. While relying on previously published literature for energy estimates associated with MSW compost, we had to conduct original research to derive energy estimates for food and yard waste compost. We called engineers and composting technicians at a variety of food and yard waste

[31] "Survey of Existing Food Waste Programs for the New York City Dept. of Sanitation," Recourse Systems, Inc., April 1990.

composting facilities to inquire about the energy used by their operations. We also contacted a number of university and other experts about their research on compost energetics.

Compost meeting certain maximum levels of contamination with heavy metals and other impurities can be used for a variety of horticultural and agricultural purposes. Lower quality compost can sometimes be used as daily landfill cover or as a fuel source.

Compost is valued for its ability to improve soils and enhance plant growth. When used as a soil amendment, compost promotes the grouping of soil particles and creates spaces to facilitate water drainage and root development. In addition to aiding in aeration and drainage, the organic material in compost helps absorb and retain moisture for future availability to plants. Compost can prevent disease and inhibit weed germination. When used as a mulch, compost also helps prevent erosion and conserve water.

While valued most as a soil amendment, compost also contains major and minor nutrients required for plant growth. The nutrient values found in compost vary with the composting process and the nutrient content of the materials composted. In addition to providing nutrients, compost helps store nutrients supplied by fertilizers in the same way it holds moisture. This can reduce the frequency with which fertilizers need to be applied.

Researchers and practitioners have found that compost can be utilized as a substitute for peat on a volume-for-volume basis in soil mixes for use by landscapers, nurseries and gardeners.[32] In this study therefore, we compare the net energy used to turn organic waste into compost with the energy used to harvest and prepare peat for market.[33] These results are reported separately for MSW, yard waste, and food waste compost in the subsections that follow.

Except with plants preferring acidic soils, compost is often a better soil amendment than peat. This is because compost is usually somewhat higher in major nutrients than peat, has a more neutral pH, and has a carbon-to-nitrogen ratio that is more beneficial to plant growth. Additionally, applying compost avoids the environmental consequences associated with mining peat bog wetlands. Finally, compost can be used more extensively in large-scale agricultural applications because of its lower price and more neutral pH.

In agricultural applications, compost can be landspread to improve nutrient supplies and increase crop yields. Luis Diaz and his colleagues at CalRecovery, Inc. have pointed out that applying well-stabilized compost to crops can reduce energy consumption by 1) contributing additional nutrients to the soil, thereby decreasing the amounts of chemical fertilizer needed for crops, 2) increasing the efficiency with which chemical fertilizers are used, 3) decreasing the amount of energy needed to

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[32] The value of compost as a soil amendment in general and a peat substitute in particular is discussed in G.L., "Plant Nurseries Cut Costs with Compost," *Biocycle*, May 1991, p. 72; and "What Good is Compost," *Garbage*, July/August 1990, pp. 46-47. We also discussed the feasibility of comparing peat and compost with Elton Smith, horticulturist at Ohio State, Columbus, Ohio and Howard Stenn, composting trainer and horticulturist in Seattle.

[33] The horticulturists we consulted said that compost could be substituted for horticultural grade peat roughly on a volume for volume basis. Our analysis accounts for the fact that peat weighs about 38 percent as much as the same volume of compost, and the fact that it takes about 2 lbs. of MSW to produce 1 lb. of compost. Estimates on the amount of energy needed to harvest, process, and transport peat are based on information provided by a Project Manager employed by a large peat harvesting company in North America. This person requested anonymity. Data on energy used by the aerobic composting process and estimates of energy to transport compost to market are derived from "Energetics of Compost Production and Utilization," L.F. Diaz, C.G. Golueke, and G.M. Savage, *Biocycle*, September 1986, pp. 49-54. This article examines a system for composting a mixture of 80 percent MSW and 20 percent sewage sludge. Estimates of energy consumption and methane production associated with anaerobic digestion of MSW were derived from "A Systems Analysis of the Biological Gasification of MSW and an Assessment of Proven Technologies," by R. Legrand, T.M. Masters, and G.W. Fallon Hunter of Hunter, Reynolds, Smith and Hills, presented at the Conference on Energy from Biomass and Wastes XIII, New Orleans, LA, Feb. 13-17, 1989. R. Legrand, who is now with Radian in Austin, Texas, provided updated estimates of energy consumption via telephone (January, 1992).

prepare soils for planting, and 4) avoiding energy needed to compensate for soil fertility losses associated with erosion.

In an article published in 1986, Diaz and his colleagues illustrate the energy that may be saved by using compost to prevent erosion. They site studies showing that applying compost reduces erosion by 20 percent when conventional agricultural practices are followed to cultivate corn on fields having a slope of 6 to 10 percent. They estimate the associated energy savings that would otherwise have been expended to replace nitrogen and phosphorous in the lost soil would be equal to about 219 kJ/half year/kg compost applied or 133 kJ/half year/kg of waste processed. While this example may not be representative of all types of crops and conditions, it does suggest how much energy compost application might save by virtue of just one of its energy-saving capabilities.

While compost is produced aerobically (in the presence of oxygen), a valuable soil amendment very similar to compost can also be produced anaerobically (in the absence of oxygen).

Aerobic composting technology is well-developed and widely used in Europe, where around 400 MSW composting systems are currently operating. MSW and yard waste composting systems are also gaining popularity in North America. A variety of methods are used to compost organic wastes. For example, materials can be composted aerobically in turned or static windrows (piles), either of which are exposed to open air; or in enclosed vessels aerated with fans.

Anaerobic decomposition (also called "digestion" or "biogasification") is widely used to treat waste water solids, and, to a lesser extent, agricultural manure. Anaerobic treatment of solid waste is a newer, less well developed technology. However, some full-scale anaerobic MSW facilities are already operating on the European continent and others are planned. Experimental methods and pilot projects for anaerobic digestion of solid waste have also been developed in the U.S. Agricultural engineering researchers from the University of Florida at Gainesville have designed a full-scale anaerobic demonstration plant for which funding is being sought.

Though a newer technology, anaerobic digestion of solid waste offers potential net energy and economic advantages over aerobic composting, since anaerobic systems produce methane (natural) gas in addition to producing a compost-like soil amendment. The methane produced is contained in the gas tight digestion vessel used for the process. Once captured, the methane can then be used to fuel engines on-site or to fuel turbines at a neighboring utility. The methane can also be upgraded to pipeline quality, transported longer distances, and used for a variety of purposes such as generating electricity or fueling vehicles (when compressed). Anaerobically produced soil amendments may also be more beneficial to plants than aerobically produced compost, since the former are less likely to contain phytopathogens.[34]

While our text discusses energy savings both from aerobic composting and anaerobic digestion of organic materials, Table 1 reports energy savings from anaerobic digestion alone since this represents the best use of organic waste from an energy standpoint.[35] Our estimates assume that the methane produced by anaerobic digestion is transformed to electrical energy by using it to feed turbines at a neighboring utility or other facility.

It is important to note that the energy use figures provided in this section are for individual facilities (some actual and others hypothetical) and do not necessarily reflect the typical energy use of food waste or yard waste composting and digestion operations. Indeed, the amount of energy consumed by these systems depends on a variety of conditions including the processes used and the degree to which human labor is utilized to do work that could be done with machines. Thus, the fact that figures on the energy used to produce compost anaerobically are highest for food waste composting and lowest for MSW composting does not mean that this relationship is true for all facilities.[36] Still, where possible, we report on the energy consumption of individual facilities that we believe to be representative of large-scale composting operations.

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[34] Conversation with D. Chynoweth, University of Florida at Gainesville (January, 1992).

[35] See discussion of methodology in Section B of this report.

[36] The more vigorous odor control efforts often required when composting food waste may indeed make food waste composting more energy consumptive than yard waste composting.

17.1. MSW Compost

Substituting aerobically produced MSW compost for peat saves between 242 and 277 kJ/kg of material composted, depending on the particular type of system used. The energy saved by substituting aerobically produced compost for peat pales in comparison to the amount of energy derived from burning the organic fraction of MSW. Yet, anaerobic digestion of the organic fraction in MSW compares favorably to mass burn incineration, reflecting the fact that the anaerobic digestion process is a net producer of energy.

In an assessment of anaerobic digestion, Robert Legrand and his associates calculate that anaerobic decomposition of MSW generates a net 5,127 kJ/kg of material processed when the humus-like residue from the digester is dewatered, screened and cured to produce a compost-like material. When substituted for peat, anaerobically produced soil amendment saves about 5,548 kJ/kg of MSW.

Besides calculating net energy production associated with anaerobic digestion, Legrand and his colleagues also compare the amount of electricity a typical mass burn plant generates with the electricity that a biogasification facility produces. In this latter calculation, they assume that the methane produced from anaerobic digestion is burned to generate electricity in a combined-cycle gas turbine and that the residue from the digester is burned for fuel. Digestion under these circumstances is characterized by electricity generating efficiencies that are typically 35% higher than mass burning.[37] They also determine that anaerobic digestion of MSW with residue combustion is typically half as polluting as mass burn incineration of MSW.[38]

However, it is important to note that the inevitable presence of heavy metals and other contaminants in MSW compost raises a host of public health, environmental, economic and public policy concerns. Composting the entire waste stream as mixed waste may pose a threat to waste reduction and higher-end recycling. The relatively high level of contamination found in MSW versus yard and food waste compost also reduces the marketability of MSW compost. Better MSW compost can be produced by encouraging people to dispose of batteries and hazardous waste separately from MSW and by requiring separation of organic waste from the rest of MSW before collection.[39] Still, the least contaminated and most easily marketed compost is that which is derived solely from food and yard waste. Organic waste separation is becoming the norm across Europe and is supplanting MSW composting in many communities due to concern with compost quality. By 1988, at least 71 source separation projects were operating in the then Federal Republic of Germany.[40]

17.2. Yard Waste

We derived energy estimates on aerobic yard waste composting from a particular yard waste composting facility called Cedar Grove located near Seattle, WA. Accepting over 350 tonnes of yard waste per day, Cedar Grove's compost facility is one of the largest operations composting source separated yard waste in the U.S.

Brush, branches, leaves and grass clippings are the only materials composted at Cedar Grove. These are collected by Seattle's Clean Green program and include yard waste gathered from residences and from transfer stations. After arriving at the composting facility, the yard waste is shredded and formed into windrows on a concrete pad. Retention ponds collect the run off for monitoring and treatment. A scarab turns the windrows with rotating flails to aerate the composting materials. After

[37] R. Legrand, *et al* "A Systems Analysis of the Biological Gasification of MSW and an Assessment of Proven Technologies," p. 18.

[38] Legrand, *ibid*, p. 1.

[39] R. Legrand and J.F.K. Earle "Biological Stabilization of the Organic Fraction of MSW," p. 7; Clarence G. Golueke and Luis F. Diaz, "Source Separation and MSW Compost Quality," *Biocycle*, May 1991, pp. 70-71. E&A Consultants in Stoughton, MA are conducting a study to assess the extent to which separation at the source and at the facility impacts the level of metals in MSW compost. The study which reaches similar conclusions, will soon be available from E&A.

[40] "Survey of Existing Food Waste Programs for the New York City Dept. of Sanitation," Recourse Systems, Inc., April 1990.

two months of regular turning, the compost is cured for another month in static piles. It is then screened into separate grades ready for blending into topsoil or other horticultural products.[41]

Cedar Grove's manager provided information regarding the energy usage of their composting process. Based on this information, we estimate that all phases of their composting operation (including preprocessing, composting, and curing) consume about 76 Btu's per pound of yard waste composted.[42]

Substituting aerobically produced yard waste compost for peat represents a net energy savings of about 244 kJ/kg. As with MSW compost, the energy saved by substituting aerobically produced compost for peat is very small in comparison to the 3,166 kJ/kg of energy Table 1 suggests can be derived from burning yard waste.

Yet, yard waste can be digested anaerobically, just as MSW can. We were unable to locate any literature regarding the energetics of anaerobic yard waste digestion. Experts in anaerobic technology, Robert Legrand and David Chynoweth, provided assistance with deriving an estimate of the net energy produced when source separated yard waste is anaerobically digested. The estimate assumes that the amount of energy consumed in the digestion process would be approximately the same for MSW and yard waste. The estimate also assumes that approximately 40 percent of yard waste is dry and free of ash; and that 50 percent of the dry, ash free solids in yard waste are converted into methane.[43]

Based upon these assumptions, we estimate that anaerobic digestion of yard waste produces a net 3,135 kJ/kg of waste digested. Substituting anaerobically digested yard waste for peat would save about 3,556 kJ/kg of yard waste, which is about 10 percent more energy that a mass burn incinerator could generate with the same yard waste.

17.3. Food Waste

Canadian and U.S. municipalities are becoming more interested in food waste composting, though they lag behind Europe in establishing such facilities. Several municipalities in Canada are at various stages of piloting aerobic composting programs to co-process household food and yard wastes. These include five communities in the province of Ontario (Mississauga, Toronto, Guelph, Richmond Hill and Halton).[44] While a few pilot programs have been started in the U.S., a large proportion of municipal food waste composting in the U.S. is done within MSW composting operations. Some food waste composting is also done in commercial and institutional settings, for example in restaurants and by businesses accepting residuals from food preparation and in hospitals, schools and camps.

