

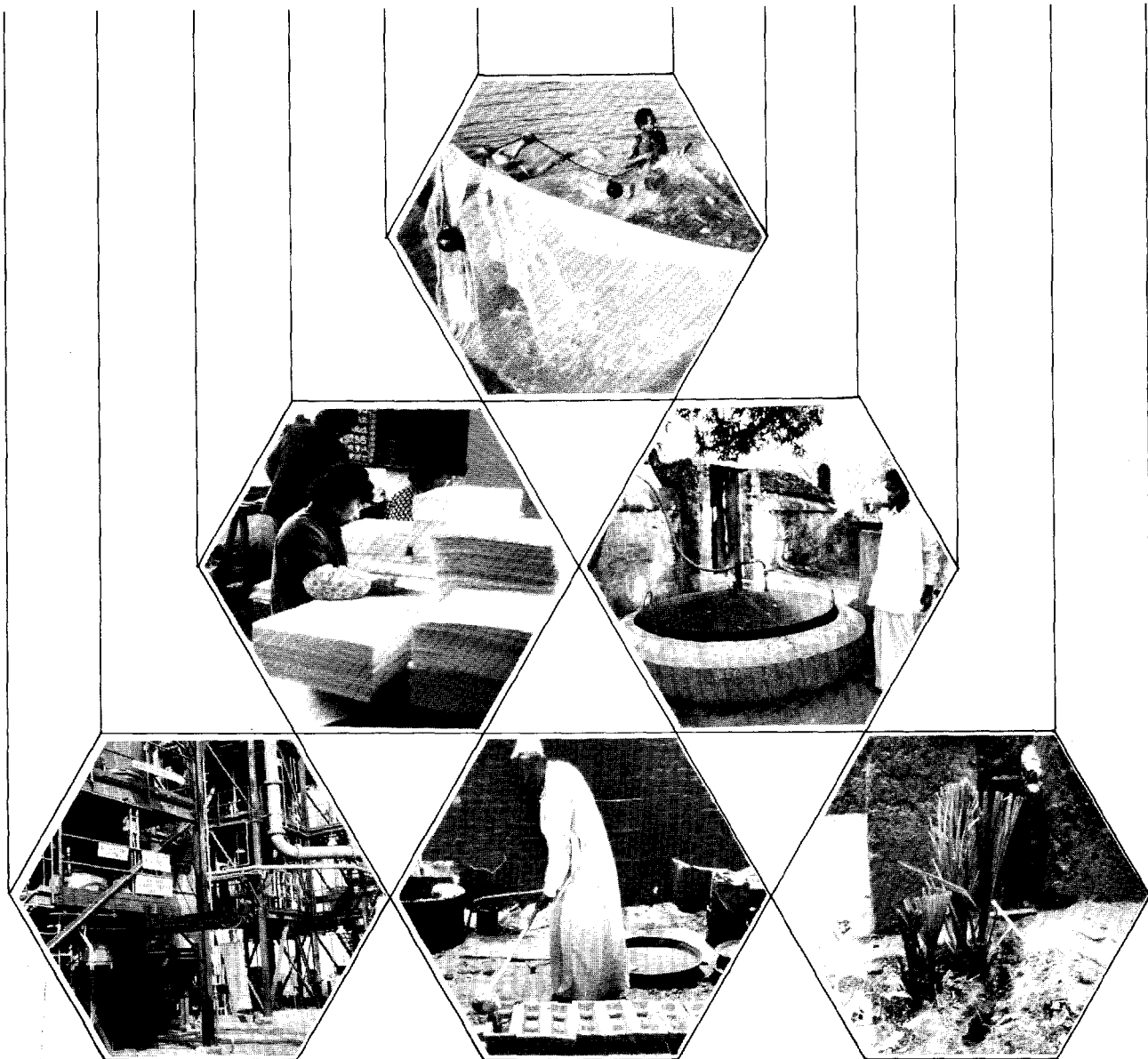
Integrated Resource Recovery

Municipal Waste Processing in Europe: A Status Report on Selected Materials and Energy Recovery Projects

WTP37

April 1985

James G. Abert



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April 15, 1985

Dear Madam/Sir:

Subject: UNDP/World Bank Integrated Resource Recovery Project
(Waste Recycling--GLO/80/004, GLO/84/007)

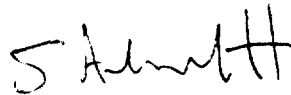
In 1981, a three-year Global Research and Development Project on Integrated Resource Recovery (Waste Recycling) was initiated as Project GLO/80/004 by the United Nations Development Programme through its Division for Global and Interregional Projects. The World Bank, through its Water Supply and Urban Development Department (WUD), agreed to act as executing agency.

The primary project goal is to achieve economic and social benefits through sustainable resource recovery activities in the developing countries by the recycling and reuse of solid and liquid wastes from municipal and commercial sources.

Increasing recognition of the need for technical and economic efficiency in the allocation and utilization of resources and the role that appropriate recycling can play in the water and sanitation sector has led to the inclusion of this project in the formal activities of the United Nations International Drinking Water Supply and Sanitation Decade.

This report deals with municipal waste processing in Europe. It is a status report on selected material and energy recovery projects. It is intended for those readers, primarily from developing countries, interested in the potential application of industrial country techniques for reuse and recycling of solid wastes. We wish to present the potentials of these processes when modified to the conditions of developing countries to decision-makers and other professionals.

The report was written by Mr. James G. Abert as one of the UNDP/World Bank Resource Recovery Series. Comments and remarks on this report are most welcome.



Saul Arlosoroff, Chief
Applied Research & Technology
(UNDP Projects Management)
Water Supply & Urban Development Department

Enclosure

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INTEGRATED RESOURCE RECOVERY PROJECT

UNDP/World Bank GLO/80/004

Recycling from Municipal Refuse (Technical Paper No. 30), 1984.
S. Cointreau et al.

Remanufacturing (Technical Paper No. 31), 1984. R.T. Lund, MIT.

Aquaculture (Technical Paper No. 36), 1985. P. Edwards.

FORTHCOMING PUBLICATION:

Health Effects of Wastewater Irrigation and Their Control in Developing Countries, 1985. H. Shuval et al.

RURAL WATER SUPPLY HANDPUMPS PROJECT

UNDP/World Bank INT/81/026

Rural Water Supply Handpumps Project Report No. 3: Laboratory Testing of Handpumps for Developing Countries, Final Technical Report, 1984. Consumers' Association Testing and Research Laboratories.

Rural Water Supply Handpumps Project Report No. 4: Progress Report on Field and Laboratory Testing (Technical Paper No. 29), 1984. S. Arlosoroff et al.

TO BE PUBLISHED IN JUNE 1985:

Rural Water Supply Handpumps Project Report No. 5: Proceedings of Workshop Ministry of Machine Building Industry, United Nations Development Programme, World Bank Workshop on the State of the Art and Application of Handpumps and Water Supply and Sanitation.
Changsha, Peoples Republic of China
August 15-21, 1984.

INFORMATION AND TRAINING
FOR LOW COST WATER SUPPLY AND SANITATION PROJECT

UNDP/World Bank INT/82/002

Water Supply and Sanitation Project Preparation Handbook, 1983.

Volume 1: Guidelines (Technical Paper No. 12). Brian Grover.

Volume 2: Case Studies--Identification Report for Port City, Immediate Improvement Project for Port City, Pre-Feasibility Report for Farmville, Pre-Feasibility Report for Port City (Technical Paper No. 13). Brian Grover, Nicholas Burnett, Michael McGarry.

Volume 3: Case Study--Feasibility Report for Port City (Technical Paper No. 14). Brian Grover, Nicholas Burnett, Michael McGarry.

Low Cost Sanitation Publications (TAG)

Ten working papers and technical notes on different aspects of low cost sanitation, latrines construction and others.

Integrated Resource Recovery

UNDP Project Management Report Number 4

INTEGRATED RESOURCE RECOVERY SERIES
GLO/80/004
Number 4

This is the fourth in a series of reports being prepared by the Resource Recovery Project as part of a global effort to realize the goal of the United Nations International Drinking Water Supply and Sanitation Decade, which is to extend domestic and community water supply and sanitation services throughout the developing world during 1981 to 1990. The project objective is to encourage resource recovery as a means of offsetting some of the costs of community sanitation.

Volumes published to date include:

RECYCLING FROM MUNICIPAL REFUSE: A State-of-the-Art Review and Annotated Bibliography

REMANUFACTURING: The Experience of the United States and Implications for Developing Countries

AQUACULTURE: A Component of Low Cost Sanitation Technology

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Anaerobic Digestion
Composting
Demand Analysis
Effluent Irrigation
Transferable Technologies
Ultimate (marine) Disposal

Series cover design (clockwise from top): Aquaculture using wastewater yields about 8 tons of fish per hectare per year in India. Biogas is produced from organic wastes in India. Sullage from a shower is used to irrigate a garden in the Sudan. The original value added to aluminum is captured by using waste oil to melt scrap and then pouring new ingots in Egypt. A "state-of-the-art" plant, built to demonstrate the pyrolysis of garbage to make fuel oil, has been shut down temporarily because of excessive operation and maintenance costs in the United States. Paper is recycled in a factory of the Shanghai Resource Recovery and Utilization Company in China.

WORLD BANK TECHNICAL PAPER NUMBER 37

Municipal Waste Processing in Europe

A Status Report on Selected Materials and Energy Recovery Projects

James G. Abert

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Washington, D.C., U.S.A.

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James G. Abert is a consultant to the World Bank.

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ABSTRACT

This report is published as one of the series to describe resource recovery-recycling options under the UNDP/World Bank Resource Recovery Project (GLO/80/004). The report does not intend to recommend any technology or components to the planners of waste management in the developing countries, but to expose different techniques that could be implemented or modified to conditions in these countries.

The technologies discussed include (1) shredding by hammermills and flails; (2) separation by air classifiers, magnets, eddy currents, ballistic separators, inclined stick-slip conveyors, vibratory screens or conveyors, optical or infra-red sensing, trommels, elutriation, and manual sorting belts; (3) pulping; (4) pelletizing; (5) drying and/or combustion in rotary kilns, flash dryers, fluidized beds, and conventional incinerators with or without heat recovery; and (6) composting. Included are resource recovery systems in Austria (Vienna), the Federal Republic of Germany (Herten, Neuss), France (Nancy), Italy (Rome), the Netherlands (Zostermeer), Spain (Madrid), Sweden (Stockholm, Kovik), and the United Kingdom (Newcastle-upon-Tyne, Doncaster, Westbury). Seven of the plants are operating at full or partial capacity, three are being tested, one is a pilot, and one is being reconstructed.

Emphasis is generally on production of refuse-derived fuel. Other products include ferrous metals, plastics, glass, paper, paper board, concrete aggregate, and by-product compost. All of the plants are capital intensive and subsidized to meet environmental priorities in solid waste management. In spite of favorable reports and promotion, few of the unit processes appear applicable to developing countries; components of systems operating in Rome (Sorain Cecchini) and Westbury (Blue Circle Cement) have the greatest promise.

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FOREWORD

Among the many studies and reports to be published under the Integrated Resource Recovery Project (UNDP GLO/80/004 - executed by the World Bank), we initiated a number of studies that describe various solutions to waste management devised in the industrial countries. We did it in those cases where we believed that implementation of such systems or components might be feasible in several developing countries.

Pilot, demonstration and operating systems in Europe promote resource recovery from municipal wastes, including waste-derived fuel. Because of the potential for economic return from appropriate selection of systems components, which can reduce the overall capital requirements and costs for waste management, the methods discussed should be of value to decision makers and supporting agencies in developing countries.