We sought information on energy consumption representative of a large-scale and well-established municipal composting facility. To our knowledge, the only such facilities are in Europe, where countries including Germany, Switzerland, and the Netherlands have begun large scale programs to compost kitchen and yard wastes separately from other wastes. Thus, the energy figures we report are for a composting plant operated in the Netherlands by the Waste Authority S.O.W. Hoorn and designed by Buhler Inc.[45] With a capacity of 29,400 tonnes per year, the plant processes a

[41] Howard Stenn, "Cedar Grove User's Guide for Landscape Professionals," as well as additional brochures from Cedar Grove.

[42] Conversations with Jan Allen, P.E. and General Manager of Cedar Grove Compost Company (October, 1991).

[43] Conversations with D. Chynoweth and Robert Legrand (January, 1992). While we selected a conversion rate of 50 percent, the conversion rate for yard waste depends on the type of waste used and can vary from around 25 to 70 percent.

[44] "Canada Launches Municipal Composting Projects," *Biocycle*, June 1991, pp. 30-32.

[45] Energy figures from conversations with Urs Maire and Mark Larsen, a manager and an engineer with Buhler Inc.'s Waste Processing Group. Background information on the facility was obtained from a paper entitled "Bio-Waste Composting Facility at the Waste Authority of S.O.W., Hoorn/Netherlands," by T. Schutte, B. Goggel, and U. Maire, Buhler Inc., 1991, which was also published in *Biocycle*, June 1991, pp. 70-71. That paper describes the process for collecting and co-composting biowaste (food waste) and yard waste used by the Waste Authority S.O.W. Hoorn and designed by Buhler, Inc.

combination of food and yard waste collected commingled in single containers from 75,000 homes.[46] In 1992, the waste authority will expand the plant's capacity to 58,800 tonnes per year in order to double the number of homes served. The plant uses a aerobic static/dynamic composting process with forced aeration and a WENDELIN™ composting system with automatic pile formation. Enclosing the composting system inside a building with biofilter exhaust prevents virtually all potential odor emissions.

The plant is highly automated. Thus, it probably uses more energy than other biowaste composting systems. Still, the plant has low operating costs (including debt service) of $40 (US) per tonne of waste. The composting plant's designers note that this compares favorably to operating costs of $100 (US) per tonne for an incinerator plant. Mature and of high quality, the compost produced at the facility contains very low levels of heavy metals and meets the most stringent standards currently in force in the Netherlands.

Based on information provided by an engineer with Buhler Inc., we estimate that the plant uses about 600 kJ/kg of waste composted. It is important to note that the exhaust fans which clear the facility of carbon dioxide and water vapor use almost half of the energy consumed at the facility. Comparing this figure to 421 kJ to harvest and prepare a substitutable amount of peat, we find that substituting aerobically produced food waste compost for peat results in an energy loss of 179 kJ/kg of food waste. If we consider the 2,744 kJ/kg estimate in Table 1 that can be derived from burning food waste in a mass burn facility, we determine that substituting aerobically produced compost for peat represents a net energy drain of 2,923 kJ/kg. This probably overestimates the energy loss, however, since the 50 percent to 70 percent moisture content of food waste means that it is difficult to burn.[47]

However, like MSW, food waste can be digested anaerobically as well as aerobically. The University of Maine recently carried out a demonstration experiment which composted food waste from five university cafeterias along with manure in the University dairy farm's anaerobic digester.[48] For 20 weeks, approximately 1,200 kg of vegetative wastes were added to the farm's digester. Farm personnel estimated that adding food waste to the digester increased the electricity generated by at least 50 kilowatt hours per day. This would represent at least 1,050 kJ/kg of material digested. In a report on the pilot project, a professor in Agricultural and Resource Economics at the University cautions that this estimate was not derived in a statistically sound manner and believes that the actual figure is higher. We could not use these estimates to derive a net energy balance since their report did not mention the amount of energy consumed by this food waste composting operation.

To estimate the approximate energy a large-scale anaerobic digestion plant could produce from food waste we again consulted Robert Legrand and David Chynoweth. Our estimate assumes that preprocessing food waste prior to anaerobic conversion requires only about 75 percent of the energy needed to preprocess MSW, but that energy used at later stages of the process would be the same. The estimate also assumes that approximately 30 percent of food waste is dry and free of ash, and that 80 percent of the dry, ash free solids in food waste are converted into methane.[49] Based upon these assumptions, we estimate that anaerobic digestion of food waste produces a net 3,794 kJ/kg of waste digested. We find that digesting food waste in an anaerobic vessel and substituting the residue for peat could be expected to save 4,215 kJ/kg of food waste or about one and a half times the energy derived

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[46] The waste authority collects and average of approximately three times as much food waste as yard waste on a weight basis. Representatives from Buhler did not have data on the relative amount of food and yard waste actually composted at Hoorn, so our analysis assumes that all the food and yard waste collected is composted.

[47] The efficiency with which food waste can be burned to produce energy quite likely is lower than the 45 percent average efficiency we applied to all waste stream components in Table 1 to estimate the amount of energy they would yield in a mass burn plant.

[48] "Anaerobic Treatment of Food Wastes at the University of Maine," by George Criner, Associate Professor, Department of Agricultural and Resource Economics, University of Maine, 1990. This anaerobic facility is used on an ongoing basis to treat animal wastes and produce energy for sale to the local electric utility.

[49] Conversations with D. Chynoweth and Robert Legrand (January, 1992).

from incinerating food waste in a massburn plant.

18. Wood Waste

For a long time, wood industries such as lumber and saw mills have effectively used the wastes they create. They have traditionally burned wastes to help fuel their manufacturing processes and have used wood byproducts to make plywood, particleboard and similar commodities. Wood wastes generated by other industrial processes and by household and commercial activities are now being recycled at increasing rates throughout North America.[50] Small companies are springing up to recycle and repair used pallets and to construct fence boards out of used wood. Others companies convert wood wastes into fiber for hardboard and particleboard. Some grind the waste into hog fuel. Many others produce wood chips for use in composting facilities and beauty bark for landscaping operations. Wood waste recyclers obtain the wastes from a variety of sources, including construction and demolition sites as well as landfills.

In this study, we look at energy savings from substituting recycled for virgin wood fiber in particleboard manufacture. Particleboard and similar products such as hardboard and fiberboard are fairly common end uses of recycled wood. All of these products can be manufactured with both recycled wood fibers and virgin wood byproducts. We interviewed personnel at the Wood Exchange, a company located near Portland, Oregon that both repairs pallets and converts construction and demolition debris and other wood wastes into fiber.[51] They sell this material to other manufacturers who combine the fiber with virgin wood byproducts to produce particleboard and hardboard.

On average, equipment at the Wood Exchange processes over 25 tonnes of wood waste into fiber in an hour. Wood Exchange personnel estimated the amount of electricity consumed by this process. Based on information provided, we calculated that their operation consumes about 563 kJ/kg of wood waste. Wood Exchange personnel also estimated the amount of fuel they use to collect and transport the wood waste utilized in their operation. (The collection energy is accounted for in Table 2, which appears later in this report, while the manufacturing energy is reflected in Table 1.)

After processing the wood into fiber, the Wood Exchange ships the fiber to particleboard and hardboard manufacturers. During wet seasons, particleboard manufacturers often have to use additional energy to dry the recycled wood fiber before using it, since particleboard manufacture is a "dry process." Our analysis reflects the additional drying energy and assumes that particleboard manufacturers can use recycled wood without further drying during 6 months out of the year.[52]

Accounting for added drying energy, we find that using recycled wood in place of virgin wood in the manufacture of particleboard saves a total of about 6,422 kJ/kg of waste, or about 90 percent of the energy produced from burning wood in a massburn plant.[53]

19. Leather

We did not find any recycling processes for leather. Inasmuch as it only accounts for 0.1% of

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[50] Christine T. Donovan, "Wood Waste Recovery and Processing," *Resource Recycling*, March 1991, pp. 84-90.

[51] Conversations with Kai Carlson, General Manager of the Wood Exchange (January, 1992) and with Tom Anderson, formerly with Wood Exchange (November, 1991).

[52] Telephone conversation with Dudley Kennon, Duraflake, Albany, Oregon (January, 1992).

[53] "Highlights from Wood for Structural and Architectural Purposes," *Forest Products Journal*, Feb 1977, by Conor W. Boyd, Peter Koch, *et al.*, Table 5; and telephone conversation with Conor Boyd (January, 1992). Extraction and transport of raw materials and preparation of particleboard finish in the form of planer shavings, plywood trim, and sawdust is reported to consume approximately 4.617 million Btu's per oven dry (OD) ton of particleboard, or 2,308 Btu's per oven dry pound of particleboard. Heating (ie., drying) virgin wood requires 5.598 million Btu's per OD ton or 2,799 Btu's per OD pound of particleboard. When comparing the use of virgin to recycled wood, we assume that it takes an average of 1.24 pounds of recycled wood to produce 1 pound of oven dry particleboard.

Ontario's waste, whether it is left in or out of calculations does not materially affect our conclusions.

20. Tires/Other Rubber

Tire wastes can be utilized in a variety of ways. According to the task force set up by the Ontario Ministry for the Environment, the most environmentally benign uses of scrap tires include using old tire casings for retreading and transforming components in used tires into other products. [54]

Retreading is the process by which tires can be recycled. It is really a combination of reuse and recycling in that the old tire's casing becomes the base for new tread material made from virgin rubber. Energy savings for retreading are estimated to be 16,165 to 48,796 kJ/kg. This is over one to almost four times as much energy as would be produced by burning tires in a mixed waste EFW facility. The increasing popularity of radial tires, however, has complicated the retreading process and made retreading less common than in previous decades. [55]

Tires can also be recycled into new products in two ways: 1) by cutting them up and assembling them into mats and bumpers; and 2) by transforming them into crumb rubber by mechanical grinding or cryogenic size reduction. Crumb rubber can then be used in weather seals, shoe soles, pipe insulation, asphalt paving and other products. According to Michael Blumenthal, who is the Executive Director of the Scrap Tire Management Council in Washington D.C., by early 1991 there were approximately 15 companies in the U.S., and 7 companies in Canada producing crumb rubber from scrap tires.[56] However, significant barriers have thus far precluded such tire recycling technologies from being more widely implemented. Besides the economic risks associated with tire recycling ventures, the inferior physical characteristics of the rubber particles themselves have limited the application of tire recycling technologies. [57]

Crumb rubber is difficult to remold since it is normally an inert substance that does not adhere to other moldable materials such as polyurethanes, epoxies, and thermoplastics. Air Products, a *Fortune*-500 company, has researched the feasibility of treating crumb rubber with a reactive gas to enhance the ability of rubber particles to bond with these other materials. Their research has determined that using this proprietary surface modification technology yields rubber particles with much improved bonding capabilities. They have used their surface treated rubber to form polyurethane-rubber composites with physical properties that are essentially identical to unfilled polyurethane. Air Product's economic evaluation of this technology suggests that between $1.35 and $3.00 per pound can be saved on materials by substituting a portion of surface treated rubber for cast polyurethanes.

Stuart Natof, a Program Manager with the U.S. Department of Energy, notes that the use of surface-treated rubber particles in polymer composites yields the greatest energy savings potential of all scrap tire uses. According to Natof, substituting surface treated rubber for a portion of the virgin polymers in composite materials represents a savings of between 66,700 and 229,300 kJ/kg of material substituted. Taking the mid-range of this estimate yields a savings of 147,500 kJ/kg. Recycling tires into surface-treated rubber therefore saves almost ten times the amount of energy yielded when tires are burned in a massburn incinerator.

Other rubber products besides tires can be recycled at an estimated energy savings of 25,672 kJ/kg. This is more than twice the amount of energy produced at an EFW facility when rubber is burned with MSW.

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[54] Robert Spencer, "New Approaches to Recycling Tires," *Biocycle*, March 1991, pp. 31-34.

[55] Joseph Wallace, "All Tired Out," *Across The Board*, November 1990, p. 27.

[56] Robert Spencer, "New Approaches to Recycling Tires," *Biocycle*, March 1991, pp. 31-34.

[57] B.D. Bauman, Air Products and Chemicals, Inc., "Scrap Tire Reuse Through Surface-Modification Technology," (flier produced for the U.S. Department of Energy); and conversation with Stuart Natof, Program Manager in Waste Materials Utilization for U.S. Department of Energy, Washington D.C.

21. Cotton Textiles

One use for old cotton textiles is in papermaking, producing writing papers. Estimated energy savings in that use are over 42,100 kJ/kg, six times higher than the Btu's produced by burning mixed textiles in solid waste.

22. Synthetic Textiles

The average energy consumed in manufacturing synthetic textiles is estimated at about 58,000 kJ/kg, based on polyester, nylon, acrylic modacrylic and olefin production. Assuming that energy is entirely saved if synthetics are re-used as rags, recycling synthetic textiles saves more than eight times as much energy as an EFW facility generates from incinerating them as a component of MSW.

23. Diapers

Weyerhaeuser and Procter and Gamble have both undertaken pilot projects for recycling single-use diapers. Both programs attempted to recover valuable fiber in diapers through a wet washing process, and were initiated to evaluate the economic and technological feasibility of recycling diapers on a commercial scale. Proctor and Gamble's 10-month pilot project collected disposable diapers from 800 households and 35 day care centers. It was completed in February 1991. Three separate materials were reclaimed in the diaper recycling process: southern softwood bleached kraft pulp, mixed plastics, and absorbent gel material. Pilot tests demonstrated that the processes used to reclaim the materials are generally effective and technologically feasible. Analysis determined that kraft pulp recovered from disposable diapers can be of sufficiently high quality to be sold for reuse in a wide variety of products including bond and computer papers, newsprint, commercial tissue, and possibly, disposable diapers. No market presently exists for the commingled plastics recovered, though this low grade material could potentially be used to produce "plastic lumber." Currently, no manufacturers are utilizing post-consumer absorbent gel material, but testing showed that this material (of which up to 70% is pulp) could be used to make paper mache objects such as flowerpots.

Arthur D. Little, Inc. provided an evaluation of the pilot program for Procter and Gamble and prepared conceptual designs for commercial scale diaper recycling facilities of three different sizes. Our low estimate of energy saved from recycling diapers, appearing in Table 1 of this report, is based the amount of electricity Little predicts one of these facilities would consume. (This facility would produce about 4.1 tonnes of reclaimed bleached kraft pulp per day on a dry basis and would serve approximately 30,000 households, or a population of about 1.2 million people.)[58] Our analysis considers only energy saving associated with the reclaimed pulp and ignores potential savings associated with the reclaimed plastic and absorbent gel material, since only the pulp is currently marketable. Recycling diapers instead of using raw materials to produce kraft pulp saves about 62,575 kJ/kg of dry pulp, or 6,801 kJ/kg of diapers recycled. [59]

On the whole, findings from Procter and Gamble's pilot project suggest that while technologically feasible on a larger scale, diaper recycling is not economic under current market conditions.[60]

Cloth diapers have been reused for centuries and represent a superior method for reducing solid waste, conserving materials, and limiting other environmental impacts. In "Diapers: Environmental Impacts and Lifecycle Analysis," Carl Lehrburger and colleagues compare the resources consumed by,

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[58] "Report on Disposable Diaper Recycling Pilot Program: Final Report to the Procter & Gamble Company," Arthur D. Little, Inc., April, 1991, p. 41.

[59] Tellus Institute, *op. cit.*, tables on pp. 2T-18 and 2T-22.

[60] "Seattle Solid Waste Utility Report on Disposable Diaper Recycling Pilot Project," October 1991, p. 10; and telephone conversation with Lynn Hailey, Procter & Gamble public information representative, November, 1991.

and pollution associated with, single-use and reusable diapers.[61] While disposable diaper recycling could save landfill space and represent a less energy intensive way to manufacture kraft paper for certain applications, Lehrburger points out that most of the pre-use environmental impacts of single-use diaper manufacturing would remain. In addition to using a greater amount of energy, single-use diapers consume more raw materials and generate more carbon monoxide and particulate air emissions than reusables.[62]

Lehrburger and his colleagues gathered data on energy used during each step of the manufacturing process for both single-use and reusable diapers and during the laundering of reusables. Their calculations assumed that 15 percent of the MSW waste stream, including single-use diapers, is burned for energy. They gave single-use diapers an incineration energy credit based on this assumption. We adjusted their figures by deleting the incineration energy credit, since the methodology we employ in this report compares the amount of energy saved with recycling *alone* to the amount of energy produced by mass burn incineration. The manufacture and use of disposable diapers consumes 75 percent more energy than the manufacture and use of reusables. Reusables save 15,096 kJ/kg of diaper waste. To this figure, we add 28 kJ, the energy savings that accrue if reusable diapers are recycled into cotton rags for paper production after their last use as diapers. (This assumes that half the cotton fibers remain at the end of a reusable diapers' lifecycle.) With reusable diapers recycled into cotton rags at the end of their lives, we estimate that substituting reusable for disposable diapers saves 15,124 kJ/kg of waste. This yields a net energy benefit of 4,412 kJ/kg over incineration of diapers in a massburn plant.[63]

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61 Carl Lehrburger, Jocelyn Mullen, and C.V. Jones, January 1991, "Diapers: Environmental Impacts and Lifecycle Analysis," Report to The National Association of Diaper Services in Philadelphia, Pennsylvania, available from Carl Lehrburger, P.O. Box 998, Gt. Barrington, MA 01230. This report assumes 87 percent of reusable diapers are home laundered and 13 percent are washed by commercial diaper services, based on another study by Smith and Sheeran.

62 Carl Lehrburger, *ibid.*, p. 81.

63 The savings may actually be much more since the estimated 10,713 kJ/kg mass burn value is probably much lower in reality due to the large amount of urine and other moisture in used diapers. Moisture in a used diaper accounts for three fourths of its weight. Lehrburger's study suggests 944 kJ/kg of used diapers would be a generous estimate.

IV. COLLECTION SYSTEM ENERGY IMPACTS FOR RECYCLING VERSUS INCINERATION

According to Ontario's Ministry of the Environment, Blue Box recycling programs reach more than half of the province's households.[64] By 1995 the province expects that 90% of all households, including apartments, farms and cottages, will have direct access to recycling programs. These collection systems for recyclables will target most cans, glass and newspapers generated as household wastes. In addition, whether collected at curbside in Blue Boxes or at drop off depots, some of these recyclables collection systems will include additional materials, such as, corrugated cardboard, PET or HDPE plastic food/beverage containers, or junk mail.[65]

For industrial/commercial/institutional (ICI) generators of waste, Ontario's Ministry of the Environment intends to implement mandatory source separation for selected recyclable materials. For example, retail malls would separate corrugated cardboard, aluminum, steel and glass; office complexes would separate fine paper, glass, aluminum, corrugated cardboard; hospitality businesses (e.g., hotels and restaurants), aluminum, steel, newspaper and glass; institutional generators, newspaper, aluminum steel and glass.

The Ministry also intends to establish a baseline of recyclable materials that will go beyond those which are currently being collected. This expanded list of materials targeted for collection will likely include materials such as leaf and yard wastes, corrugated cardboard and PET and HDPE plastics.

These provincial programs and plans mean that for many waste stream materials a dual collection system is already, or soon will be, in place. Whether one of these targeted materials is collected from the garbage can or dumpster and hauled to an incinerator, or collected from recycling bins and hauled to a materials recovery facility (MRF) or a composting plant, would not appear to substantially alter total energy expended to collect and transport waste materials. Communities in which incineration facilities might be sited will be providing both garbage and recycling collection regardless of whether an EFW facility is sited there. Thus, any impacts on energy needed to collect and transport materials will occur because of greater or lesser relative distances to an EFW facility versus a recycling or composting facility, and because hauling a tonne in a recycling truck is more or less energy intensive than hauling a tonne of waste in a garbage truck.

For purposes of the analysis herein, we assume that EFW, recycling and composting facilities will be equivalent distances from collection routes. We also assume that collecting and transporting a tonne of mixed garbage, source separated recyclables or source separated yard wastes requires the same energy usage. Available information on collection route lengths and times does not point to any particular collection system being unequivocally more efficient than another, as long as recyclables are not extensively sorted at each stop by the recycling truck crew. Nor does there appear to be any information that suggests substantial differences in fuel used to collect a tonne of recyclables or compostables versus a tonne of mixed garbage. Thus, whether a tonne of a targeted material is collected in the garbage truck or the recycling truck will not matter in terms of energy expended to collect and

[64] Information about Ontario's plans for recycling is drawn from "Ontario's Waste Reduction Action Plan: Backgrounder," February 21, 1991, and "An Ontario Waste Reduction Action Plan, Notes for Remarks by Ruth Grier, Minister of the Environment, to Eastern Ontario Mayors, Wardens and Reeves Conference," February 21, 1991.

[65] According to an article in the January 15, 1991, *Recycling Times*, Ontario's blue box program now provides for the collection of post-consumer boxboard, rigid plastic containers and corrugated cardboard. Two local paper mills are purchasing the boxboard and corrugated cardboard.

transport materials to the facility where they will be managed.

Materials likely to be targeted for separate collection by the province's recycling program plans are newspaper, corrugated cardboard, office paper, PET and HDPE plastics, glass containers, aluminum beverage containers, tin food and beverage containers, and yard wastes. That leaves mixed paper, other container plastics, film/packaging plastics, other glass, other ferrous and non-ferrous metals, food wastes, wood wastes, leather, rubber, textiles and diapers as waste stream materials for which additional collection energy expenditures may be necessary to recycle rather than incinerate.

Of these materials not targeted for separate collection by Ontario's current and/or future programs, food waste, wood waste and diapers are the only ones for which a separate collection system is likely to be specified as part of its recycling program. The main exception to separate collection of food waste is in those communities where it would be co-collected with yard waste. The Ontario community of Guelph currently collects food waste in this manner. In that situation no additional collection network would be required to begin recycling this non-targeted material.

Otherwise, there almost certainly would be a net increase in energy used for collecting solid waste materials, because the energy saved (avoided) when food waste is kept out of mixed garbage and set out for separate collection would be less than the energy required to send a truck out on a separate collection route picking up just food waste.

Low amounts of food waste are generated in households. Thus, food waste probably would be collected mainly from restaurants, hotels, hospitals, cafeterias and other businesses or institutions that provide meal preparation services to large numbers of customers. To the extent that residential units could be folded into collection routes without necessitating more collection trucks, then some residential food waste, especially from larger multi-family buildings, might also be recycled as part of a commercial food waste recycling program.

We assume that the typical truck used for collecting food waste (or recyclables, compostables or garbage) would use a fifth of a gallon of fuel for each kilometer of truck use, where a gallon of fuel has a kJ value of 144,400.[66]

With the increase in fuel usage to collect food waste there would be a corresponding savings in fuel usage to collect food waste mixed in with garbage. The number and distribution of homes and businesses serviced by garbage collection would not be changed when separate food waste collection is instituted. But less mixed garbage waste would be collected at each stop, so that trucks could make more stops before a trip to the transfer station, incinerator or landfill is required to unload. Fewer trips to unload, means fewer miles traveled and less fuel expended in garbage collection.

Estimates of the decrease in garbage collection energy when waste is recycled vary widely. For purposes of this study we use the range 20% to 40% to represent the amount of fuel savings in garbage collection associated with fuel expenditure to collect food waste.[67] As a result the net increase in fuel caused by food waste recycling is estimated to be .124 to .165 gallons of fuel per kilometer covered picking up food waste.

The amount of food waste generated by Ontario's food service businesses, the density of these businesses is terms of establishments per road mile, and the location of potential EFW incinerator sites or food waste compost facility sites are not specified as part of Ontario Hydro's NUG plan. We had to rely on data from other communities, as well as our own professional judgement, in making calculations for net energy impact of a separate food waste collection system.

First, we assume that the typical commercial food waste collection route would cover 40 to 48 kilometers in completing a daily route and hauling food waste to a composting facility. Second, we assume that the typical route would yield a 20 yard truck load at 340 kg per cubic yard, or 6.8 tonnes

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[66] White, Allen L., *et al*, "Energy Implications of Alternative Solid Waste Management Systems," Boston, MA: Tellus Institute, prepared for the Coalition of Northeastern Governors Policy Research Center, Inc., Appendix page D1.

[67] See White, *ibid*, p. 65-66. Also Seattle's residential garbage collection contracts with the two companies providing these services to the city specify that 50% of the fee paid for garbage collection services is based on tonnage collected, and decreases proportionally to any decrease in garbage tonnage collected from households.

picked up, during the 40 to 48 kilometer route.[68] Increased system wide fuel usage, from the figures given above, then would be 5 to 7.9 gallons per day, or 0.74 to 1.16 gallons per tonne collected. On a fossil fuel equivalent kilojoule per kilogram basis, then, food collection would entail an incremental energy expenditure of 107 to 165 kJ/kg collected.[69] The midpoint of this range, 136 kJ/kg,[70] is shown for food waste on Table 2 in the column labeled "Incremental Collection Energy."

For diapers, 81 kJ/kg incremental collection energy is reported in Table 2. This estimate reflects collection energy for commercial laundry service pickup and delivery of reusable diapers, and assumes zero collection energy is incurred for the 87% of reusable diapers which are home laundered.[71]

For wood waste, 163 kJ/kg incremental collection energy is reported in Table 2. This estimate reflects a wood recycler's estimate of energy required to collect wood from construction and demolition sites and landfills.

To develop estimates for incremental collection energy expenditure for the remaining non-targeted waste materials, we first assume that adding a material to existing source separated collection will increase overall collection system energy usage at only half the rate for adding a separate system to collect food waste, i.e., at the rate of 68 kJ/kg for materials with the same density on a collection truck as food waste.

But added collection system energy will also depend on the density of the new material being picked up, with, say, plastics using more energy per kilogram collected than, say, small scrap metal, because plastics require more recycling truck space per kilogram than do scrap metals. To account for relative densities, we adjusted 50% of food waste collection energy -- 68 kJ/kg -- up or down in proportion to 20% of the ratio of the density of food waste to each remaining non-targeted material's density, and added or subtracted that figure to or from 68 kJ/kg.[72]

These calculated incremental collection energy figures for non-targeted materials are reported in Table 2 in the column labeled "Incremental Collection Energy." For example, the density of other recyclable paper is estimated to be only 68 kilograms per cubic yard. Thus, (50% x 136 kJ/kg for food waste) + (340/68=) 5 x 20% x (.5 x 136) = 136 kJ/kg to add other recyclable paper to an already existing curbside collection route.

According to the calculations reported in Table 2, we estimate that incremental collection energy for non-targeted waste materials will be between 84 and 323 kJ/kg. On average, including zero incremental collection energy for targeted materials, collecting an extra kilogram of recyclables or compostables from households or businesses in Ontario's denser population centers will add about 86 kilojoules to energy expended on solid waste management collection systems.