We look forward to receiving any comments and case study information, from which future editions will benefit. Please send them to Mr. S. Arlosoroff, Chief (WUDAT) and UNDP Projects Manager, Water and Urban Development Dept., World Bank, Washington, D.C. 20433, U.S.A.

PREFACE AND ACKNOWLEDGMENTS

This report is written in an attempt to answer questions of officials in the developing countries about waste processing facilities in Europe which attempt to recover materials for reuse and prepare a processed refuse-derived fuel. Mass burning facilities are not covered here. Visits were made to each of the plants described in the main sections of the report. (Figures and tables not otherwise credited are based on information gleaned from these visits.) Data on those plants mentioned in Chapter 14, "International Organizations and Other Recovery Activity," are based on secondary sources of information rather than first-hand observation.

The report focuses on: (1) the composition of the waste processed at each particular facility, (2) the equipment installed, (3) its operating specifications, (4) the current (1983/84) status of the plant, (5) the characteristics of the recovered products, and, to a lesser extent, (6) energy balance and (7) economic data.

There are two reasons for the lesser emphasis on economics. First, many of the plants are still in shakedown, accumulating test, evaluation and modification costs. Second, international comparisons of costs are particularly difficult at this time due to the volatility of exchange rates and the recent inflation.

In the first instance, knowing the costs associated with bringing prototype facilities on line does not tell the reader the cost of replication, which would not include the one-time costs of the prototype's start-up. The estimation of the replication costs for almost all of the plants reported on here awaits the passage of time and more site-specific detailed examination.

The author wishes to thank Dwight Reed, President of the National Soft Drink Association, who provided the leave of absence necessary to accomplish the site visits and supported the project throughout, as well as Beth Bolton and Tara Bowman who capably typed the text.

James G. Abert

1. MUNICIPAL WASTE PROCESSING IN EUROPE: A STATUS REPORT

The purpose of this report is to provide developing countries with scientific, technical and economic information on alternative and potentially adaptable technologies for resource recovery that take advantage of current European municipal waste-processing practices. Many development and developing country officials express a need to obtain information on the increasing number of resource recovery facilities in Europe as well as in the United States and Japan. This report looks at current European efforts to separate material resources from household waste and to process the waste so that it may be used as a supplemental fuel source. The burning of waste, as it is collected -- without any processing to extract material resources or improve its fuel characteristics-- is not covered in this report; neither is the separation of recoverables from the waste by the householder. Although this report does describe some handsorting at central locations, it is only mentioned when handpicking is a part of a larger mechanized separation operation. The latter, the mechanized processing, is the primary focus of this report.

The twelve European operations reviewed here represent the principal efforts being made to recycle resources based on municipal waste, including the production of a processed fuel, both in Great Britain and on the continent. Of the facilities described, three are in the United Kingdom, one in Spain, one in Italy, one in Austria, one in France, two in the Federal Republic of Germany, one in the Netherlands, and two in Sweden (see Table 1). Chapter 14 discusses other recovery activity apart from that described in detail in the twelve plant-specific sections.

These focus on the current flow sheets for the facilities. Each unit process is described in some detail. Start-up and operational problems are also discussed in each case, along with such financial detail as can be obtained. Where available, energy balances (or energy utilization) are also given. Because of the start-up nature of much of the waste-processing activity and because virtually all of the plants have gone through, or are currently involved in, extensive modifications, economic information is of little value for comparative evaluation with respect to the question of constructing second or third generation plants, whichever the case may be, in Europe, let alone in a developing country. While unfortunate, this is generally the case with the development of any new technology, and waste processing is no exception. Comparative economic analysis awaits the passage of time.

As for additional operating descriptions and detail on physical characterizations of the unit process, each chapter contains references and a list of contacts from which further information may be obtained. As mentioned, the report closes with a discussion of other waste-processing activity in Europe and a final series of summary comments on the overall situation there.

Table 1: Facilities Described in This Report

PROCESS, INVENTOR OPERATOR, LOCATION	CAPACITY	STATUS OF DEVELOPMENT	ESSENTIAL UNIT PROCESSES	PRODUCTS
Byker, UK	30 tph	Production plant (Operational)	Shred, Trommel, Air Classification, Screen, Initial Pelletization, Dry, Final Pelletization, Magnet	dRDF (for co-firing for district heating). On-site boiler. Ferrous.
Doncaster, UK	10 tph	Production Plant (Operational)	Trommel, Air Classification, Screens, Dryer, Pelletization, Counter Current Wash. Optical Sorter, Infra Red (Test)	dRDF (for external sale) Ferrous, Colored Mixed Glass Paper/Cornugated (Test)
Westbury UK; Blue Circle Cement	17-20 tph	Production Plant (Operational)	Primary and Secondary Shredding, Screening, Pneumatic Transport	RDF, Ferrous
Madrid, Spain: ENADIMSA	10 tph	Pilot (Operational)	Flailmill, Trommel, Paper Separator, Adhesive Belts, Ferrous Clean Up, Snappy Screens in Compost Clean Up Circuit.	Paper, Plastics (light and heavy), Ferrous, Compost
Rome, Italy: SORAIN CECCHINI	20-22 new line *	Production Plant (Operational)	Bag Opener, Trommel, Air Classifier(s), Differential Shred, Screens, Pulping RDF, Plastic Clean Up, Special Compost Equipment.	Ferrous, Paper, Plastics, RDF, Compost
Vienna, Austria: RINTER	Two lines, 20 tph each	Production Plant (Closed, Undergoing Reconfiguration)	Bag Opener, Shredder, Air Classifier(s), Hot Air Classifier, Wet Rotary Screen, Paper Pulp, Dewater, Wet Lap	Ferrous, Fibers, Plastics, RDF, Compost
Nancy, France: REVALORD	Three lines 7-8 tph each Plant total 22 tph	Production Plant (Shakedown)	Trommel, Screen, Air Knife, Bounce/Stick Ballistics Separator, Air Table, Optical Sorter, Electronic Sorter	Paper, Cornugated, Glass FVC Plastic, Ferrous, RDF
Herten, Germany: MVU	Two Lines, 25 tph each	Production Plant (Shakedown)	Trommel, Shredder, Hot Air Classifier/Dryer, Trommel, 2nd Shredder, Pellet Mills, Cooler.	dRDF, Ferrous
Neuss, Germany: TRIENKENS	60 tph plus 6 1/2 tph Industrial/ Commercial	Production Plant (Operational)	Hand Pick of Industrial/ Commercial, Trommel, Shredder, Trommel, Air Classifier, Bioreactor.	Paper, Plastics, RDF, Ferrous, Compost
Zoetermeer Netherlands: ESMIL	20 tph	Production Plant (Shakedown)	Bag Opener, Magnet, Air Knife, Shredder, Air Classifiers, Rotary Plastic/Paper Organic Separator(s).	RDF, Plastics, Ferrous, Gravel Substitute
Stockholm, Sweden: FLM	27-30 tph	Production Plant (Operational)	Shredder, Ballistic Separator/ Screen, Dryer, Pelletizers, Cooler.	dRDF, Ferrous, Compost
Stockholm, Sweden: FLAKT	12 1/2 tph	Production Plant (Operational)	Special Light Shred, Trommel, Air Classifier, Shredder, Trommel(s), Flash Dryer.	Paper, Plastics, RDF, Ferrous

*over 1000 tpd plant disposal capacity

Current Status of Municipal Waste Processing in Europe

In many instances the information that officials in developing countries hear about the status of waste-processing facilities in the developed countries tends to be somewhat exaggerated. With few exceptions, waste-processing facilities worldwide are still in the developing stage. Few of these plants have had results commensurate with the expectations held for them.

In part, this has been due to difficulties in the marketplace. Because of the international recession, the market value of secondary materials, even of the better grades, has been severely depressed. And, when market prices for superior grades of secondary paper, ferrous metals, and plastics decline, buyer standards generally increase. Since material separated from household waste is seldom of the best grade, it is difficult, if not impossible, in this circumstance to market the material extracted from the waste at any price.

The main difficulties, however, are technical. The problem of separating even reasonable quality materials on a day-by-day operational basis has proven to be more consequential than anticipated. The waste material is difficult to handle because of its great variability. There are several dimensions: variability in composition, in particle size and in moisture content. As a result, it has not been easy to devise appropriate equipment to handle such materials over the range of variability exhibited. What works fine for one set of physical characteristics proves to be less than desirable for another, indeed, sometimes fails to work at all when these characteristics change -- and they sometimes change hourly, more often by day of the week, and almost universally by season of the year.

Hence this status report is by and large a chronicle of the attempts of developers to modify their initial engineering judgments to take into account the realities of day-to-day operations. As for waste processing in general, the industry is probably still a number of years away from the point at which the initially specified equipment for any recovery operation -- even one based on several prototype experiences in different settings -- will not require some modifications "on line" to enhance its performance.

The problem is simply that waste processing is going through stages of evolution that virtually all manufacturing processes experience. Often this takes decades. It is unrealistic to expect that waste processing would shorten this process. There are no pat answers to solid waste management problems. For some number of years, perhaps as long as a decade, this means that the investment in recovery technology will bear a certain level of risk, whether done in a developed, industrial country or whether undertaken in a developing one.

The problems in developing countries are compounded by the differences in economics. The principal motivation for the investment in waste processing in the developed countries is the high cost of waste disposal. The search for a technological solution is driven by the relatively high cost of labor versus the cost of capital. For the most part, neither of these sequential conditions exists in the developing countries. In the developing countries resource scarcity, particularly that involving foreign exchange expenditures, may be the driving factor. Even then, a labor-intensive approach may be preferred to a capital intensive one.

Focus of the Text

What information, then, does this report provide? First, as noted at the outset, it provides a current (as of approximately the middle of 1984) account of the status of twelve operating facilities in Europe. This information can be compared with other available data on the situation at these plants. Independently done, the reports provide a source of factual information.

Second, it is expected that if technology transfer is possible with respect to the machinery utilized in these plants and the requirements for waste processing in a developing country, it will likely be confined to individual unit processes. Special attention has been given in this report to the description of selected unit processes, particularly the initial size classification and separation steps used by each facility. In the main, the objective of these initial steps is to separate what is primarily a combustible material from the remainder of the waste. It is believed that such an objective has merit for the potential use of the residue waste in developing countries as well. The products are a potential fuel and a relatively easy handpickable materials concentrate.

Third, the report gives an idea of the effectiveness of particular unit processes and lays a basis for an evaluation of their suitability for developing countries. To continue with the example just given, in a developing country, a simple rotary screen that separates the moist organics, dirt, and ash from larger fragments of paper and plastics and some agricultural matter could radically affect the potential for utilizing the waste as a fuel source. This is because the material containing larger particles will have a higher energy content and a lower moisture value in relation to the average for the previously mixed waste and, hence, will be a better fuel. The material containing smaller particles will also be improved as a candidate for handpicking. Care has been taken to assemble as much unit process input-output data as could be obtained both from site visits and other sources, published and unpublished. Output characteristics taken in relation to those of the input feedstock are the basic substances of any effectiveness evaluation. They allow for a degree of prediction as to a device's adaptability to circumstances with different waste composition.

Fourth, this report provides a fairly comprehensive listing of contacts for each facility discussed, which includes the name, title, address, telephone number, and often telex code. In addition, Chapter 14 provides a listing of contacts that includes governmental sources. This chapter also examines the work being undertaken by the European Economic Community. Several Directorates are currently sponsoring what appears to be the most comprehensive program of research development and testing for waste processing in the world.

Throughout the text, an effort has been made to report on the initial capital and current operating costs of the facilities covered, but, in addition to the cautions already given, care should be taken in translating these to any other currency, or to any other construction and operating environment. In the first instance, most of these plants were built during a period of relatively rapid inflation in building costs. With inflation running at 10 to 15 percent per year, the margin for error in estimating accurately what a plant built in, say 1978, would cost today is quite significant. Likewise, the difference in skill levels and labor rates, even among industrial countries, let alone between the industrialized segment of the world economy and the developing segment, is quite well known. This makes it rather difficult, and indeed misleading, to make a comparative evaluation of operating economics.

Initial Processes: Size Separation versus Size Reduction

The first group of waste-processing plants constructed in the United States and in Europe utilized one or more high horsepower, size reduction hammermills as the first step of unit processing. The idea was to decrease the variability in particle size by bringing the large particles down to a nominal size approaching that of the smaller ones. To accomplish this task, all of the waste was fed into the hammermill. While it has been learned that some previewing of the material is necessary, size reduction can be effectively accomplished and it remains one of the primary approaches to starting the sequence of steps for recovering resources from household waste.

Previewing is necessary to eliminate hazardous materials that could cause explosions, certain types of oversize materials that could either damage the shredder or block the operation, or material that is simply difficult to shred, such as rolled up rugs and mattresses. As these have virtually no recovery value, little is lost by separating them from the waste.

However, a second school of thought has emerged regarding the most desirable initial step in the process flow. This school, which favors the use of a trommel screen, argues that since much of the material is already of a relatively small particle size, it is not necessary to pass it through a size reduction unit. Also energy is used processing this already undersized waste. Some is even made smaller, perhaps so small in

the case of glass as to be unrecoverable. Furthermore, it is said that the general mixing that takes place in the initial hammermilling step often makes recovery more difficult at subsequent steps in the process flow.

Of the twelve sites discussed here, five use hammermilling as the initial processing step while five use a trommel screen (see Table 2). The remaining two facilities have settled on a compromise of sorts in that they use a flail mill. Rather than solid masses of steel, which make up the hammers in the hammermill, the flail mill has wire or chain breakers attached to a rotating shaft. The flails cut up organic material, open plastic bags, but fold up or go around objects that they cannot cut.

Table 2. Initial Process: Size Separation versus Size Reduction

<u>Plant</u>	<u>Equipment</u>
Byker (U.K.)	Hammermill
Doncaster (U.K.)	- Trommel Screen
Westbury (U.K.)	Hammermill
Madrid (Spain)	Flail Mill
Rome (Italy)	- Trommel Screen
Vienna (Austria)	Hammermill
Nancy (France)	- Trommel Screen
Herten (Fed. Rep. of Ger.)	- Trommel Screen
Neuss (Fed. Rep. of Ger.)	- Trommel Screen
ESMIL (Netherlands)	Hammermill
PLM (Sweden)	Hammermill
Flakt (Sweden)	Flail Mill

There is less mixing of the waste than with the hammermill configuration and there is less shattering of glass. The latter feature is important when glass is to be recovered or when it is desirable to minimize the amount of glass carried over into the fuel product -- where it becomes part of the ash -- which is a noncontributing residual in the combustion process. Obviously, a lower ash fuel will be preferred by the user.

In plants that employ initial screening, one or more size reduction steps generally follow. These operate on the oversize fraction that remains after the initial screening. The trend in the design of waste-processing facilities seems to be toward initial trommeling rather than initial hammermilling. However, there is still a good deal of variation in the diameter and the hole size of this initial trommeling step (Table 3).

Table 3. Trommel Screens: Usage and Hole Size

Initial Unit Process Size Separation	
<u>Plant</u>	<u>Fraction</u>
Doncaster (U.K.)	+40 mm + 200 mm x 350 mm. Separate fines and oversized from product.
Rome (Italy)	+80 mm. Oversize separation, - 30 mm fines removal.
Nancy (France)	+50 mm, Squirrel Cage (180 mm centers), +200 mm.
Herten (Fed. Rep. of Ger.)	+60 mm. Fines removal.
Neuss (Fed. Rep. of Ger.)	+120 mm. Oversize paper/plastics rich product.
Size Reduction Followed by Trommel Screening	
Byker (U.K.)	After Shredding: +15 mm, +150 mm, Fines - 20 mm and oversize removal.
Madrid (Spain)	Flail Mill. Lights, after air classification, +25 mm. Fines removal.
	Heavies, after air classification, +70 mm; then +15 mm. Fines removal.
Flakt (Sweden)	+220 mm after coarse shred. Air classification -200 mm, shredding, +40 mm Fines -20 mm.

In some cases the main purpose of the initial trommel simply is to remove fines from the fraction to be processed for paper and/or plastics recovery, or to be processed into fuel. In others, the purpose is more complex since it sets the stage for a number of further size separation processes. In Herten, Federal Republic of Germany, for example, the initial trommel has only one size hole, screening out -60 mm fraction, which is essentially a discard.

On the other hand, in the Nancy, France, facility the initial trommel accomplishes several separations: it (1) separates a -50 mm fine fraction for further processing, particularly for glass recovery; (2) separates flat pieces of cardboard and newspaper for later handpicking by means of squirrel cage segment of the trommel; and (3) passes out, as an oversize, paper and corrugated boxes also for handpicking, from a +200 mm fraction.

Table 3 gives an idea of the variability that exists among facilities even in units that serve basically the same purpose. Such variability may be related to a difference in waste characteristics or simply to a difference in design concepts and engineering judgments. Table 3 also serves as a lead into the individual facility chapters. Illustrating the diversity within a single unit process naturally leads one to expect a diversity in equipment suits taken in total.

Density is used as the means of separation in two types of unit processes. The most common is air classification. Here the light material is blown away from the heavy material. In several facilities density differences allow for separations to be made by a rising current device where the mixed material is emersed in water; the lighter material floats off and the heavy material sinks.

Several other plants rely on adhesion to accomplish separation. Here, wet moist material, usually paper or garden waste, clings to a belt and is carried away while other materials such as plastic bottles, metals and glass roll down the belt. Almost all plants take advantage of the magnetic property of ferrous material to remove it from the mixed waste. One plant, in Nancy, France, even takes advantage of electrical conductivity -- that is, eddy current separation -- to extract aluminum and polyethylene containers from the waste stream. Even when shredding is used for size reduction, some innovations have been made on the basis of the shredder's tendency to chop paper into small segments while stretching and pulling plastic into longer pieces. Such shredding allows for both differential screening and differential air classification of plastic and paper at later steps in the processes. Finally, in two facilities -- in Doncaster and Nancy -- optical separation is utilized to separate glass from opaque materials such as rocks, stones, seashells, and the like. The recovered material is a usable, although color mixed, glass meeting the specifications of the glass container industry for remanufacture into bottles and jars.

The final form of the fuel fraction from the processed waste may be either "fluff," or the fluff material may be "pelletized" to make the fuel easier to transport and to give it a longer storage life. Because of the moisture level of most European waste (20 to 30% or higher), to obtain pellets with the desired properties of hardness and integrity, the feedstock, even though it has been processed, must be dried before pelletizing. Most plants have had to retrofit driers for this purpose, and this has led to several different approaches.

At the Byker facility in the United Kingdom, for example, the drying takes place between an initial and a final step of pelletization. At the Doncaster plant, however, the drying takes place before the initial and only stage of pelletization. The experience with drying should be of particular interest to those evaluating the potential of waste processing in developing countries, where wastes generally have a higher moisture content, particularly during the rainy season, than is the case in Europe. That means some type of drying operation will be needed to process this waste into a viable fuel whether fluff or pelletized. This is discussed at greater length later in the report. This is only one example of the lessons that can be learned from an examination of the current status of waste processing in Europe.

While the text of this report cannot completely describe the totality of Europe's experience with waste processing -- even for the facilities described in the twelve plant-specific sections -- the reader is directed to sources of supplementary information through the reference and citation listings appearing at the end of each section.

2. BYKER RECLAMATION PLANT (UNITED KINGDOM)

The Byker plant at Newcastle-upon-Tyne recovers energy and ferrous metals from waste materials. It is designed to process a maximum input of 480 tons (long) of municipal waste daily, for sixteen hours, five days a week. The product is a fuel pellet sometimes called densified refuse-derived fuel (dRDF) that is burned on-site for district heating. The plant, which was opened in October, 1979, is in operation at present, although it suffered the pangs of shakedown that have troubled all municipal waste-processing facilities. Because the plant's construction, operation, and modifications have been supported by the U.K. Department of Environment, considerable data are available on the operation of the facility. The Department of the Environment requires an evaluation component to be included in the shakedown and operating procedures of the projects to which it supplies partial funding. The Warren Spring Laboratory carries out much of this effort for the Department of the Environment.

The stages of treatment at Byker consist of a primary pulverizer, a rotary screen, a rotary air classifier, magnetic separation from the heavies followed by landfill, screening of the lights for additional removal of fines, secondary shredding, a first stage of pelletizing producing predensified material, drying, a second stage of pelletizing followed by pellet cooling. This flow of materials is shown in Figure 1. The pellets are cofired with coal. Weight reduction, in relation to the input waste, is on the order of 30-50 percent and volume reduction 60-70 percent. The refuse-derived fuel that is produced represents about 35 percent of the input waste (by weight). Ferrous metal scrap recovered is 6 percent. Table 4 gives the breakdown of the plant's refuse feedstock.

Description of the Plant and Operations

The description here is based on the references cited at the end of this section. Collection vehicles entering the site are weighed and their weights are automatically recorded. They then proceed to the reception hall in which they discharge into a separate storage area. The discharge area is indicated by a series of traffic lights operated from a small control cabin in the reception hall. This system ensures that the vehicles discharging their loads will not interfere with the operation of the front-end loader working on the storage floor. This area, with its 5 meter drop from the reception hall, allows the collection vehicles to discharge and turn around quickly and also affords 500 tons storage. As a result, plant operations can be carried out independently of vehicle deliveries. It is believed that the storage area and method of waste handling are an improvement on most traditional systems in that refuse can be handled with a conventional four-wheel loader instead of an overhead crane. Thus plant availability is better and the building can be lower and therefore more economical to construct.