Table 2 also reports estimates of incremental energy to prepare recyclable materials for

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[68] For some additional information on food waste collection see Appendix E, "Recycling Potential Assessment and Waste Stream Forecast," from the City of Seattle's Final Environmental Impact Statement-Waste Reduction, Recycling and Disposal Alternatives, July 1988.

[69] Kunz and Emmerson, *op. cit.*, p. 34, estimate curbside collection of recyclables requires 361 kJ/kg This figure does not include any garbage collection energy savings. In another study (Hannon, Bruce, "System Energy and Recycling: A Study of the Beverage Industry," Urbana, IL: Center for Advanced Computation, University of Illinois at Urbana-Champaign, revised March 17, 1973), energy consumed hauling garbage was estimated at 207 kJ/kg, based on 3.6 tonnes in a truck load, average distance traveled 32 kilometers, and 11.2 kilometers per gallon of truck fuel. Hannon used 137,750 kJ per gallon for gasoline. At 144,400 energy usage for garbage collection would be 227 kJ/kg collected.

[70] Love, *op. cit.*, p. 58, estimates garbage collection energy usage at 198 kJ/kg collected in a densely populated urban center. At a 60 to 80% rate for incremental energy expenditure, Love's estimate implies additional energy costs between 119 and 158 kJ/kg collected.

[71] C. Lehrburger, *op. cit.*, pp. 74-75.

[72] The densities for various waste stream materials are from a source separation analysis we conducted as part of the Washington State Department of Ecology's Best Management Practices Analysis for Solid Waste. See, Section C, "Separation Analysis," in Matrix Management Group, *et al*, *Best Management Practices Analysis for Solid Waste - Statewide Findings and Recommendations*, Volume III, Washington State Department of Ecology, Publication Number 88-33C, January 1989.

markets. The processing energy necessary to compost food and yard wastes was included as a deduction to the energy savings reported in Table 1, so Table 2 does not include any processing energy for food and yard wastes.

The major categories of materials preparation are:

- Baling at 105 kJ/kg for paper, plastic, aluminum cans, tin cans, leather and textiles.
- Processing to remove contaminants at 79 kJ/kg for all recyclables.
- Ash landfilling avoidance at 33 kJ/kg recycled for the 30% of a pound of ash produced and needing landfilling if the recycled kilogram were burned instead.

Table 2 Incremental Energy Required To Collect, Process and Transport Source Separated Recyclable or Compostable Materials

Waste Stream Materials	Incremental Collection Energy (kJ/kg)	Additonal Energy to Prepare Materials for Markets (kJ/kg)	Breakeven Kilometers to Markets(c) — Lowest Energy Savings: Truck	Lowest Energy Savings: Rail	Highest Energy Savings: Truck	Highest Energy Savings: Rail
Paper						
Newspaper	0	151 (a)	7063	31355	16486	73183
Corrugated Cardboard	0	151 (a)	3366	14941	17066	75757
Office (Ledger & Computer Printout)	0	151 (a)	14459	64184	16602	73698
Other Recyclable Paper	136	151 (a)	1336	5931	16876	74911
Metallic, Plastic or Wax Coated	136	151 (a)			16586	73624
Plastic						
PET	0	151 (a)	21796	96755	49338	219012
HDPE	0	151 (a)	24672	109520	33746	149799
Other Containers	323	151 (a)	24386	108250	25792	114491
Film/Packaging	272	151 (a)	28060	124560	38412	170513
Other Rigid	272	151 (a)	13551	60153	43232	191906
Glass						
Containers	0	46 (a)	236	1049	2948	13087
Other	85	46 (a)	190	841	190	841
Metal						
Aluminum Beverage Containers	0	151 (a)	110259	489444	170994	759044
Other Aluminum	94	46 (b)	110498	490502	198046	879131
Other Non-ferrous	94	46 (b)	60270	267540	67018	297495
Tin and Bi-Metal Cans	0	151 (a)	3409	15133	19896	88317
Other Ferrous	84	46 (b)	7719	34267	11413	50662
Vehicular Batteries	NP	NP	NP	NP	NP	NP
Household Batteries	NP	NP	NP	NP	NP	NP
White Goods	NP	NP	NP	NP	NP	NP
Organics						
Food Waste	136	NA	733	3255	733	3255
Yard Waste	0	NA	214	950	214	950
Memo: MSW Compost			0	0	0	0
Wood Waste	163 (d)	46 (b)	0	0	0	0
Leather	119	151 (a)	ND	ND	ND	ND
Rubber						
Tires	88	46 (b)	744	3303	73016	324119
Other Rubber	94	46 (b)	7708	34214	7708	34214
Textile						
Cotton	119	151 (a)	22984	102026	22984	102026
Synthetic	119	151 (a)	31880	141517	31880	141517
Diapers	81 (e)	NA	0	0	2379	10559
Construction & Demolition Debris	NP	NP	NP	NP	NP	NP
Small Quantity Hazardous	NP	NP	NP	NP	NP	NP
Average	86	96	8166	36250	16305	72377

NP = not processible and/or not processed in mass burn EFW facility.
NA = not applicable: processing and market preparation energy usage deducted in estimates for recycling energy savings from remanufacturing/reuse included on Table 1.
ND = no data available.

Footnotes for Table 2:

(a) Includes 105 kJ/kg for baling (Love, op.cit., p. 58) + 79 kJ/kg for processing (White, et al, op. cit., p. D1) - - 33 kJ/kg avoided landfilling energy usage. The latter figure is based on 109 kJ/kg for landfilling (White, et al, p. D2) and a 70% weight reduction from incinerating waste so that only 30% remains as ash.
(b) Estimate same as explained in footnote (a) except no baling necessary to prepare material for markets.
(c) Love, op. cit., p.60, reports direct energy requirements for truck transport at: 1.82 kJ/kg/km; rail direct energy requirement is: 0.41 kJ/kg/km.
(d) For wood waste, the kJ/kg incremental collection energy is based on a wood recycler's estimate to collect wood from construction and demolition sites and landfills.
(e) For diapers, the 81 kJ/kg incremental collection energy reflects commercial laundry service pickup and delivery of reusable diapers. Assumes zero collection energy for estimated 87% of reusable diapers home laundered. (Source: C. Lehrburger, op. cit., pp. 74-75.)

Preparing materials for markets incurs an average additional energy usage of 96 kJ/kg recycled. Incremental energy, as shown in Table 2, is 46 kJ/kg for materials that are not baled, and 151 kJ/kg for those that are baled for shipment to end users.

After collection and processing, recycled materials or finished compost must be shipped to remanufacturers, in the case of recyclables, or final users, in the case of finished compost. Energy required to ship by truck is estimated to be 1.82 kJ/kg per kilometer; via rail energy usage is much less, 0.41 kJ/kg per kilometer shipped.[73] The amount by which recycling energy conservation exceeds incinerator energy generation, as shown on Table 1, less the incremental collection and market preparation energy usages reported on Table 2, is the amount of energy available for shipping materials to markets.

For each material recycled or composted rather than incinerated, net energy saved will be partly used to transport materials to markets. The last four columns of Table 2 indicate the maximum mileage by truck or rail which each material could be shipped before energy saved by recycling was used up in shipping material to market. The table provides this breakeven shipping distance for both the lowest and highest of each material's recycling energy savings estimates given in the last three columns of Table 1.

As shown by the break even shipping distance estimates given on Table 2, most materials can be shipped long distances, half way round the globe and much further, to find a buyer/user, and the energy saved by recycling would still be greater than energy generated by burning the waste material.

The breakeven shipping distance estimates on Table 2 also agree with some commonly held notions and practices about which materials can go to distant markets. Glass and compost, for example, typically are used close to the community in which they are collected. But paper, plastics and aluminum cans can be (and are) shipped to quite distant markets.

In conclusion, then, energy conserved by recycling Ontario's residential waste exceeds by three to five times the energy generated by incinerating that waste, as shown in Table 1. Figure E-1 in the Executive Summary depicts the amount by which recycling's energy conservation exceeds incineration's energy generation for seven categories of solid waste materials. The most striking energy conservation is in metal, plastic and textile materials. Metals are not incinerable, so that, for example, aluminum cans save about 350 times more energy when they are recycled than when they are thrown in the garbage can. Plastics, on the other hand, burn better than any of the other waste categories shown on Figure E-1. But energy saved by recycling plastics is more than four times greater than their mass burn value.

Rubber, textiles and paper generate almost as much energy as plastics when incinerated in mixed refuse. Yet like plastics, all three materials yield much more substantial energy savings when recycled.

Among the seven waste materials depicted on Figure E-1, glass offers the least amount of energy savings when recycled. But glass is even less incinerable than metal; so that, for example, energy conservation from recycling glass containers is about thirty times greater than energy generated by incinerating glass in mixed refuse.

Only for the organic components of MSW—food, yard and wood waste—is energy generated from incineration close to the energy conserved when these wastes are recycled. However, for food and yard waste, the moisture content of these materials as typically received at an incineration facility probably means that their energy generation estimates are overestimated in the comparison shown on Figure E-1.

Thus, for all major categories of solid waste, we may fairly conclude that incineration in a mass burn facility is an exceedingly inefficient method of obtaining energy from waste. Even after taking into account energy usage for separate collections, processing and transportation to markets, recycling in general is a better source of energy than mass burn incineration.

[73] Love, *op. cit.*, p. 60.

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Recycling versus incineration: an energy conservation analysis

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ELSEVIER

Table 1
Energy generated by mass burn incineration versus energy conserved by recycling

Waste stream material	Residential waste composition (%)	Material heating value (kJ/kg)	EFW facility material energy equivalent to steam-electric power fuel energy[a] (kJ/kg)
Paper			
Newspaper	10.3	18 608	8444
Corrugated cardboard	14.6	16 282	7388
Office (Ledger & computer printout	5.7	18 143	8233
Other recyclable paper	4.8	16 747	7600
Metallic, plastic or wax coated	0.5	17 910	8127
Total	35.8	17 331	7865
Plastic			
PET	0.3	46 287	21 004
HDPE	0.9	46 287	21 004
Other containers	0.2	36 983	16 782
Film/packaging	4.3	32 099	14 566
Other rigid	1.8	36 983	16 782
Total	7.5	35 669	16 186
Glass			
Containers	5.7	233	106
Other	2.1	233	106
Total	7.8	233	106
Metal			
Aluminum beverage containers	0.4	1628	739
Other aluminum	1.1	698	317
Other non-ferrous	0.1	698	317
Tin and bi-metal cans	3.1	1628	739
Other ferrous	7.7	698	317
Vehicular batteries	0.5		
Household batteries	0.1		
White goods	1.0		
Total	14.0	889	403
Organics	16.0		
Food waste		6048	2744
Yard waste		6978	3166
Memo: MSW compost			
Wood waste	11.9	15 584	7072
Leather	0.1	16 747	7600
Rubber			
Tires	0.9	32 564	14 777
Other rubber	0.7	25 353	11 505
Textile	2.6	16 049	7283
Cotton			
Synthetic			
Diapers	1.1	23 609	10 713
Construction and demolition debris	0.6		
Small quantity hazardous	1.0		
Total/weighted average	100.0	13 514	6132

Table 1
Continued

Energy saved when recycled into		
same material/use		Other Materials[b] (kJ/kg)
Low est. (kJ/kg)	High est. (kJ/kg)	
21 450[c]	23 346[d]	38 600[b]
13 665[e]	32 108[f]	38 600[b]
34 699[c]	35 786[c]	38 600[b]
10 318[g]	32 108[f]	38 600[b]
		38 600[b]
18 863	30 264[h]	
60 825[i]	110 950	
66 058	82 573	
61 639	64 198[j]	
66 058	84 899	
41 868	95 887[k]	
59 934	87 877	
907[l]	5517	582[m]
		582[m]
907	4209[n]	
201 562[o]	312 098[o]	
201 562[o]	360 900[p]	
110 148[q]	122 429[r]	
7094[o]	37 100[o]	
14 496[p]	21 218[p]	
35 150	64 155	
		4215[s]
		3556[s]
		5548[t]
6422[u]	6422[u]	
No data	No data	No data
16 265[v]	48 796[v]	147 800
25 672[q]	25 672[q]	
		42 101[x]
58 292[y]	58 292[y]	
6801[z]	15 124[aa]	
20 060[bb]	31 270[bb]	

Source for residential waste composition: *Residential Waste Composition Study: Vol. 1 of the Ontario Waste Composition Study.*

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VALORGA
PROCESS

La filière méthanisation des déchets organiques et le procédé Valorga

Avril 1996

SYSTEMES DE VALORISATION DES DECHETS

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Annexes

1 Généralités

La méthanisation est un processus de décomposition des matières organiques en milieu anaérobie. Cette dégradation, qui s'effectue en plusieurs étapes à l'aide de bactéries spécifiques et dans des conditions, notamment de température, bien précises, s'accompagne d'une production de biogaz riche en méthane.

Ce processus, utilisé dès le début de ce siècle dans le traitement des boues de stations d'épuration urbaines, s'est développé progressivement pour le traitement des effluents liquides, notamment effluents d'élevage et déchets agro-industriels.

Ce n'est que plus récemment, à partir des années 70 et 80, que des travaux sur la méthanisation en continu à haute concentration en matière sèche, dont les ordures ménagères, ont vu le jour, en particulier en Europe et aux Etats-Unis.