Figure 1. Flow Diagram for Byker Reclamation Plant

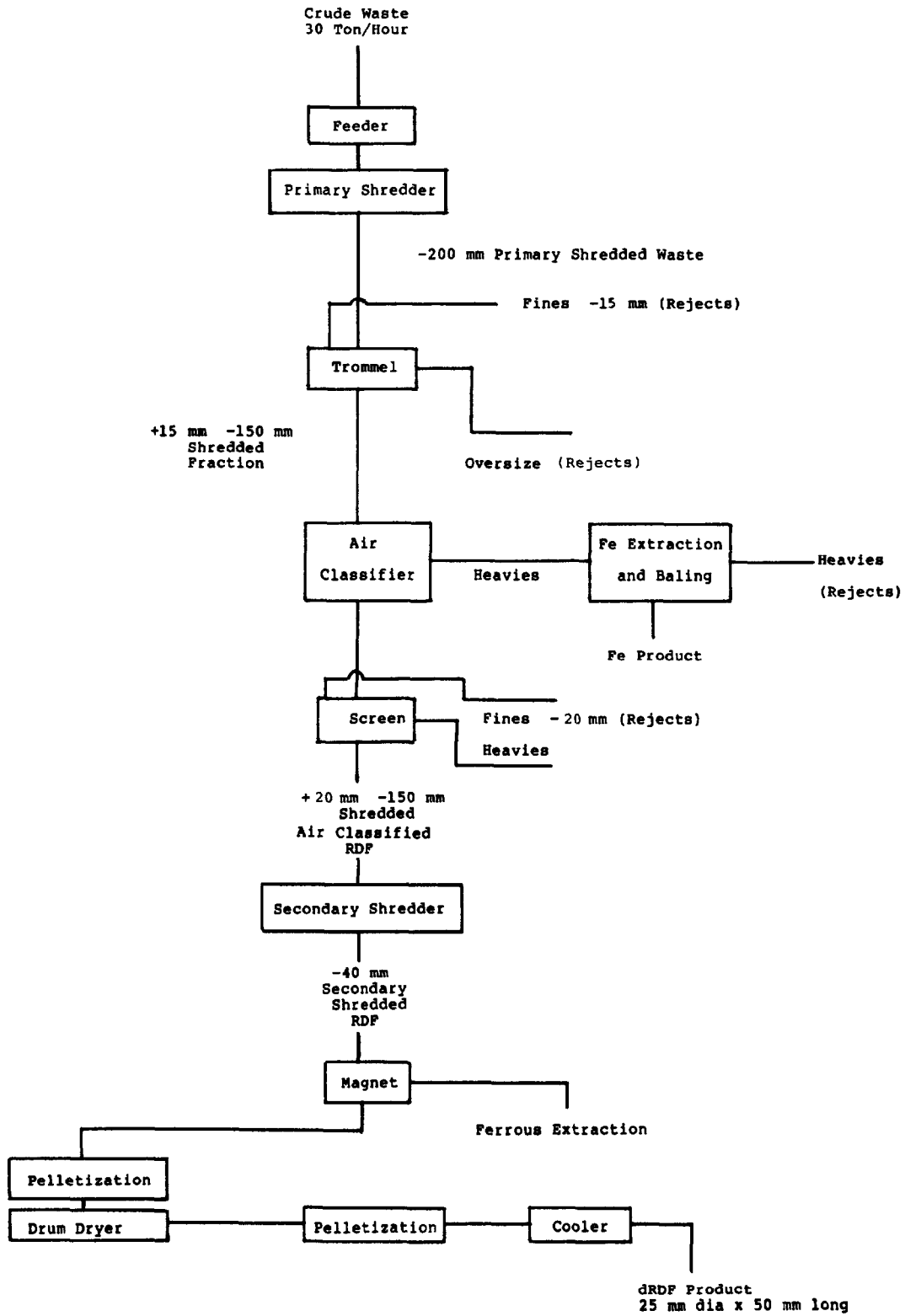


Table 4. Refuse Analysis

Waste Composition	Design Range % by Weight	Tonnage Based on 30 TPH
Screenings below 12 mm	10-15%	3.66
Paper and Cardboard	30-40%	10.25
Vegetables & putrescibles	15-25%	5.87
Textiles, rags, etc.	3-5%	1.17
Plastics, Rubber - all types	4-8%	1.76
Wood	1-2%	0.43
Ferrous Metals	8-10%	2.63
Nonferrous Metals	1-2%	0.43
Glass	8-10%	2.63
Unclassified	3-5%	1.17
		30.00

Moisture Content: 20-30%

Density: 6 cubic meters per ton average

Source: Hewitt and Wall, "Byker Reclamation Plant," p. 4.

The front-end loader is used to separate large items, for example, washing machines, refrigerators, and the like, from other articles, which, although they may not have any economic value, could be hazardous to the unit operations in the plant, particularly the shredder.

The Byker Reclamation Plant is run by the waste disposal department of Tyne and Wear County Council. The county also operates four incinerators and two transfer stations to serve a population of 1.2 million. If the reclamation plant should ever be out of commission and forced to use its transfer options, the material could be taken to one of the existing incineration plants.

Advantage has been taken of the sloping topography of the site to provide a load-out station under the storage area so that, if the processing plant happens to be out of action for any reason, the whole plant can operate as a simple transfer station, with the refuse from the storage area being transferred through slots to large capacity vehicles stationed in the subway. The slots are actually two metal doors which, when lifted, allow the raw refuse to be loaded into vehicles located below the floor in the transfer subway.

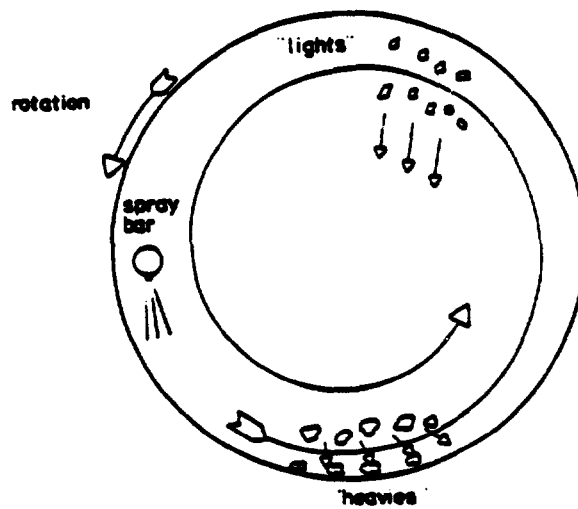
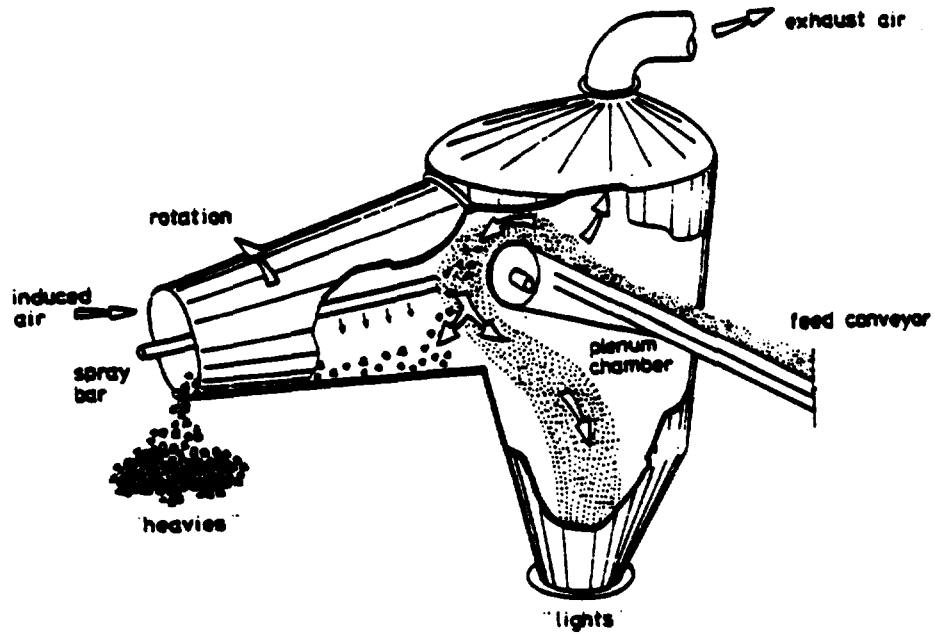
Further development of the plant has since introduced a small conveyer after the shredder, but prior to the rotary screen and going to the rejects load-out station. This means that, should the separation portion of the plant be out of action, but the shredder operative, pulverized material can be loaded directly to large capacity vehicles under the rejects slot. The advantages of this modification are: (a) increased payload of transferred material because of the greater density with pulverization; (b) faster reduction of storage material because of greater payload; (c) better economical use of driver/vehicles; and (d) continuous operation at feed end of plant.

During normal operations, the front-end loader pushes the raw refuse onto a vibrator feeder with a small reception hopper. This feeder regulates the flow of refuse to the primary pulverizer. This is a 500 hp Newell Dunford vertical shaft hammermill, which reduces most of the refuse to particles -150 mm in size. The machine is rated at 40 long tons per hour. This shredder is also known as Tollemache. In the United States it is manufactured by the Heil Company. The machine features a ballistics reject chute for dense objects, which is approximately 0.05 percent of the input for U.K. refuse. This product, together with the rest of the shredded refuse, is elevated by a plate conveyer to the next processing step, a rotary screen.

The conveyer moves the shredded waste into a chute from which it is carried by another conveyer into an enclosed rotary device (2.5 m diameter), called a trommel screen. This screen is divided into three sections. Each has different hole sizes through which undersize material passes. The holes in the first section are smaller than those in the second and third. The first section removes primary organic fines less than 12 mm, which are taken to landfill. The second section removes the product of interest which is between 12 mm and 150 mm. This is elevated by belt conveyer for feeding to an air classifier. The third section removes oversize material which is also taken to landfill. The largest pieces exit the end of the trommel and are taken to landfill as well.

As stated, the middle fraction is conveyed to the air classifier, where lights are separated from heavies. The Newell Dunford air classifier (Figure 2) consists of a rotating cone with its access at a low angle to the horizontal. Pulverized refuse is fed into the cone at its large end. Inside the cone the refuse encounters an induced flow of high velocity air, which enters at the small end of the rotating cone and conveys the light combustibles into a plenum chamber, where they are deentrained and collected. Recently, lifters have been welded into the rotating cone to raise the light material and drop it into the air stream, thus improving the separating ability of the device. Earlier, compressed air was used to create this effect, but this was both ineffective and expensive. The heavies cascade out of the small end of the cone and the air is recirculated with a continuous bleed to atmosphere through a series of wet dedusters. Heavies are readily discharged because of the cone's

Figure 2. Newell Dunford Classifier



Note: Compressed air spray bar has been replaced with lifters.

Source: Porteous, A., Refuse-Derived Fuels. London: Applied Science Publishers Ltd., 1981, p. 32.

rotation and its inclination to the horizontal. About 60 percent of the separation of the light and heavy fraction takes place between the point at which the waste leaves the head roller of the feed conveyer and the point where it hits the inner surface of the cone at the large end.

The air-classified heavy fraction has a density of approximately 222 kg/m³. It consists mainly of ferrous and nonferrous metal, glass, rubber, wood, plus some wet paper, vegetable matter, and cardboard. This heavy fraction is carried by a conveyer under a magnetic separator from which the extracted magnetic metal is fed to a reciprocating feeder, weight hopper, and an automatic metals baler. The baler discharges by a slideway into a skip for transportation and for subsequent processing. Metals recovery is just under two tons per hour. The air-classified heavy fraction, once the ferrous metal has been extracted, has a density of about 170 kg/m³. This reject material represents about 60 percent (by weight) of the waste initially brought into the plant. It is distributed into one of two trucks by a system consisting of a reversing conveyer and two spreaders.

The Byker plant has had some important first-phase modifications. As mentioned earlier, the primary rotary screen -- the trommel -- was designed to carry out three functions: (1) remove a high percentage of fine (-12 mm) materials; (2) size the product feed to the air classifier within a range of +12 mm to -150 mm; and (3) reject oversize material (+150 mm), including large textiles, and tramp metals. This device was found to be less than satisfactory for two of the three functions. First, fines removal was very inefficient; only about 25 to 35 percent of the fines were removed (note that 30% of the total waste consists of -12 mm fines). Second, an excessive amount of less than 150 mm (that is, potential air classifier feed), was being carried over as oversize. In the first instance, much of this fine material is noncombustible and therefore it detracts from the fuel quality of the refuse-derived pellets. In the second instance, the loss of potential fuel to the oversize has a negative effect on the economics of the plant.

Various attempts were made to increase the efficiency of the fine screening section, primarily by increasing the size of the holes. Although this method did help to improve the fine reduction efficiency, it also sacrificed the potential fuel product as more combustibles were screened out in the first section of the trommel. It was decided that a better solution would be to add a further screening step to the system and to place this right after the air classifier. The machine selected for this operation is a PLM ballistics separator that not only screens out fines (-20 mm), but also ballistically classifies between light and heavy material. This equipment, made in Sweden, is described in more detail in Chapter 12. It is sufficient to point out here that the PLM ballistic separator classifies by mechanical agitation rather than by combined mechanical and air stream separation.

The problem of loss of material to the oversize was resolved by enlarging some of the holes in the air classifier feed-screening section. This was done by trial and error. The results are described below. Also, the retention time in the primary shredder was increased in order to decrease the nominal particle size of its output.

At the present time the first section of the trommel is -15 mm while the second section contains some 6-in round holes, some square openings 10 by 10 in, and some rectangles 10 by 8 inches.

The light fraction is discharged from the PLM ballistic separator into a secondary shredder, which is of the horizontal hammermill type. The nominal size of the product of this shredding step is 40 mm. This shredded light fraction is transferred from the secondary shredder onto another conveyer which passes under an electromagnetic overband separator to remove any small ferrous metal objects remaining.

The shredded fraction (Table 5) is discharged from an elevating conveyer to a dual-purpose drag link conveyer, which feeds this material directly into the feed hopper for the pelletizers, or alternately to the overfeed storage hopper, which also acts as a leveling conveyer. Here feedstock can be stored for about 20 minutes of pelletizer operations. Provision is made in the pelletizer feedbox to pass feedstock over a sensor that indicates moisture content. If necessary, water or other liquids -- binders -- could be added before pelletization, but this has not been necessary because the material has actually been too wet for proper pelletization.

Table 5. Initial Pellet Mill Feedstock

<u>Size</u>		<u>Composition</u>	
<12 mm	10%	Paper	80%
12-50 mm	54%	Plastics	10%
50-125 mm	33%	Textiles	5%
>125 mm	3%	Misc.	5%
<u>Density</u>		<u>Moisture Content</u>	
40-70 kg/cubic meter		20-25%	

Source: Hewitt and Wall, "Byker Reclamation Plant," p. 6.

When the moisture level is approximately 15 percent, one can produce high-quality, hard, biologically stable fuel pellets derived from household waste. Higher or lower moisture levels cause problems. At the Byker plant, the moisture range turned

out to be in the range from 20 to 40 percent, with the majority of the pellet mill feedstock between 25 to 35 percent. It was found that during the initial operating phase, selected commercial-type waste, which has a lower moisture content than household waste, could be made into acceptable pellets. But, because of the higher moisture content of the household waste, pellets made from it broke apart and did not have either the stability or the integrity required. These pellets became known as grott. Mixing of the more moist household and the drier commercial waste was tried at various points in the process, that is, at the front end and elsewhere, but the material could not be mixed adequately to produce a feedstock consistently lower in moisture. Instead, the materials having a different moisture content became layered in the pellets and the pellets broke apart regardless of the mixing. It was therefore concluded that some type of drying system would be required if hard, stable, refuse-derived fuel pellets were to be produced from the household waste.

Another initial problem was that the pelletizing machines were not reliable. This was corrected by trial and error by the machine manufacturer (Simon Baron) and the plant operators. The throughput of each of the Simon Baron machines installed at Byker was established at approximately 4 to 6 tons/hr on low moisture content material (15-25%) to 10 tons/hr or more on high moisture content material (upwards of 25%). The availability figure was raised to upwards of 85 percent. Note that while throughput goes up as moisture content increases, the machines are not making pellets, but rather the grott referred to above.

There was little space available within the plant to add a drying operation. Options considered were to dry the pellet feedstock, which is the more conventional approach, or to go ahead and make the grott and then dry this material and add another stage of pelletization. This second approach was adopted. Grott production became known as predensifying. This predensification is accomplished with the two pelletizers originally installed in the plant. The predensified material is dried in a rotary cascade dryer. A third pellet mill has been purchased and installed, this time a California pellet mill (CPM) with a 24 in diameter die.

The pellets from this mill are discharged into a cooler, where they are conveyed on an open-mesh continuous metal belt through which air is drawn to cool them. The pellets are discharged from the cooler to a boom conveyer. The air used for cooling is drawn into the dust extraction system. Chaff also withdrawn from the cooler is recirculated as feedstock to the CPM mill.

Currently the output of the plant is about 9 tons/hr of pellets 25 mm in diameter and 50 mm long. The bulk density of the pellets is about 37 lb/ft³. The ash content is estimated by plant personnel to be about 12 percent, which seems low. For an input of 30 tons/hr, approximately 10 tons/hr of grott, that is,

predensified material, is produced. The dryer removes about 18 percent of the weight of these pellets, which, with the drying action of the first stage of pelletizing itself, produces material in an acceptable range of moisture for efficient final pelletization. Dryer temperature is 450o F at the intake, and 100o F at the outlet. Approximately 6 lb/ft³ of light material is fed to the initial stage of pelletizing. The grott produced during this step is between 15 and 20 lb/ft³. Final pellet density may reach 40 lb/ft³.

Adding the dryer and the second pelletizing step was the most significant modification made to the plant's original equipment. As mentioned earlier, the Newell Dunford air classifier at first used a compressed air system. The compressed air was introduced into the cone through air jets mounted on the tube located parallel to the access of the cone. The compressed air, which moved in the same direction as the cone surface, caused turbulence in the waste as it fell into the cone. The air expanded toward the large end and carried the light fraction from the waste with it into the plenum chamber. The compressed air and the secondary air-fed axleloy, created a spiraling motion toward the large entry. However, the cost of compressing the air was excessive and it was found that the same effect could be obtained by the installing of lifters.

The reclamation plant is situated close to the Byker Wall housing estate (population of about 2,500), which has a district heating system. A new boiler house was constructed to supply the houses with heat and hot water. A number of Powell Duffryn Vikos multifuel, solid-hearth boilers operate on various mixes of coal and the pellets produced from the plant. The boom conveyer feeding the pellet storage area is reversible and can also feed an elevating conveyer system to the boiler house next door. The original plan was to have the powerhouse burn about 170 tons of the fuel pellets a week. That would have left about half the production to be sold elsewhere. However, because of problems with the pellet-handling system in the boiler house, the district took very little fuel in the early days. At present they are taking about 100 tons per week. The ashing of the boilers is done by hand and here, too, problems have arisen because the quantity of ash per therm of useful heat output is considerably higher for the pellets than for coal.

An attempt is being made to expand the market for the pelletized fuel, but, as is the case elsewhere, many users have been reluctant to buy a new and as yet unproven fuel. Other uses for the material have been explored, for example, there have been some test runs using the fuel fraction in an unpelletized form as core material in the manufacture of chipboard or fiberboard. The pellets themselves have been used for making paper for carpet underpadding and even for bingo tickets, but only on an experimental basis.

One problem in the ferrous recovery circuit has been the contamination of the bales, particularly by film plastic. The contract with the buyer of the metal bales specifies not more than 10 percent nonmetal in the bales. Currently the contamination level runs around 17 percent. As a result, the material is not suitable for detinning and the best price that can be had for it is about 2.5 pounds sterling per ton. The pellets sell for about 12 pounds per ton; however, they cost roughly 18 pounds per ton to produce. Table 6 shows a lower cost per ton because it is computed on an anticipated higher tonnage figure than is actually being achieved. The plant, which cost about 3.5 million pounds in 1978 was supported in part by the Department of the Environment.

Table 6. Plant Economics

	Pounds Sterling/Ton
Capital costs amortized	4.6
Running costs (without deduction of income)	
Vehicles to tip but not including tip operation	= 3.4
Plant operation	= 8.3
	11.7
Gross cost/ton	= 16.3
Less income, say 100,000 pounds per year	= 2.0
Net costs with income included	14.3
Net running costs with income included	9.7

Source: Hewitt and Wall, "Byker Reclamation Plant," p. 6.

Employment

Sixteen people are employed at the plant, including the manager, supervisors, five drivers, four attendants, and office staff. Plant maintenance is performed on a contract basis and is carried out on weekends.

Energy Balance

Even with the addition of the rotary cascade dryer, the energy balance is quite favorable. At 30 tph input of waste, the energy consumed is 2,000 kwh without the dryer, and 4,800 kwh with the dryer. Using ten tons of pellets per hour as an output figure yields 140,000 MJ/hr. The pellets have a calorific value of 14,000 KJ/kg. Dividing this by 3.6 to convert to kwh yields a figure of 38,900 kwh. Hence the ratio of energy produced to energy consumed is 19 without the dryer and 8 with the dryer.

Summary

The Byker plant is an example of a facility that has achieved an operational status despite various setbacks including the need to charge out a number of unit processes and to make major modifications to others. As a straight shred, screen, and pelletizing operation -- as distinct from one employing screening (generally trommeling) before size reduction (shredding) -- it offers valuable lessons. The double pelletizing step, with the drying operation sandwiched in between, probably is not the most efficient or economic sequence, but it fits the space limitations and seems to get the job done. This is, after all, a demonstration and much has been learned by doing. In particular, one can look to the operating experience of this facility for data on screening, on air-classification and on pelletizing.

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Contact

Norman Driver, Plant Manager
Byker Reclamation Plant
304 Walker Road Byker
Newcastle upon Tyne NE6 1AH,
England
Ph. 654701

3. DONCASTER WASTE RECYCLING PLANT (UNITED KINGDOM)

Like the Byker plant, the Doncaster Waste Recycling Plant follows the pilot plant and research work done by the Warren Spring Laboratory. The Warren Spring research work, which is supported in part by the U.K. Department of the Environment, began in 1972. The Doncaster plant is a project of the South Yorkshire County Council.

Unlike the Byker plant, the Doncaster plant does not have a primary first stage pulverizing operation. In this respect, the Doncaster plant is more like the Sorain Cecchini plant in Rome, which is described later in this report.

The Doncaster plant is a more comprehensive recycling effort than the plant at Byker. In addition to the pelletized refuse-derived fuel and ferrous metals recovery, which both plants have in common, the Doncaster plant recovers glass. The schematic flow diagram for the Doncaster facility is shown in Figure 3.

One benefit of testing glass recovery at Doncaster is that the plant is located close to glass manufacturing companies. As a result, the glass, when recovered, can be transported to market at relatively low costs, always an important consideration in any recycling undertaking. Treatment at the Doncaster plant takes place in three main sections: the primary core, where the fuel materials (paper, board, and plastics) are separated; the refuse-derived fuel section, where these materials are processed into dRDF pellets; and the glass recovery section. A large rotary screen (or trommel) is used for the initial sizing and sorting. One reason for not having a primary shredder at Doncaster is that hammermilling shatters the glass, making its recovery more difficult, if not impossible. Also, hammermilling is a costly process and therefore it is believed it should be confined to the treatment of a minimum proportion of the feed. However, some argue that, apart from the issue of glass recovery, preliminary hammermilling gives a more uniform feed, improves refuse flow characteristics, and assists subsequent classification operations. An analysis of Doncaster's waste is shown in Table 7.