2 Valorga Process

La société Valorga S.A. a développé ses premiers travaux à partir de 1981, au départ dans le cadre de recherches universitaires à l'Université des Sciences et Techniques du Languedoc. Cette action a été reprise et amplifiée par la société Valorga Process, aujourd'hui filiale de la société Idex.
L'objet de ces travaux résidait dans la mise au point d'un procédé de méthanisation en continu à haute concentration en matière sèche de la fraction organique des ordures ménagères et d'autres déchets agricoles ou agro-alimentaires.

Ces travaux ont rapidement conduit à la mise en place de plusieurs pilotes industriels :

— **1982** : pilote de 5 m^3 à Montpellier pour des essais de digestion anaérobie de la fraction organique des déchets ménagers et de mélange de substrats (lisiers + ordures ménagères).

— **1986-1987** : pilote de 50 m^3 à Vannes pour des essais de digestion anaérobie de mélange de substrats (fraction organique des ordures ménagères, lisiers, boues de station d'épuration).

— **1984-1990** : pilote de 500 m^3 à La Buisse (près de Grenoble pour le traitement de 8 000 tonnes/an d'ordures ménagères).

— **1988-1994** : pilote de 250 m^3 à l'Université de Liège en Belgique traitant encore aujourd'hui un mélange de fumier pailleux et de lisier.

Valorga Process, forte de son expérience unique en la matière, constitue une des filières de traitement des ordures ménagères avec les objectifs principaux suivants : valorisation maximale de la matière organique, protection de l'environnement et production d'énergie.

Le développement de ce procédé a permis :

— La construction en 1987 et le démarrage en août 1988 de la première usine au monde de traitement d'ordures ménagères par digestion anaérobie en continu et à haute teneur en matière sèche, à Amiens, traitant la totalité des déchets ménagers de cette municipalité, soit 55 000 t/an. Depuis fin 1994, le traitement s'est étendu aux déchets ménagers d'Abbeville, ce qui porte le tonnage annuel traité à 70 000 t/an. Cette usine constitue la principale référence industrielle du procédé Valorga.

En 1996, la capacité de l'usine est augmentée à 100.000 t/an grâce à la construction d'un 4ème digesteur qui traitera les déchets issus de la zone sud du district d'Amiens.

— La cession du droit d'exploiter les brevets de Valorga Process et la fourniture des études de base à la société Sedep, pour la construction en 1990 de l'unité de méthanisation de l'usine de traitement des ordures ménagères de Tahiti (capacité de traitement de l'usine : 90 000 tonnes/an).

— La construction en 1993 et le démarrage en janvier 1994 de l'usine de traitement des déchets ménagers triés à la source de Tilburg (Pays-Bas), pour le traitement de 52 000 tonnes de VGF (Vegetable - Garden - Fruit) par an.

— L'adjudication en février 1995 d'un contrat de construction et d'exploitation pour l'usine de traitement des déchets ménagers de Campobasso (Italie) d'une capacité de traitement de 48 000 t d'ordures ménagères et boues de station d'épuration.
La construction devrait commencer en fin d'année 1996 pour une mise en service fin 1997.

— L'adjudication en mars 1996 d'un contrat de construction d'une usine de traitement de déchets ménagers triés à la source de 35.000 t/an à Engelskirschen (Allemagne)

Différents projets ont fait l'objet de choix de filières de traitement incluant la méthanisation et sont suivis par Valorga Process, notamment en France (Lille, Rouen), en Belgique, en Hollande, en Grande Bretagne et aux Etats-Unis.

3 Une technologie adaptée au principe du traitement multifilières

Les nouvelles réglementations, les contraintes écologiques et les technologies disponibles incitent de plus en plus les collectivités locales à considérer la gestion des déchets dans le cadre d'une approche multifilières.

Cette approche multifilières consiste, dans la mesure du possible et compte tenu de considérations économiques, à mettre en oeuvre différentes techniques adaptées à la récupération et/ou au traitement des différentes fractions constitutives des déchets.

Ainsi voit-on se combiner de façon simultanée le recyclage de certains matériaux réintroduits dans les circuits industriels (verre, métaux, plastiques, une partie des papiers-cartons), le traitement biologique des fractions organiques (déchets de cuisine, déchets de jardin, papiers « souillés »), l'incinération des fractions combustibles (papiers et plastiques non recyclés), la mise en décharge des matériaux non valorisables ou des résidus ultimes des traitements précédents.

Cette approche multifilières réserve donc tout naturellement une place importante au traitement biologique des fractions organiques, en considérant d'une part que ces fractions non stabilisées ne peuvent être dirigées directement en décharge, d'autre part que l'incinération de ces fractions organiques humides ne constituent ni un recyclage, ni une valorisation puisque la matière organique est détruite et que le rendement énergétique de la combustion est faible.

Le type de traitement ou de valorisation n'est pas indifférent du mode de collecte et le traitement biologique est d'autant plus intéressant que la matière organique trouve facilement des débouchés commerciaux (amendement pour l'agriculture) après traitement.

La mise en place d'une collecte sélective, aux endroits où cela est possible (en particulier habitats pavillonnaires, zones rurales), visant à séparer à la source les fractions organiques (poubelle « verte »), permet d'obtenir un produit à traiter quasiment dépourvu d'impuretés et donc un amendement, après traitement, stabilisé et de très haute qualité.

Lorsque les déchets sont collectés en vrac, la mise en place d'une chaîne de tri mécanique, en amont du traitement proprement dit, permet la séparation des fractions organiques des autres constituants.

Le traitement biologique des fractions organiques, en aval d'une collecte sélective ou en aval d'une collecte en vrac suivie d'un tri mécanique, peut s'effectuer par digestion anaérobie (fermentation en absence d'oxygène) appelée aussi méthanisation, ou par compostage aérobie, ou par méthanisation et compostage aérobie combinés.

La méthanisation (avec ou sans compostage) présente les avantages suivants par rapport au compostage seul :

— la fermentation anaérobie conduit à la production d'un gaz combustible riche en méthane, le biogaz. Il s'agit donc d'une technique permettant une production et une valorisation énergétique.

— la fermentation en absence d'oxygène a lieu dans des réservoirs fermés appelés digesteurs, qui assurent un confinement total des odeurs. Il faut noter que lors du processus de fermentation, les acides organiques volatiles malodorants sont des composés **intermédiaires** de la digestion anaérobie, qui sont naturellement transformés en biogaz dans les réactions biologiques, alors qu'ils se volatilisent et doivent obligatoirement être récupérés pour un traitement dans un biofiltre lors d'un compostage aérobie.

— l'occupation des surfaces au sol est faible.

La méthanisation des fractions organiques est normalement suivie d'une phase courte (environ deux semaines) de « stabilisation » qui complète l'hygiénisation de la matière digérée. Après cette stabilisation, le produit parfaitement mûr (degré 5 de la norme allemande LAGA M10) peut être stocké et commercialisé.

La méthanisation engendre des jus excédentaires (la production de biogaz est le résultat de la transformation d'une partie de la matière sèche) qui peuvent être soit rejetés en station d'épuration, aux normes en vigueur, après un traitement sur site, soit évaporés biologiquement par compostage aérobie. En effet, lorsque les déchets organiques sont riches en déchets de jardin, il peut être intéressant d'associer en parallèle la méthanisation et le compostage aérobie. Ainsi, les déchets de cuisine, les papiers souillés et les pelouses, rapidement dégradables et humides (teneur en matière sèche de 20 à 25%) sont mieux adaptés à la digestion anaérobie. Les déchets de jardin ligneux et les résidus d'élagage sont mieux adaptés au compostage aérobie. C'est ce compostage aérobie qui assure alors l'évaporation biologique des jus excédentaires.

Une simple séparation granulométrique permet de séparer la fraction fine, riche en déchets de cuisine, papiers souillés et pelouses, de la fraction grossière riche en déchets ligneux.

4 Le procédé Valorga

Le procédé Valorga est un procédé de traitement des ordures ménagères issues d'une collecte sélective ou non. Dans le cas d'une collecte en vrac, la méthanisation fait suite à une unité de tri permettant la séparation de la fraction organique (fermentescibles et papiers-cartons) des autres constituants, la partie combustible pouvant être traitée par incinération. Cette chaîne de tri développée par Valorga Process est décrite et schématisée en annexe 1.

Le procédé Valorga permet:

- la dégradation de la matière organique avec production de biogaz contenant environ 55 % de méthane,
- la valorisation agronomique de la matière organique résiduelle sous la forme d'un produit stabilisé à haute valeur fertilisante.

Une installation de traitement des déchets organiques utilisant le procédé Valorga est constituée d'une unité de réception et de préparation des déchets, de l'unité de méthanisation, de l'unité de séchage biologique et affinage de l'amendement organique et de l'unité de valorisation du biogaz

4.1 L'unité de réception et préparation des déchets organiques

Elle est constituée :

- d'un pont bascule permettant la pesée des camions de collecte arrivant à l'usine,
- d'une fosse située dans un hall de réception ou d'un hall de déchargement fermé avec un système d'aspiration de l'air vicié,
- en fonction de la nature exacte des déchets à traiter, d'un système de calibrage, d'ouverture des sacs et de réduction granulométrique,
- les transporteurs et trémie nécessaires pour l'acheminement du produit vers l'unité de méthanisation.

4.2 L'unité de méthanisation

Elle permet la fermentation anaérobie de la fraction fermentescible et comprend :

- l'introduction des matières, après mélange et malaxage, sous forme de boue épaisse, à forte teneur en matière sèche, permettant notamment la réduction des volumes de cuverie,

— la digestion, dans des fermenteurs sans pièces mécaniques internes. La dégradation s'effectue à une température comprise entre 35 et 40 °C, sous des conditions anaérobies. Le transfert et l'homogénéisation des matières sont favorisés par la recirculation de biogaz sous pression, à la base des digesteurs,

— l'extraction du digestat et son pressage : le produit digéré extrait du digesteur, subit un pressage mécanique d'où ressort un "pressat" à 55 % de matière sèche destiné à l'unité de séchage biologique,

— le recyclage des jus de pressage utilisés pour dilution des déchets organiques, après séparation des inertes et clarification. Ces jus clarifiés sont stockés et chauffés par injection de vapeur au niveau du stockage afin d'obtenir un mélange déchets organiques + jus à la température de consigne. La clarification des jus de pressage conduit par ailleurs à la production d'une boue, envoyée comme le pressat vers l'unité de stabilisation et affinage de l'amendement organique,

— la compression du biogaz recueilli dans les bâches souples et sa recirculation pour agitation dans les digesteurs. Ce système breveté de recirculation du biogaz sous pression constitue une des spécificités du procédé.

La figure 2 en annexe 2 schématise l'unité de méthanisation.

4.3 L'unité de stabilisation et affinage de l'amendement organique

Elle a pour objet de stabiliser le pressat et les boues d'une part pour en favoriser l'hygiénisation, d'autre part pour gagner quelques points de siccité afin d'optimiser l'affinage et la commercialisation.

Elle est constituée :

— d'un bâtiment fermé avec aspiration de l'air vicié où le produit est stocké pendant deux semaines environ et éventuellement retourné,

— d'un système d'affinage (trommel et/ou épierreur) permettant d'extraire les indésirables,

— d'un stockage et conditionnement des amendements organiques avant commercialisation,

— d'un biofiltre permettant de traiter l'air vicié issu non seulement de cette unité de stabilisation et affinage, mais de l'unité de réception/préparation des déchets et de l'unité de méthanisation.

N.B. : Lorsqu'il y a « évaporation biologique » des jus excédentaires par compostage aérobie des déchets de jardin ligneux, celui-ci suppose le retournement systématique voire l'aération par ventilation forcée des matières en fermentation.

4.4 L'unité de valorisation du biogaz

Le biogaz produit est utilisé dans l'unité de valorisation, soit pour être vendu en l'état, soit pour la production de vapeur, soit pour la production d'électricité, soit pour sa réinjection dans les réseaux de transport et distribution du gaz naturel, après épuration.

5 Références industrielles

Le procédé Valorga a été validé industriellement depuis plus de six ans à l'usine Valorga d'Amiens qui traite la totalité des ordures ménagères collectées en vrac de la ville d'Amiens (France), et a été choisie plus récemment par le Syndicat Samenwerkingsverband Midden Brabant (SMB), aux Pays Bas, chargé du traitement des déchets organiques triés à la source (déchets de cuisine et de jardin) de 20 communes de la Région du Moyen Brabant. L'usine Valorga de Tilburg, principale commune de ce groupement intercommunal, a été mise en route en janvier 1994.

On peut également noter l'utilisation du procédé dans l'usine de traitement des ordures ménagères de Tahiti.

Les deux principales références industrielles de Valorga Process sont décrites ci-après.

5.1 L'usine de Tilburg

5.1.1 Introduction

Le plan d'élimination des déchets élaboré dans la Province du Nord Brabant prévoyait que jusqu'en 1994, 40 % des ordures ménagères actuellement mises en décharge devaient faire l'objet d'une collecte sélective afin d'en assurer le recyclage et la valorisation. Des systèmes de collecte sélective ont été introduits dans cette région depuis 1990, et ils permettent déjà de récupérer environ 50 kg/habitant.an. L'introduction du nouveau plan concernera une quantité supplémentaire de 150 kg/habitant.an, constituée à 75 % de déchets de cuisine et de jardin (DCJ) et à 25 % de papiers, carton, verre, etc.