Description of the Plant and Operations

The plant is laid out to permit the eventual installation of two primary cores, each rated at approximately 10 tons/hr. However, only one core has been installed thus far. In the current configuration (Figure 3), the waste is fed from the primary hopper through a bag opener to the large (3 m in diameter, 8 m long) rotary screen that separates the waste into three streams. The first stream (-40 mm) goes to the glass recovery circuit; the second stream (+40 mm to roughly -250 mm) goes to the air classifier; and the third stream (+250 mm) is passed under an infrared sensor that identifies large cardboard and paper for fiber recovery. This last operation is still being

Figure 3. Doncaster Refuse Treatment Plant Schematic Flow Diagram

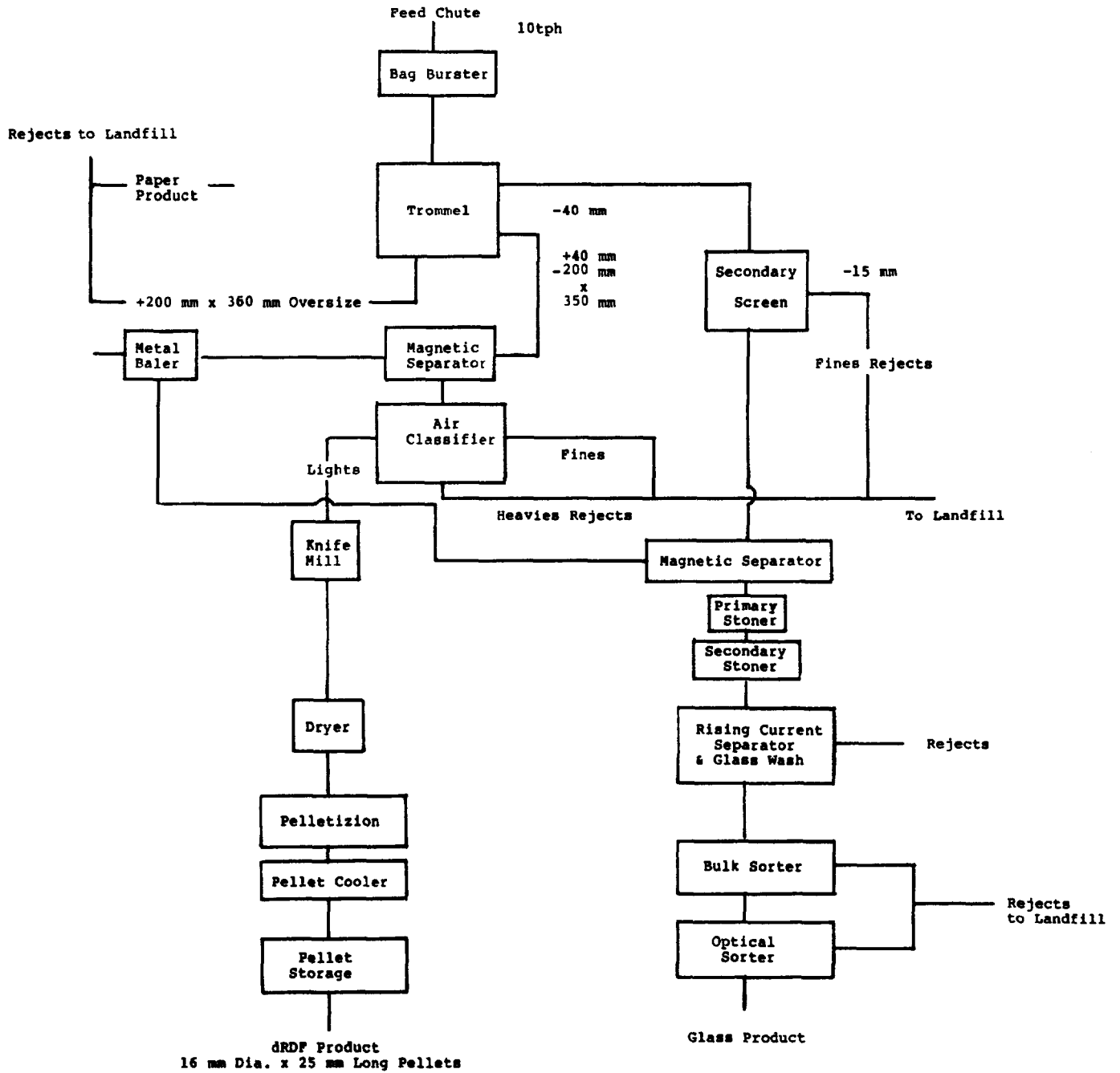


Table 7. An Analysis of Household Waste Constituents with Calorific Values
(Doncaster April 1981)

Material	% by Weight	% by Volume	Calorific Value KJ/Kg	National Average % by weight (1979)
Paper	24	49	12,200	27
Plastic	5	9	32,700	5
Textiles	4	5	13,400	4
Metals	11 (8)	13	-	7
Glass	11 (8)	2	-	9
Vegetable/Putrescible	28 (26)	15	4,900	29
Fines - below 20mm (ash)	15 (20-25)	5	5,000	11
Unclassified	2	2	16,700	6

Percentage expressed of refuse as received, at approximately 30% moisture content.

Note: The figures in () are actuals.

Source: Thomas and Tunaley, "Doncaster Resource Recovery Project...", p. 17.

Table 8. Typical Materials Balance on Process Core (November 1979)

Fraction	% by weight	Apparent Assay (% by weight)										Distribution by weight									
		Pa	Pl	Tx	Pu	Gl	Fe	NFM	MC	MNC	Fi	Pa	Pl	Tx	Pu	Gl	Fe	NFM	MC	MNC	Fi
-40 mm Fines	40	1	<1	<1	13	5	<1	<1	<1	4	75	2	3	3	34	40	3	19	7	57	87
Magnetics	7	6	1	1	<1	1	92	<1	-	-	-	2	2	2	<1	1	87	1	-	-	-
Air Classifier																					
"Heavies"	10	1	2	<1	45	17	3	3	10	11	8	<1	4	1	29	37	4	47	57	40	2
-38mm Fines	4	2	<1	-	26	11	<1	<1	4	1	56	<1	<1	-	6	9	<1	1	9	1	6
"Lights"	29	57	11	8	15	2	1	1	1	<1	5	66	74	77	28	14	2	31	22	1	4
Gross Oversize	10	75	7	5	5	<1	2	<1	1	<1	3	30	18	18	3	<1	3	2	5	1	1
Totals	100	25	4	3	16	5	7	1	2	3	35	100	100	100	100	100	100	100	100	100	100

Note: Pa = Paper, Pl = Plastic, Tx = Textiles, Pu = Putrescibles, Gl = Glass, Fe = Ferrous, NFM = Nonferrous metals, Fi = Fines (-15 mm).

Source: Thomas and Tunaley, "Doncaster Resource Recovery Project...", p. 20.

tested. Before air classification, the second stream is passed under an overhead magnet.

The ferrous metals are magnetically extracted from the intermediate size fraction, which are baled for use by the smelting industry to make grey iron. The revenue derived is approximately 5 pounds sterling per ton, FOB Doncaster. The remaining material is conveyed into the air classifier, which consists of a rotating drum with a forced draft of air that liberates the light paper and plastic matter from the dense and heavy items; the latter drop through the air current and are conveyed away to be rejected. (See Table 8 for the materials balance at the air classifier.)

The air classifier is a unique device, built by the Motherwell Bridge Tacol Company. The horizontal rotating drum has a feed helix attached to the inner circumference that acts as the control-flow discharge unit for the heavies. The feed is supplied by a high-speed conveyer, which introduces the refuse evenly to the air stream. The conveyer speed can be manipulated to obtain the optimal projectory for the air velocity and separation desired. The lights are conveyed to a disengagement chamber. The first stage of the helix scroll controls the flow of discharge of the heavy material. In the second stage, the scroll discharges the lighter paper-rich fraction to the disengagement chamber. A screening section present here is fitted into the second stage of the unit for the removal of dust and fines liberated in the classifying process. Technical data on the air classifier are given in Table 9.

Table 9. Technical Data, Doncaster Project Air Classifier Plant (Motherwell Bridge Tacol Ltd, 1979)

<u>Element</u>	<u>Specification</u>
Design throughput	5 tons/h (minimum)
Bulk density	130 kg/cubic meter (average)
Dimensions of drum:	
Overall length	5.550 m
Inside diameter of drum	2.100 m
Length of screen section	2.500 m
Outside diameter driving rings	2.425 m
Drum screen material	6 mm steel plate, stiffened
Drive unit-variable speed friction	4.5 kw installed
Dimensions of disengagement chamber:	
Overall length	5.500 m (adjustable)
Overall width	3.000 m
Height from floor	7.500 m
Chamber material	3 mm steel plate, stiffened
Total installed load	25.6 kw
Total absorbed load at design	20.0 kw
Process cost, electrical power	4.0 kw per ton

Source: Holmes, Refuse Recycling and Recovery, p. 34.

The light versus heavy split of the air classifier is approximately 65/35. However, 5 percent of the lights go to the fines in the screening section. Thus, the overall split is 60/35 plus 5 percent fines. The light material is 60 to 65 percent paper, 10 to 25 percent plastic, 10 percent putrescibles, and between 3 and 4 percent unidentified noncombustible material. The ash content measured on a dry weight basis is 15 percent. The air input for the classifier is a 15 hp blower; the air velocity in the chamber is 30 m/sec. The heavies from the air classifier, as well as the fines, are considered rejects and sent to landfill. The air classifier lights are conveyed to the refuse-derived fuel segment of the plant. There they are shredded in a knife mill which, while it is a satisfactory means of size reduction for paper or board, will not tolerate metals or abrasive particles. Hence, the air classifier must operate efficiently and not fly metals and hard plastics. The objective of this shredding step is to reduce the particle size of the air classified lights to a nominal -25 mm. In order to move this very light material through the mill, an 8 inch negative pressure is maintained.

The shredded material is fed pneumatically; this system was adopted so that drying and transport could be combined in one step. It was expected that a gas burner of a size capable of raising the inlet temperature to 200o C would be sufficient to dry the shredded lights material from a moisture content of 25 to 30 percent down to an anticipated 20 percent prior to pelletization. However, the retention time in the hot air flow is very short, and much of the latent energy is exhausted with the air. As a result, it has been necessary to raise the air temperature to 300o C to achieve the desired reduction in moisture content, and this has necessitated plant modifications.

Modifications to date include the installation of a larger propane gas burner and fan as well as some redesigning of the pneumatic duct work. It was also determined that a pellet cooler and screening system after the pellet mill are essential if the integrity of the pellets, once produced, is to be maintained and if the fine materials that break off from the pellets are to be separated for repelletization. The pelletizer originally installed is a 20-in die California Pellet Mill. The dies have tapered holes through which the dried and shredded air-classified light fraction is forced by a series of spring rollers.

Although high-quality, dense pellets were produced from the beginning, it was found that quality and quantity change with the feed material. Initially the air classifier was run at very low throughput rates and this produced a material that was much more amenable to pelletizing than the material obtained when the air classifier throughput rate was raised.

The plant found that moisture content is particularly important if dense pellets with high integrity are to be produced. When moisture content fell below 10 percent, the feed rate was reduced considerably and blockages were common. At

higher levels of moisture, however the pellets would crumble into grott. In practice, good pellet integrity could only be achieved at throughputs in the range of 1 1/2 to 2 1/2 tons/hr. The capacity was expected to be nearly three times as high. Also suffering capacity difficulties was the knifemill used to reduce the size of the air classified lights before pelletization. It was expected to have a capacity of 5 tons/hr, but, this could not be achieved because the material contained some heavy textiles and multiple thickness magazines. This caused the feed rate to pulse through the shredder. To correct this problem, the outlet screen was modified to 50 mm and an additional flywheel installed to increase the mechanical momentum. Despite these efforts, this unit still has an operational throughput of only about 2 1/2 tons/hr, but it now has the capacity to accept some contraries and local surging of feedrate. A modification currently being undertaken is the installation of an additional pelletizer (cuber) which produces a 30 mm square pellet about 50 mm long. This unit is manufactured by Bootham North Ltd. It will use the undried light fraction without this material being shredded.

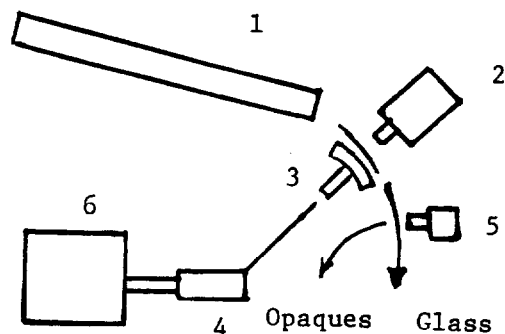
It should be mentioned that as yet no satisfactory method has been devised to remove textiles from the waste. Textiles cause a number of problems in addition to fouling the knife mill. Initially a ragger was installed in the first trommel. This was a simple moving wire that suffered from severe slippage (the rags fell off while still in the trommel). But, when lugs were added to prevent this, the textiles became entangled with the return wire and the guys would then be blocked. The "wash line" concept was eventually abandoned in favor of a moving flexible rail (similar to the handrail of an escalator). The increased width enabled all the working parts to be totally enclosed to avoid fouling. Unfortunately, because the size of the ragger was substantially increased, it became a significant obstruction in the center of the trommel, which therefore was susceptible to damage from large items such as timber that became wedged between the rotating drum and the fixed ragger. Despite the installation of a touch-sensitive leading rail along its length (which would trip out and stop the trommel screen if large items threatened to foul it), the ragger did not function adequately and had to be removed. Fouling of the holes in the trommel by textiles and large pieces of plastics still occurs, but it has been reduced considerably since the lands between the large holes were modified to make it more difficult for textiles to wrap around. Now the trommel is only shut down for cleaning once each day. The holes in the screen are now 40 mm square and 200 mm square. One section of the screen has 200 mm by 350 mm oblong holes.

The glass recovery circuit, as discussed below, has also had some problems. Here the -40 mm material from the primary trommel is fed to a vibratory incline screen where materials below 15 mm (mainly ash and fine vegetable matter) are removed. This is taken to the landfill where it can be used as cover instead of topsoil. The screen decks are made of plastic and appear to resist fouling and clogging. There are two such screens. The

remaining fine fraction (+ 15 mm - 40 mm) contains a large proportion of glass, which is concentrated by a series of processes, each exploiting particular properties of the various materials or impurities. First, a winnowing process is used that employs modified destoners using a vibrating plate/screen together with a gentle upward current of air to separate the feed into a stream of dense material and a light fraction rejected to landfill. The destoners are manufactured by Gunson Sortex. In the destoners, the glass fraction is enriched to about 30 percent glass.

The next step is a rising current separator, also called an elutriator, in which the lighter impurities are removed in a current of recirculated water. In effect, the glass sinks to the bottom of the waterbath, while the organic material floats off the top. The glass is taken from the bottom of the waterbath by a rotary conveyer. At this point, the glass fraction contains 90 percent glass and 10 percent stone, china, and heavy impurities. Wemco is the manufacturer of the rising current separator. The glass concentrate is next elevated by means of a helical conveyer. It then passes through a single-channel bulk transparency sorter manufactured by Gunson Sortex (see Figure 4). The material is passed through a light beam. When any opaque material interrupts the beam, a photocell controls the solenoid to allow a jet of compressed air to divert the material to a reject chute. Another helical conveyer follows, and then a six-channel electronic sorter similar to the single channel machine described earlier. The objective of the optical sort is to separate the glass from the nonglass, or opaque material, which is rejected. Glass of 99.7 percent purity has been produced by this means. Glass manufacturers will accept this as cullet.

Figure 4. Simplified Scheme of Electronic Sorter for Separating Glass from Opaques



- (1) Slide
- (2) Lamps
- (3) Inspection Head
- (4) Light Detectors and Infrared Light Barrier
- (5) Air Valves for Opaques
- (6) Electronic Control System.

However, only about 15 to 20 percent of the glass in the input waste is recovered, rather than the 65 percent anticipated. The problem is that there are simply too many unit operations. A large proportion of the glass is lost to the air-classifier heavies. This glass should have gone through the 40 mm holes in the initial segment of the trommel, but it did not and it ended up in the middling product. Also, the -15 mm fines have been found to contain about 15 percent glass. There is also about 3 percent glass in the stoner rejects. Finally, when the helical conveyers become covered with fine dirt as a result of carrying the wet glass and impurities, this forms a film over the glass and causes the optical sorter to mistakenly identify some glass as opaque material. Overall, 25 to 35 percent of the glass feed to the sorters, which should have been accepted by the optical sorter, is rejected. A new washing screen has been fitted at the outlet of the vibratory elevator and this should help to improve recovery efficiency considerably.

Products and Economics

Table 10 shows the anticipated products from the plant should it successfully emerge from its current shakedown phase. At the notional values shown, a potential income of 300,000 pounds is anticipated. Table 11 compares characteristics of the dRDF produced and coal. The value shown is used in computing the potential revenue for this product. Capital costs and the source of the funding for the plant are given in Table 12, while Table 13 provides a breakdown of operating costs.

Table 10. Potential Products - Quantity and Values (Estimated)
(Assuming 85% availability of Plant at current performance)

<u>Product</u>	<u>Recoverable Proportion</u> (% of Input)	<u>Tonnage Anticipated</u> (Ton)	<u>Notional Value</u> (Pounds sterling per ton)	<u>Potential Income</u> (Pounds sterling)
Glass	4	1,200	25	30,000
dRDF	25	7,500	25	190,000
Ferrous Metal	7	2,000	10	20,000
Paper Fibre	4	1,200	25	30,000
Fines & Putrescibles	35	10,000	2	20,000
Others (Textiles etc)	5	1,500	7	10,000
Total Income Potential				300,000

Note: Operating at 900 tons per week input.

Source: Thomas and Tunaley, "Doncaster Resource Recovery Project...", p. 22.

Table 11. RDF and Coal Compared

<u>Property</u>	<u>dRDF</u>	<u>Coal</u>
Moisture	17 %	6 %
Ash	14 %	6 %
Sulphur	0.3 %	1.6 %
Chlorine	0.9 %	0.4 %
Calorific Value	18 MJ/Kg	30 MJ/Kg
Commercial Value (May, 81)	25pounds/ton	48pounds/ton

Source: Thomas and Tunaley, "Doncaster Resource Recovery Project...", p.24.

Table 12. Doncaster Recycling Plant Capital Costs and Sources of Funds (Pounds Sterling)

<u>Element</u>	<u>Design and Procurement</u>	<u>Provision and Installation</u>
Land		100,000
Buildings & Services		1,150,000
Plant -		
Primary Core	170,000	550,000
Fines/Glass Circuit	190,000	360,000
Metals Circuit	10,000	80,000
dRDF Circuit	200,000	450,000
Mobile Plant and Vehicles		220,000
Total Capital Cost		3,480,000
D of E Contribution (to March 1981)		1,306,000
SYCC Commitment		2,174,000
Further Development Envisaged (Estimated) (During 2 year experimental period)		200,000
 (Estimated Outturn at November 1980 prices)		

Source: Thomas and Tunaley, "Doncaster Resource Recovery Project...", p. 18.

Table 13. Operating Costs

<u>Budget</u>	<u>Pounds Sterling</u>
Salaries and Wages	125,000
Other Employment Costs	25,000
Premises and Plant Repairs	30,000
Electricity and Services	70,000
Rates	45,000
Other Supplies	5,000
Mobile Plant & Transport	75,000
Vehicle Plant & Transport	10,000
Total	385,000

(Estimated 1981/82 at November 1980 prices).

Source: Thomas and Tunaley, "Doncaster Resource Recovery Project...", p. 22.

From the data in these tables it is clear that the economic outlook is not bright. However, the tables do not tell the entire story. There have been some significant benefits to the community from the increased efficiency of refuse collection. It has been estimated that two collection vehicles and their crews have been saved because of the facility's more central location in contrast to the landfill. In addition, turnaround has been reduced to 6 minutes (at the plant) compared to 27 minutes (at the landfill). It is also said that substantial savings have been realized in refuse vehicle maintenance and repair as a result of their not having to venture on to the landfill.

Energy Balance

The energy requirements for the operation of the plant are shown in Table 14. Note that there is a substantial energy dividend. Nevertheless, work is underway to attempt the recirculation of the hot exhaust from the dryer in order to reduce the plant's energy requirements.

Table 14. Energy Balance Figures

<u>Element</u>	<u>Electrical Energy Used @ 10t/hr Input</u>	<u>Gas Used for RDF Drying</u>	<u>dRDF Fuel Energy Value</u>
Primary Core	180 kwh/h		
RDF	225 kwh/h	350 kwh/t	5600 kwh/t
Glass Circuit	95 kwh/h		

Source: Thomas and Tunaley, "Doncaster Resource Recovery Project...", p. 25.

Summary

Because of its various problems, the plant has not been able to consistently produce either the refuse-derived fuel pellets or the glass. However, a number of firing trials have been conducted with the refuse-derived fuel pellets that have been produced. Not all have been successful. In general the problems have been in the handling of the pellets rather than in their burning characteristics. What fuel has been produced to date has been sold. It is said that one customer is prepared to take the total output, but that further trials will be conducted with other potential customers in an attempt to broaden the commercial acceptance of the refuse-derived fuel pellets.

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Contact

Mr. C.I. Tunaley
South Yorkshire County Council
Environment Department
County Council Offices
County Way, Barnsley
South Yorkshire, S70 2TL,
England

4. WESTBURY: BLUE CIRCLE INDUSTRIES, REFUSE-DERIVED FUEL
IN A CEMENT KILN (UNITED KINGDOM)

Blue Circle Industries has constructed a full-scale commercial plant for processing and firing domestic refuse as a fuel in cement kilns. This plant has been operating since August 1979. Blue Circle's investigation into the use of domestic refuse as a fuel began as long ago as 1971 at its research and development site at Barnstone, near Nottingham, U.K. Tests were then conducted on over 1,200 tons of refuse during 1972 and 1974 at the Westbury works, and in 1976 a six-month demonstration trial took place at another Blue Circle facility at Shoreham in Sussex. Approximately 3,000 tons of waste were converted into fuel and burned during these trials. Both Westbury and Shoreham are wet process cement plants. The primary fuel for the production of the cement at Westbury and Shoreham is coal. A further six-month trial was carried out at Blue Circle's Plymstock works in Devon, an oil-fired dry process cement production facility. Thus, with the completion of the Plymstock test, the company felt it had demonstrated that the refuse-derived fuel (RDF) could be burned with either oil or coal. This led to the implementation of the commercial operation at Westbury.

Cement is produced in a long rotary refractory -- a brick-lined, large-diameter, inclined steel tube mounted on rollers and turned slowly by electric motors. Typically, the raw materials are a mixture of limestone or chalk and shale or clay, fed in the upper end of the kiln in the form of a slurry in the wet process and in a powdered state in the dry process. At the lower, discharge end, the fuel firing the kiln is introduced; it may be pulverized coal, oil, or gas. The temperature in the burning zone should be about 1400° C. As the raw material travels slowly down the kiln, it first dries, then undergoes complex chemical reactions to form cement clinker, which is forced air cooled and subsequently ground in cement mills after gypsum is added to produce the gray powder known as Portland cement.