Dès 1989, le Syndicat « Samenwerkingsverband Midden Brabant » (SMB), a recherché des procédés de traitement de ces déchets.

Disposant à Tilburg d'une usine de traitement du gaz d'une décharge, le SMB a opté pour la méthanisation des DCJ. Après évaluation des divers procédés existants, il a décidé de confier son projet à Valorga Process, dont le système lui offrait les meilleures garanties de résultats et de fiabilité. Le contrat entre SMB et le consortium Valorga Process - Stork Protech (NL) a été signé le 18/12/1991, les études de procédé et les études de détail ont été réalisées en 1992, la construction de l'usine a eu lieu en 1993 et la mise en route de l'installation en janvier 1994.

5.1.2 Caractéristiques des déchets

Au Pays-Bas, la production de déchets ménagers s'établit à environ 450 kg/habitant.an. Près de 10 % de cette quantité correspond à des déchets encombrants (mobilier, réfrigérateurs, bicyclettes, etc...) et une cinquantaine de kg sont déjà recyclés dans le cadre de collectes sélectives.

La composition des 350 kg restants, actuellement incinérés ou mis en décharge, se présente comme suit :

Désignation	Poids (kg)
Déchets de cuisine et jardin (DCJ)	168
Papier, carton	84
Verre	25
Plastiques	24
Métaux	10
Textiles	7
Autres	32
Total	**350**

La région du Moyen-Brabant, dont la ville la plus importante est Tilburg, compte près de 380 000 habitants. Le gisement potentiel de DCJ y est de 63 840 t/an. Conformément aux objectifs du nouveau plan d'élimination des déchets, le « Samenwerkingsverband Midden Brabant » prévoit d'en collecter et d'en valoriser les trois quarts, soit environ 39 900 t DCJ/an.

Afin de simplifier le concept de tri à la source, le projet conçu par Valorga Process prévoit de privilégier le principe d'une « poubelle verte élargie » qui contiendrait, en plus des DCJ, une partie du gisement de papier et carton (PC). Ainsi, le système de digestion est dimensionné pour traiter 40 000 t DCJ/an + 6 000 t PC/an, ou 52 000 t DCJ/an seuls.

La composition des déchets à digérer (DCJ) est la suivante :

Matière sèche (MS)	:	40 à 51 %
Matière solide volatile (MSV)	:	36 à 60 % de la MS
Inertes > 0,5 mm	:	8 ± 3 % de la MS

Ces DCJ devraient être constitués à 38 % par des déchets alimentaires et à 62 % par des déchets de jardin. La proportion importante de déchets de jardins induit une quantité non négligeable de sable dans les DCJ mais cette contrainte ne constitue pas un handicap pour la filière.

5.1.3 Description

5.1.3.1 Présentation

L'usine de méthanisation comprend les éléments suivants :

— Unité de préparation des DCJ comprenant la réception des déchets, le tri des inertes, la réduction granulométrique.

— Unité de digestion anaérobie comprenant le mélange et le malaxage des DCJ, pompage dans les 2 digesteurs de 3 300 m^3 chacun, le stockage du biogaz, le système de compression et d'agitation, l'extraction de la matière digérée et le pressage dans deux presses à vis.

— Unité de traitement des eaux de procédé comprenant la clarification de l'effluent issu de la déshydratation mécanique, le stockage du jus clair et son chauffage. Ce jus est chauffé puis pompé vers le mélangeur. L'eau de procédé en excès est rejetée dans le réseau afin d'être traitée dans la station d'épuration proche du site. Le « gâteau » issu de cette clarification est mélangé avec le pressat.

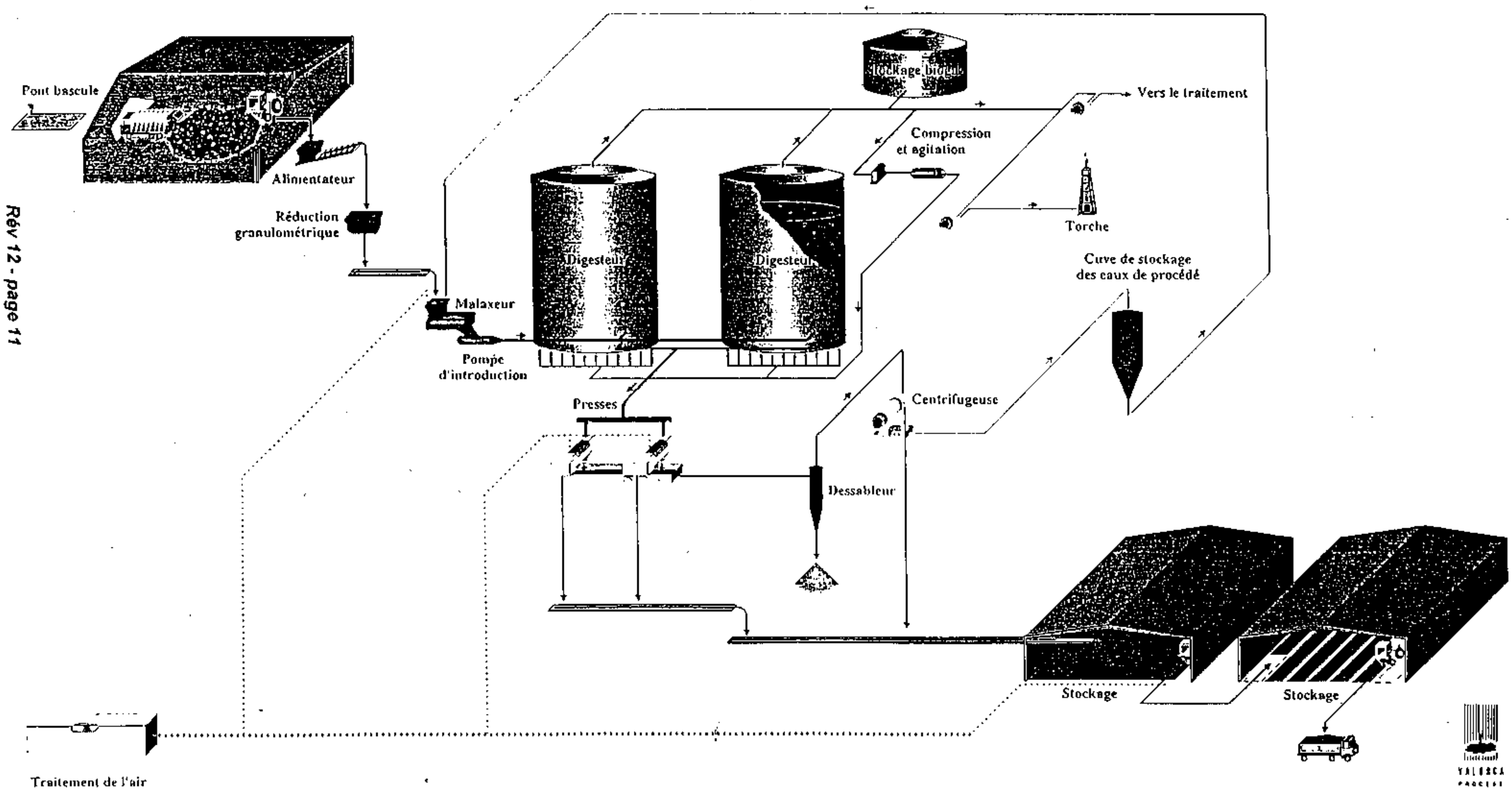
— Unité de stockage du compost comprenant un bâtiment fermé vers lequel le mélange « pressat + gâteau » est transporté pour y être stabilisé durant 7 jours ; à la suite de quoi le produit stabilisé est acheminé vers un stockage couvert, durant 7 jours.

— Unité de livraison du biogaz comprenant le stockage-tampon et injection du biogaz dans le réseau de l'usine d'épuration du biogaz déjà existante à proximité (unité traitant le gaz produit par une décharge de 100 ha recevant 500 000 t déchets/an, et sur laquelle on capte environ 10 millions de m^3 de biogaz par an). Cette usine d'épuration met en oeuvre un procédé par contact gaz-liquide avec élimination du gaz carbonique par lavage. Le biogaz ramené aux caractéristiques du gaz naturel est injecté dans le réseau d'alimentation de la ville de Tilburg.

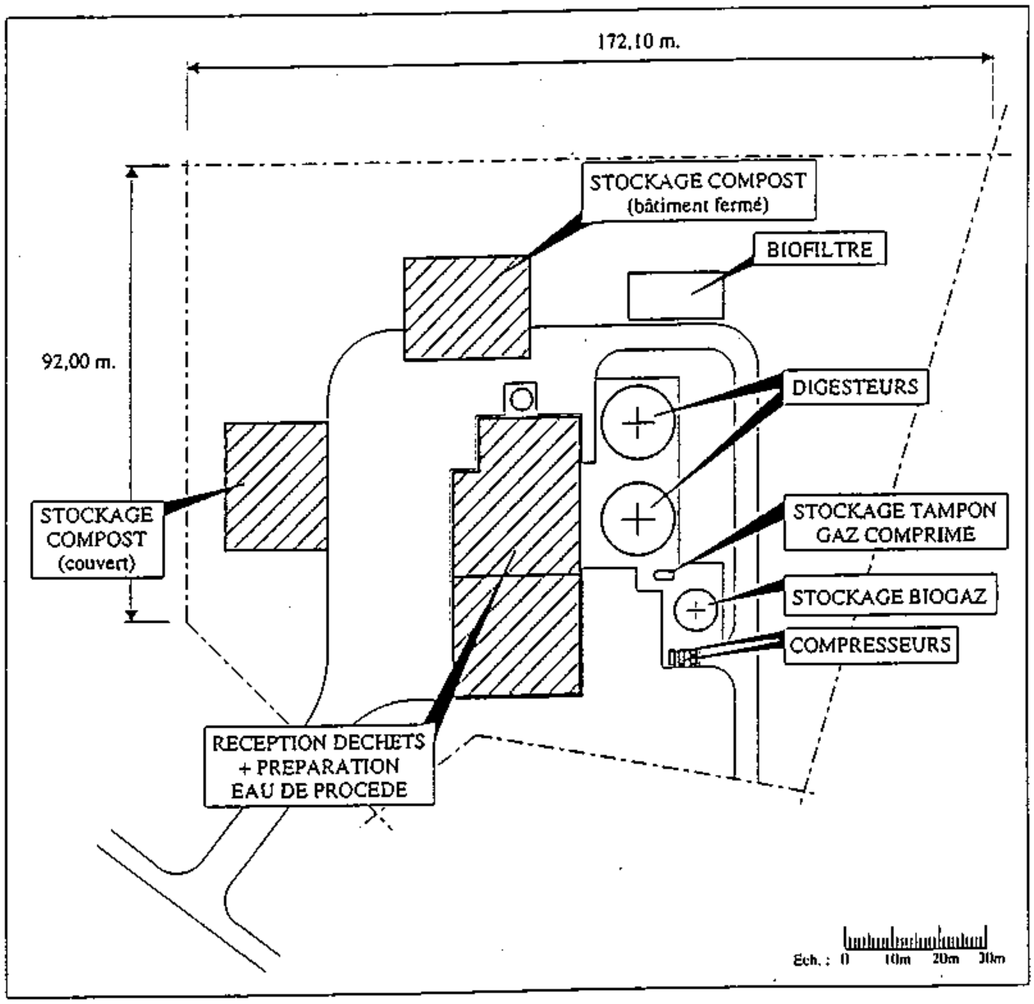
— Système de traitement de l'air vicié issu de l'unité de stockage du compost mais aussi des autres unités de l'usine.

La figure n°1 présente la configuration générale de l'usine avec ses différentes unités.

TRAITEMENT PAR METHANISATION DES DECHETS DE CUISINE ET DE JARDIN A TILBURG (PAYS-BAS)



Le plan d'implantation de l'usine de méthanisation est présenté à la figure n° 2 ci-après :



5.1.3.2 Caractéristiques et performances

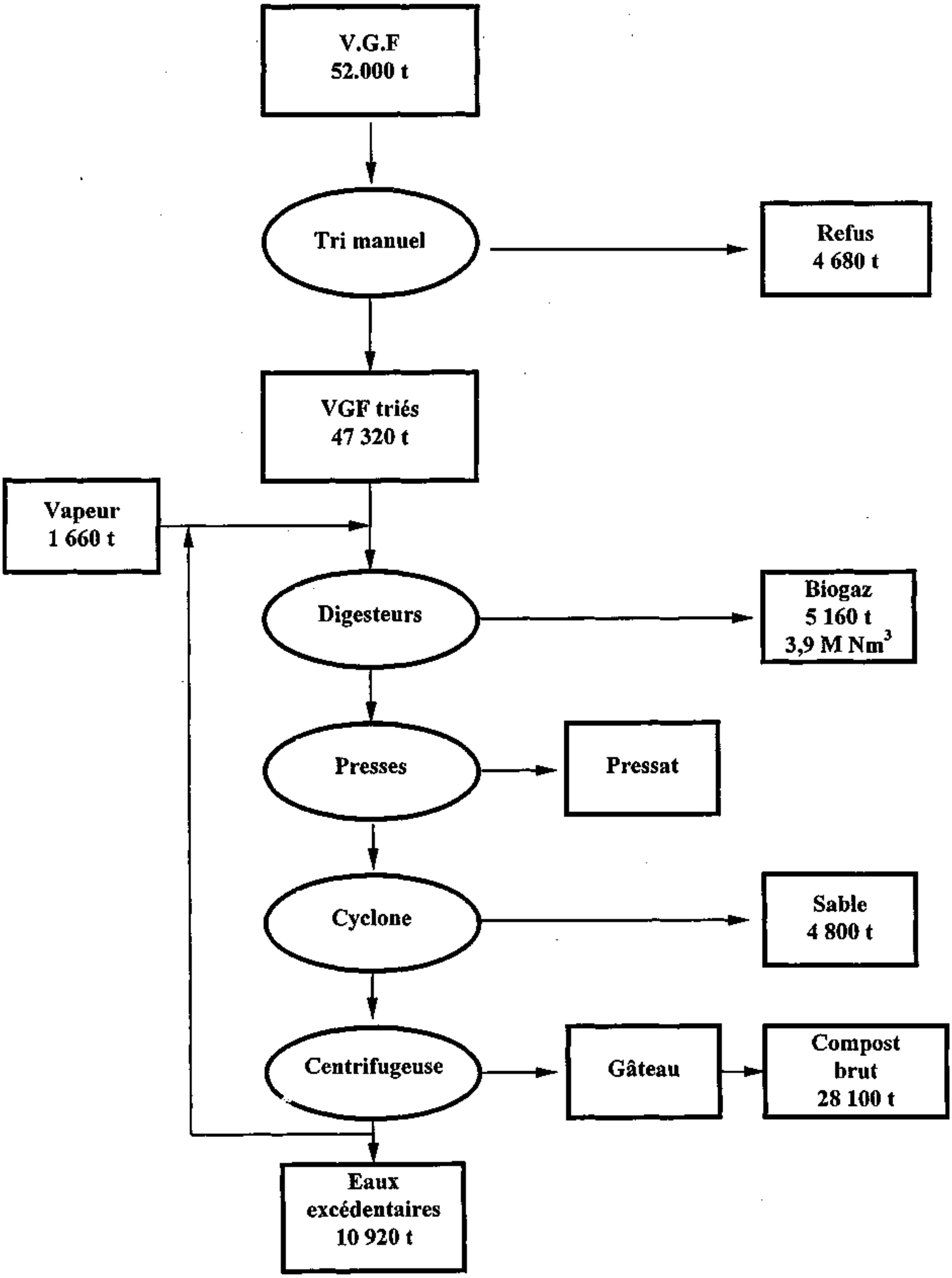
Les principales caractéristiques de fonctionnement de l'installation de digestion anaérobie sont données dans le tableau suivant :

Paramètre	Unité	Installation de Tilburg
Température	°C	37-40
pH	-	7,0 - 7,2
Temps de rétention	Jours	24
Charge volumique	kg MSV(*)/m^3.j	7,0 - 8,6
Teneur en méthane	%	56
Production de méthane	Nm^3 CH_4/t MSV(*)	200 - 250

La figure n°3 présente le bilan matière observé pendant la première année de fonctionnement et extrapolé à la capacité nominale de traitement.

(*) MSV = Matière sèche volatile

Figure n°3



V.G.F
52.000 t
Tri manuel
Refus
4 680 t
VGF triés
47 320 t
Vapeur
1 660 t
Digesteurs
Biogaz
5 160 t
3,9 M Nm³
Presses
Pressat
Cyclone
Sable
4 800 t
Centrifugeuse
Gâteau
Compost
brut
28 100 t
Eaux
excédentaires
10 920 t

L'usine de traitement de Tilburg produira en régime stabilisé 4 000 000 Nm^3 biogaz/an à 56 % de méthane (CH_4). La teneur en hydrogène sulfuré observée dans le biogaz de Tilburg est très faible (0 à 100 ppm de H_2S).

L'usine produira environ 31 000 t d'amendement organique par an. Ce produit sera valorisé en agriculture ; il devra, à ce titre, respecter les normes de qualité imposées au compost, aux Pays-Bas.

Les teneurs en métaux lourds dans l'amendement organique de Tilburg sont les suivantes :

Cadmium	(Cd)	0,5	[g/t M.S.]
Chrome	(Cr)	23	[g/t M.S.]
Cuivre	(Cu)	27	[g/t M.S.]
Mercure	(Hg)	0,1	[g/t M.S.]
Nickel	(Ni)	7,6	[g/t M.S.]
Plomb	(Pb)	67	[g/t M.S.]
Zinc	(Zn)	190	[g/t M.S.]
Arsenic	(As)	< 5	[g/t M.S.]

(*) MS = Matière sèche

Les tests d'échauffement et de respirométrie ont montré que l'amendement organique sortant de l'usine était parfaitement stabilisé (degré 5 de la norme allemande Laga M10).

5.2 L'usine d'Amiens

5.2.1 Introduction

L'usine d'Amiens, mise en service en août 1988, traite 55.000 tonnes d'ordures ménagères par an collectées en vrac, avec 3 digesteurs de 2 400 m^3 chacun. Sa capacité totale de traitement est de 72 000 tonnes de déchets par an en régime mésophile, ce qui permettra d'élargir la réception des ordures aux collectivités locales voisines.

5.2.2 Composition des ordures ménagères

Les performances présentées dans ce qui suit sont celles obtenues à partir d'une composition donnée des ordures ménagères d'Amiens, déterminée à partir d'une campagne de mesure sur 12 mois selon des modalités fixées en accord avec la ville d'Amiens. Cette composition est indiquée dans le *tableau suivant*.

Fractions	Composition	Teneur en MS(*)	MSV(*)/MS
Papiers-cartons	32	65	80
Fermentescibles	32,5	40	65
Plastiques	13,5	80	85
Textiles	3	80	80
Métaux	5	95	0
Verres/autres inertes	15	95	0

(*) MS = Matière sèche

(*) MSV = Matière sèche volatile

5.2.3 Description générale

L'usine d'Amiens comprend les principales unités déjà décrites dans leur principe. Les déchets étant collectés en vrac, elle comprend une unité de tri mécanique pour séparer la fraction organique (déchets de cuisine, de jardin et une partie des papiers-cartons) des autres fractions (métaux, verre, plastiques). Cette chaîne de tri est décrite à l'annexe 1.

Le plan d'implantation de l'usine est présenté à l'annexe 3.

5.2.4 Performances

On présente ci-après les performances de l'usine validées par plus de six ans de fonctionnement industriel.

5.2.4.1 Principales caractéristiques de la digestion anaérobie

On indique au *tableau suivant* les principales caractéristiques de la digestion anaérobie des digesteurs d'Amiens :

Paramètres	Unités	
Température	°C	37 - 40
pH	/	7 - 7,2
Temps de rétention	jour	18 - 25
Charge organique	kg MSV/m³.j	7,5 - 9
Teneur en CH_4	%	54
Production de CH_4	Nm³ CH_4/t.MSV	210 - 240

5.2.4.2 Productivité en biogaz

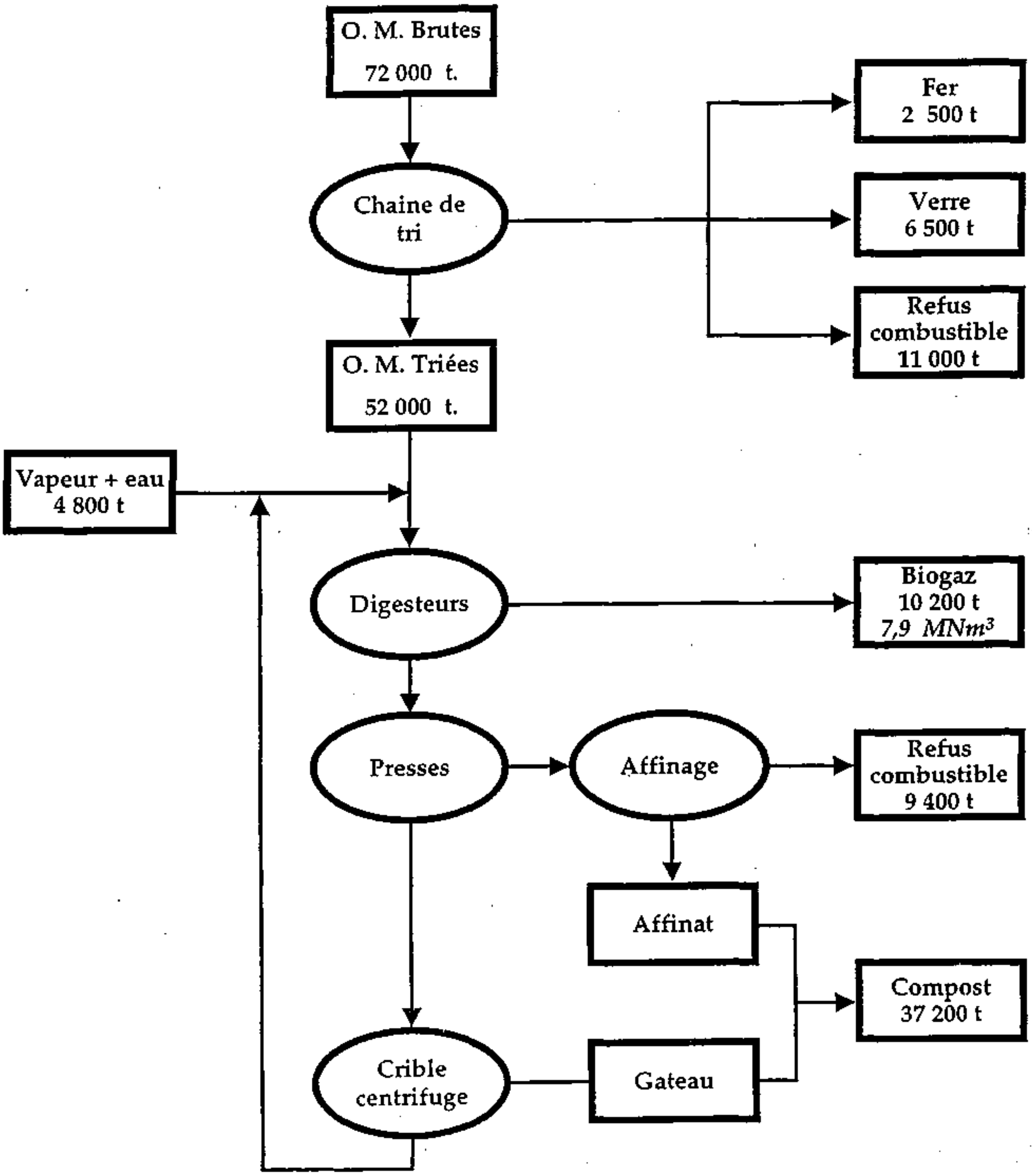
La production de biogaz et le tonnage d'ordures ménagères triées hebdomadaires depuis la mise en route de l'usine jusqu'en mai 1994, sont représentés à l'annexe n°4.

La productivité moyenne en biogaz est de 99 Nm³ de biogaz par tonne d'ordures ménagères entrante usine, soit 146 Nm³ de biogaz par tonne d'ordures ménagères triée.

Durant les sept premières années de fonctionnement et y compris la phase de démarrage, l'usine d'Amiens a produit 40.000.000 Nm³ de biogaz à 54 % de méthane (CH_4).

5.2.4.3 Bilan matière

Le bilan matière annuel à Amiens est le suivant :



5.2.4.4 Qualité des produits et devenir

5.2.4.4.1 Le biogaz

Le biogaz produit est analysé par chromatographie toutes les deux heures. Sa composition moyenne est la suivante :

- 50 à 60 % de CH_4 (moyenne 54 %)
- 40 à 60 % de CO_2
- H_2S = 200 à 2500 ppm
- H_2 < 0,5 %

N.B. : la teneur en H_2S dépend de la qualité des ordures traitées, donc du type de collecte. Une collecte sélective conduirait à une teneur moyenne en H_2S dans le biogaz de 200 à 300 ppm.

Le pouvoir calorifique supérieur du biogaz est de 5,5 à 6,5 kWh/m^3. Le biogaz est transformé sur site en vapeur (15 bars), vendue à un industriel voisin de l'usine.

5.2.4.4.2 Amendements organiques

L'affinat constitue un fertilisant organique de qualité, favorable à l'amélioration de la qualité des sols. Il fait l'objet d'un suivi qualitatif mensuel pour déterminer sa valeur agronomique et ses teneurs en métaux lourds. On présente au *tableau suivant* la composition moyenne de l'affinat d'Amiens ainsi que celle attendue en aval d'une collecte sélective.

Les boues issues du traitement des jus de pressage sont mélangées à des substrats carbonés. Le mélange, dont la teneur en matière sèche est voisine de 40 %, subit une évaporation biologique. Le produit final constitue un excellent fertilisant organique. Sa qualité est indiquée au *tableau ci-après*. Les amendements organiques d'Amiens sont destinés pour 60 % à la viticulture champenoise et pour 40 % à la culture céréalière locale.

Qualité de l'affinat à Amiens

Paramètres	Unités	Amiens (collecte en vrac)	Collecte sélective type VGF
MS	% poids brut	55	50
MSV	% poids sec	42	52
MO	% poids brut	23	26
MSVd	% poids sec	36	47
C. organique	% poids sec	18-20	20-25
NTK	% poids sec	1,1	1,6
MSV/N		40	32
C/N		18	15
P_2O_5 total	% poids sec	0,78	1,2
K_2O total	% poids sec	1,04	1,6
CaO total	% poids sec	*	*
MgO total	% poids sec	1,5	2
pH		8	8
Cd total	ppm/sec	2-3	1
Cr total	ppm/sec	100-250	30
Cu total	ppm/sec	70-150	60
Hg total	ppm/sec	2-3	< 0,5
Ni total	ppm/sec	30-50	20
Pb total	ppm/sec	350-850	75
Zn total	ppm/sec	400-750	200
Inertes totaux	% poids brut	≤ 12	< 5
Densité brute		0,5	0,5

Nota : Les premiers résultats sur les derniers développements du traitement laissent penser que les valeurs suivantes pourront être atteintes à partir d'ordures ménagères brutes :

— MS 65-70 % sur brut

— MSV 43-45 % sur sec

— MO 28-30 % sur brut

— Inertes totaux < 8 % sur brut

Composition moyenne annuelle de l'amendement organique issu du traitement biologique des boues de procédé sur substrat carboné à Amiens.

Paramètres	Unités	Amendement organique
MS	% poids brut	> 60
MSV	% poids sec	45-50
MO	% poids brut	25-30
C. organique	% poids sec	> 20
NTK	% poids sec	> 1
MSV/N		45
P_2O_5 total	% poids sec	0,7
K_2O total	% poids sec	1,1
CaO total	% poids sec	12,2
MgO total	% poids sec	1,3
pH		8
Cd total	ppm/sec	2-3
Cr total	ppm/sec	50-150
Cu total	ppm/sec	60-100
Hg total	ppm/sec	3-4
Ni total	ppm/sec	20-30
Pb total	ppm/sec	500-950
Zn total	ppm/sec	600-830
Inertes < 3 mm	% poids brut	< 20
Inertes > 3 mm	% poids brut	0
Densité brute		0,4

5.2.4.4.3 Les refus combustibles

Les refus de la chaîne de tri et de la chaîne d'affinage constituent un combustible à pouvoir calorifique élevé. Une chaîne de combustion pourrait permettre de valoriser cette matière en générant de la vapeur ou de l'eau chaude disponible pour l'industrie, avec des rejets dans l'atmosphère de fumées froides, traitées, neutralisées, non saturées en eau et avec les caractéristiques satisfaisant aux normes européennes. Cette installation de combustion n'est pas en place à Amiens. La qualité des refus combustibles d'Amiens est indiquée au *tableau suivant*.

Qualité des refus combustibles d'Amiens

Désignation	Unités	Valeur
Matière sèche (MS)	%	70,29
Teneur en carbone	% MS	46,54
Teneur en hydrogène	% MS	7,29
Teneur en soufre	% MS	0,39
Teneur en chlore	% MS	3,68
Teneur en oxygène	% MS	20,61
PCS sec	th/t	4 955
PCS brut	th/t	3 483
PCI sec	th/t	4 572
PCI brut	th/t	3 040

6 Aspects économiques

Les coûts d'investissement et les coûts de traitement dépendent bien entendu du tonnage des déchets à traiter, de leur nature, de la configuration de l'usine (chaîne de tri, valorisation du biogaz, post-traitement de l'amendement organique, incinération des refus combustibles, etc...) et du type de contrat de réalisation et d'exploitation.

A titre indicatif, un cas type est présenté ici :

Usine de traitement de 70 000 t de déchets ménagers triés à la source (poubelle verte) :

— 1 unité de préparation des déchets,

— 1 unité de méthanisation,

— 1 unité de post-traitement de la matière organique,

— 1 unité de post-traitement des jus excédentaires pour rejet en STEP,

— 1 unité de production d'électricité.

Coût d'investissement : environ **70 MF à 90 MF HT**, variable suivant les conditions locales.

Coût résultant (amortissement de l'investissement + exploitation - recettes) :
280 F/t à 320 F/t (HT)

7 Conclusion

Valorga Process, en parfaite synergie avec sa société mère Idex, peut apporter une réponse au problème du traitement des déchets d'une collectivité. La souplesse du procédé Valorga vis-à-vis d'une qualité variable des ordures et donc vis-à-vis de différents types de collecte, permet d'optimiser le traitement dans un souci global de recyclage maximum, de valorisation de la matière organique, de récupération du méthane et de respect de l'environnement. En fonction des situations, cette optimisation peut supposer une complémentarité opportune entre le procédé Valorga et d'autres types de traitement, tel l'incinération des refus combustibles et/ou la mise en place par les collectivités de système de recyclage de certains constituants tels les verres, plastiques, métaux, une partie des papiers.

Annexes

Annexe 1 - *Chaîne de tri mise en place dans le cas d'une collecte des déchets en vrac*

Elle est destinée à trier et à préparer la matière qui sera introduite en digestion ; elle comprend :

— le stockage des ordures brutes en fosse et la reprise de ces ordures,

— le tri granulométrique,

— le tri des métaux ferreux,

— la réduction granulométrique,

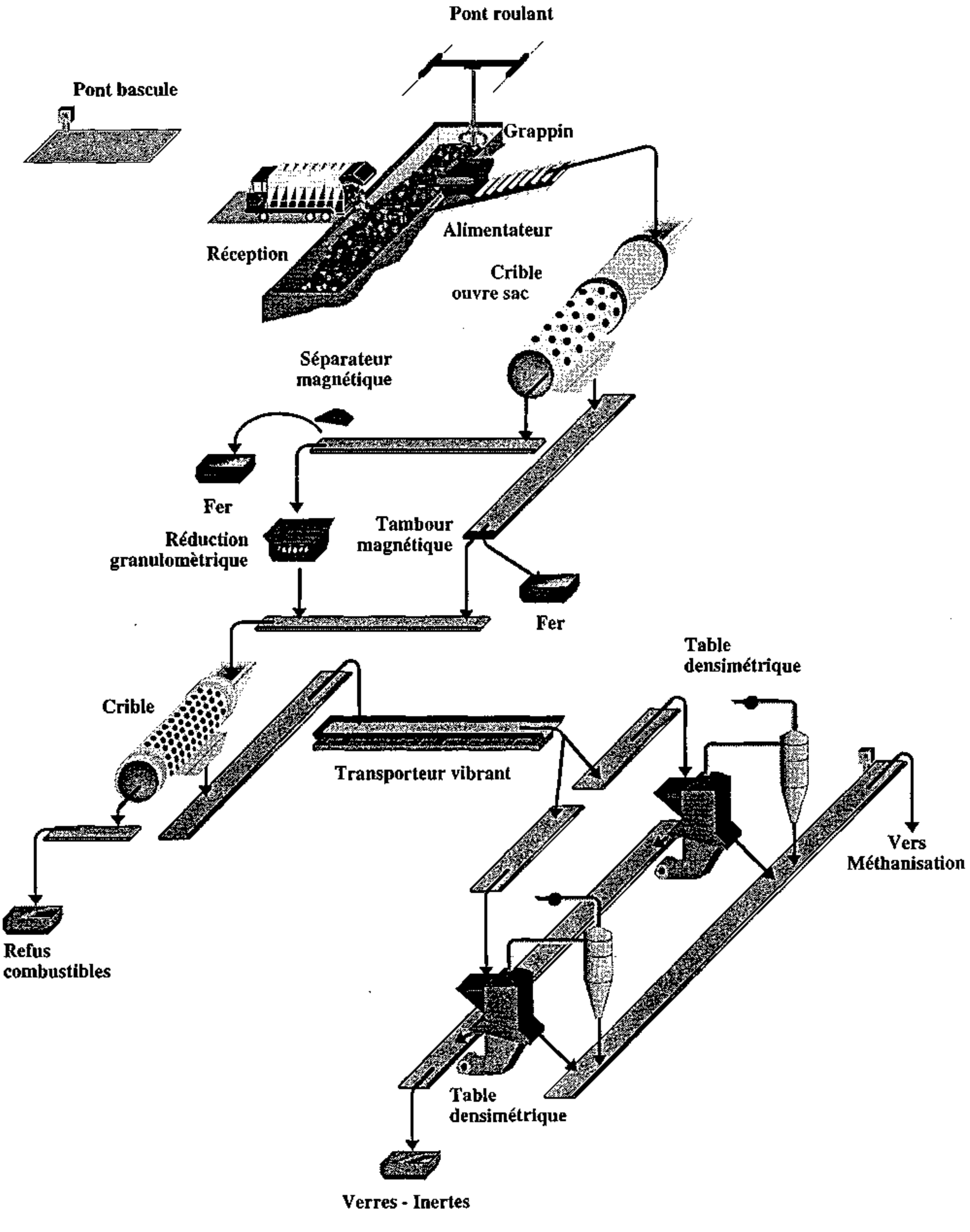
— le tri des inertes lourds.

La chaîne de tri est schématisée ci-après. Elle peut bien entendu être adaptée aux besoins spécifiques des collectivités et à la composition initiale des ordures.

Classiquement dans le cas d'une composition d'ordures ménagères standard (cf. A titre d'exemple celle d'Amiens, § 5.2.2), le potentiel méthanisable correspond à la fraction fermentescible, à la fraction papier-carton, et à 75 % à la fraction fine, soit environ 68 % du poids initial des ordures ménagères. La chaîne de tri permet la récupération de 85 % de potentiel pour son introduction en méthanisation.

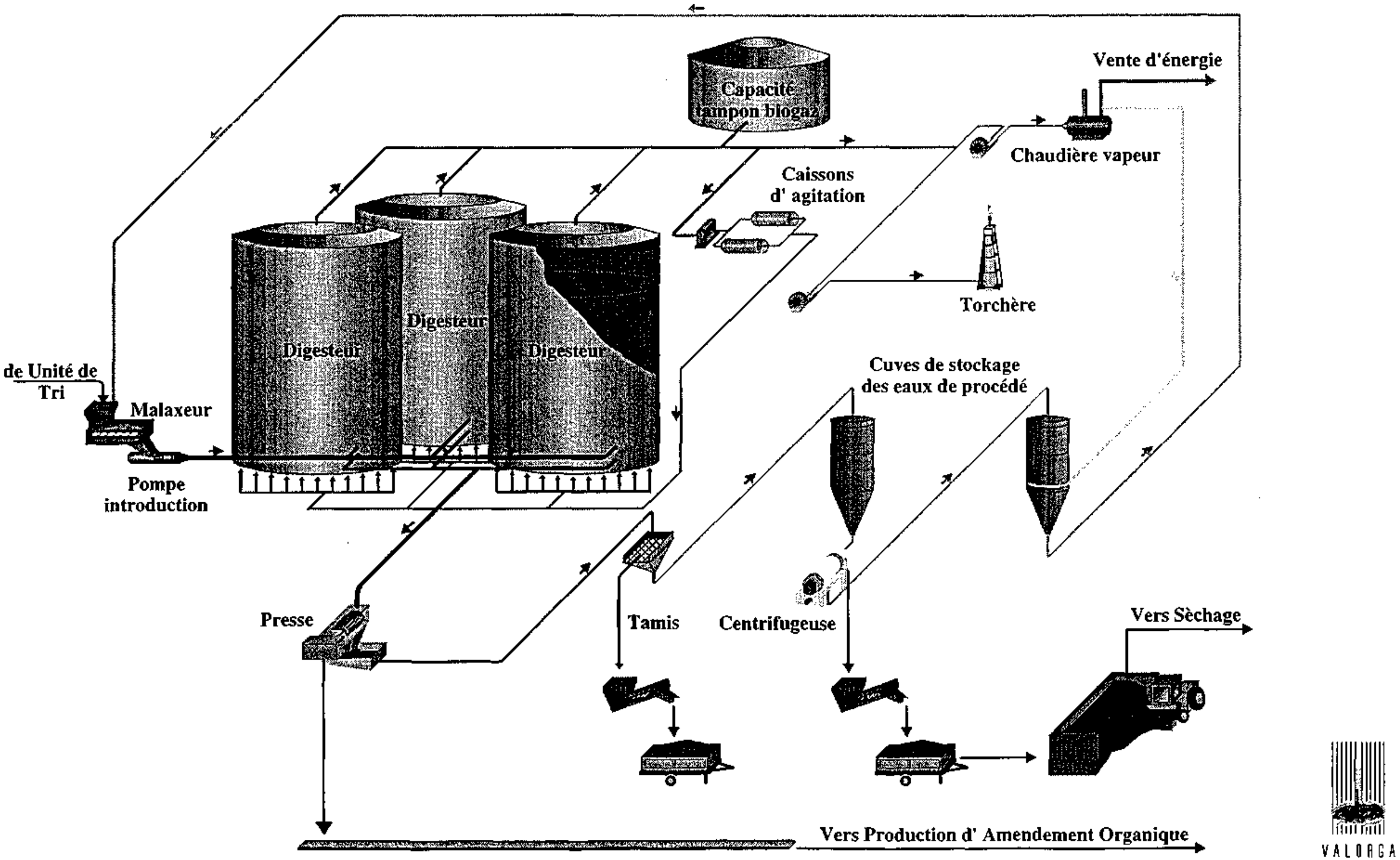
Valorga Process développe un partenariat avec des industriels et fournisseurs d'équipements de chaînes de tri avec qui elle peut s'associer pour répondre au mieux et lorsque nécessaire aux besoins de tri des déchets.

Schéma de la chaîne de tri



VALORGA PROCESS

Annexe 2 - Schéma de l'unité de méthanisation



Annexe 3 - Plan d'implantation de l'usine d'Amiens