It has been observed that the cement kiln is well suited for the disposal of domestic refuse because of several attributes of the production process. First, the high temperature generated is capable of destroying any unpleasant chemical compounds that are present and thus ensures the complete incineration of the refuse fired into the kiln. Second, the alkaline mixture in the kiln neutralizes the acidic gases of combustion. In addition, the already fitted electrostatic precipitators dedust the gases given off. The ash generated by burning refuse, by careful control and adjustment, is incorporated into the cement clinker. This eliminates any ash disposal problems common with refuse incinerators. As the refuse-derived fuel is burned at the Westbury works, it substitutes for approximately 10 to 12 percent of the energy normally derived from the primary fuel which, as previously mentioned, is coal. Table 15 gives relevant input and output data through December 31, 1983.

Table 15. Plant Performance Data through December 31, 1983

<u>Process</u>	<u>Tons</u>
Crude refuse pulverized	170,000
Ferrous metal recovered	12,000
Undesirables and fines sent to landfill	5,700
Pulverized refuse burned in kilns	152,300
Coal replacement	38,000
<u>Performance</u>	<u>Rate</u>
Average rate processed refuse per kiln	4.0 tph
Average throughput	
Line 1	21.7 tph
Line 2	20.5 tph

Source: Reuse of Solid Waste, "Discussion of Papers 4 and 5," p. 46. Updated in private correspondence.

Description of the Plant and Operations

The refuse-derived fuel-processing plant at Westbury is designed to handle up to 80,000 tons a year of crude domestic refuse received as collected off the streets by packer truck or through a transfer station. (See Table 16 for the waste composition.) There are two parallel lines of processing machinery. Each is designed to produce 17 to 20 tons/hr of processed refuse. However, each line has actually achieved more than 20 tons/hr of output. The design calls for operation on two eight-hour shifts per day, five days a week.

Table 16. Waste Composition

<u>Component</u>	<u>Weight %</u>
Paper	45-53
Rags and Textiles	10-13
Glass	8-12
Metals	7-9
Stones & Grit	7-9
Putrescible (vegetables, etc.)	4-8
Plastics	4-6
Rubber	1

Source: Coomaraswamy, Haley, and Giles, "The Use of Solid Waste as a Fuel in the Cement Industry," p. 36.

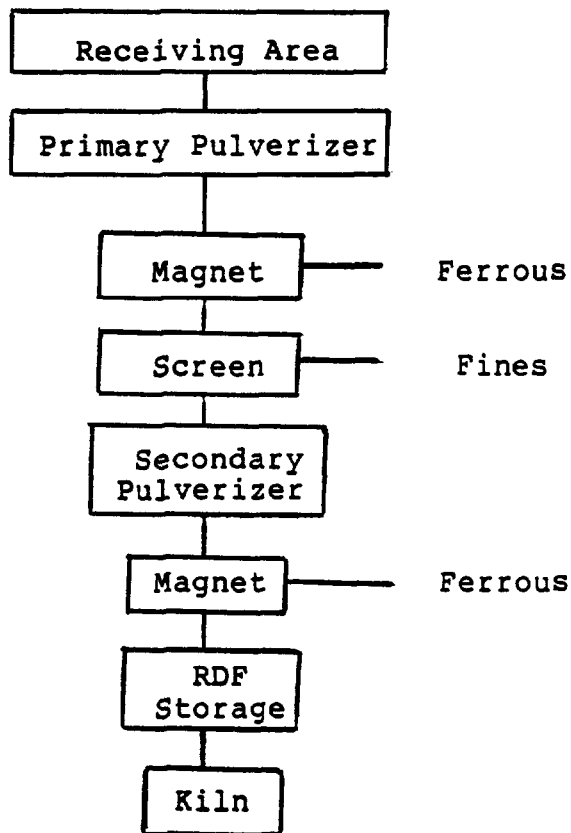
The calorific value of the refuse-derived fuel indicates a potential for a higher substitution rate. However, the moisture content of the refuse-derived fuel is higher than that of the coal. Moreover, when the refuse is injected pneumatically into the kiln, it is accompanied by additional quantities of cold air. Therefore, not all of the heat content of the refuse can be used on a one-to-one substitution basis for the coal as some must be used to evaporate the moisture and some to heat the cool air. This means that the total heat requirement increases somewhat, but the use of the primary fuel drops off more or less linearly as refuse input is increased.

The principal limitation on the amount of solid waste that can be used to replace the conventional fuel is cement quality, which is of paramount importance. A significant element in this consideration is the amount of ash in the waste. In principle, the lower the ash content, the more refuse that can be burned and therefore the greater the capacity for primary fuel replacement. Before a screening step was added to the process flow, the ash level was 30 percent. The goal for ash after the installation of the screen is 20 percent.

As mentioned above, moisture in the refuse is always a negative factor. Moisture at significantly higher levels than that found in the fuel produced at Westbury can give rise to instability in kiln operations. The moisture level of the refuse-derived fuel produced at Westbury averages 30 percent.

Figure 5 shows the sequence of the installed equipment. The refuse is first delivered to a large reception area. This is a tipping floor as distinguished from the pits found in most incinerator plants. Some larger items unsuitable for pulverization are removed manually before the material is moved by front-end loader to a live bottom bin. There are two stages of shredding. Variable speed plate feeders carry the raw refuse to the first stage of shredding. In each line the first stage of size reduction is accomplished by Hazemag "Universa" 1620 gridded primary pulverizers of fixed hammer design. A vibrating screen has recently been added between the first and second stages of pulverization. This machine is produced by the Locker Company. The screen deck has slots 24 mm by 8 mm in the direction of the flow. Magnetic separation, which also occurs between the two stages of size reduction, is accomplished by overhead magnets. Further magnetic separation takes place after the secondary pulverization step.

Figure 5. Westbury: Blue Circle Energy From Waste Facility



For secondary pulverization, one line uses two Hazemag EM mills and the other employs a Gondard Civic Mill. Two types of gridded swing hammermills were used for testing purposes. The refuse-derived fuel produced has a specification of 100 percent minus 50 mm, the majority being below 25 mm. According to the designers -- both Blue Circle and Peabody Holmes -- the processing system was configured so as to prevent long pieces of rag or plastics -- the so-called streamers -- from being formed. Apparently the combination of pulverizers installed is quite successful. Composition of the shredded product, by size, is given in Table 17.

Table 17. Size Analysis of Processed Refuse

<u>Finer Than</u>	<u>Percent</u>
100 mm	100
50 mm	97-100
25 mm	92-97
12.5 mm	80-85
3 mm	40-45

Source: Coomaraswamy, Haley and Giles, "The Use of Solid Waste as a Fuel in the Cement Industry," p. 36.

Because the cement kilns operate 24 hours a day, 7 days a week, the refuse-derived fuel is conveyed to a storage area having a 1,200 ton capacity. When needed for the cement-making process, the refuse-derived fuel is taken by front end loader to hoppers, which supply the kiln feeding system. The refuse is carried from the hopper by conveyer and passes over a weight scale before being transported pneumatically more than 300 meters to the two rotary kilns, where the cement clinker is produced.

Cement Quality

Table 18 provides data on the quality and composition of the refuse-derived fuel. Table 19 shows that the cement compressive strength does not deteriorate when refuse-derived fuel is used. The figures are the averages of production runs over prolonged periods.

Table 18. Analytical Data Refuse Fuel

Composition, weight %	Water	30
	Ash	30
	Sulphur	0.3
	Chloride	0.2-0.4
Ash analysis, weight %	SiO ₂	52
	CaO	16
	Al ₂ O ₃	11
	Fe ₂ O ₃	7
	Na ₂ O	7
	K ₂ O	1.5
Gross Calorific Value, kcal/kg:	As fired	2100-2300
	Dry basis	3100-3300

Source: Coomaraswamy, Haley and Giles, "The Use of Solid Waste as a Fuel in the Cement Industry," p.36.

Table 19. Comparison of Proportion of RDF Fired to Cement Strength

Refuse Input, % on cement clinker	0	3.4	4.7	6.5
Compressive strength, N/cubic meter				
After 3 days	22.3	21.0	20.7	22.5
After 28 days	43.1	43.2	42.0	43.2

Source: Coomaraswamy, Haley and Giles, "The Use of Solid Waste as a Fuel in the Cement Industry," p. 36.

Economics

Because the Blue Circle process is a proprietary approach to realizing the energy value of municipal waste, little information on the economics of the Westbury operation is available. It is known that the Community pays 3 pounds sterling per ton of waste tipped at the facility. The addition of a screen to the equipment, which is expected to lower the ash from 30 to 20 percent, cost 200,000 pounds.

In 1976 the U.K. Waste Management Advisory Council (Waste as a Fuel Working Party) published a study entitled Energy from Waste. This study estimated the cost and potential savings if seventeen U.K. cement works added a Westbury-like RDF-production facility and then proceeded to burn the fuel. Each is assumed to burn the RDF produced from 74,000 tons of refuse per year, offsetting 16,000 tons of coal (at 20 pounds sterling per ton). Ferrous metal is extracted and sold for 16 pounds per ton. If the local communities further pay 3 pounds per ton of waste tipped, the net savings to the cement works is estimated at 8.90 pounds (see Table 20). This is based on a ten-year evaluation using a 5 percent discount factor. At break-even -- from the perspective of the cement-making operation -- the communities tipping feed would be .37 pounds per ton. The Blue Circle Company may or may not endorse this analysis.

Table 20. Economics: Westbury Type Facility
(1976 prices)

Capital Costs	1.93 million pounds
Operating Costs	200,000 pounds per year
Net Savings	8.90 pounds per ton

Source: Energy from Refuse, pp. 39-41.

Summary

Perhaps because of the extended test and development period, operating problems at Westbury have been minimal. Wear on the primary pulverizers and erosion of the pipeline bends of the pneumatic feed system have been a significant cost factor, as has been the case in other refuse-processing plants. All pulverizers installed have ballistic separation systems rejecting uncrushable items. The primary hammertips are welded in situ. After a time, the primary hammers are replaced by a new set, the old set being rebuilt outside. Hammer wear on the primary crushers has been reduced by improved hammer-welding techniques. Most problems relating to erosion of pipeline bends have been overcome and the

wear considerably reduced by the use of replaceable liners with special construction materials as well as by improved bend design.

It is the capacity of the cement clinker to absorb the ash without reducing the quality of the cement that limits the amount of refuse that can be burned. The vibrating screen is installed to reduce the overall amount of ash in the refuse fuel and thereby raise the number of tons that can be fired in the cement production facility. In principle, the lower the ash content the more refuse that can be burned and thus the greater the capacity for fuel replacement. The amount of fuel burned under current conditions is approximately 4 tons/hr of refuse for each kiln.

It should be mentioned that the ferrous metal content at Westbury is about 7 percent of the incoming waste. This is recovered and sold for recycling.

As mentioned earlier, modern cement works already have advanced environmental protection equipment for cleaning up the exhaust gases. Thus it has been found that the particulate matter given off by the combustion of the refuse-derived fuel causes no emission problems. However, the fact that cement kilns are fitted with such able equipment, while it makes burning RDF feasible, can be considered a disadvantage from another perspective. That is, since kilns can use cheaper grades of fuel, the price their operators are willing to pay for a finished refuse-derived fuel is often lower than might be the case for those not so situated with respect to the emissions picture.

In summary, the Westbury refuse-derived fuel production plant is truly an operating facility. Run by fourteen men on three shifts under a plant manager, it falls in the relatively small group of perhaps a dozen waste-processing, energy recovery plants that operate regularly and at full scale throughout the world. The Blue Circle Company not only is interested in utilizing refuse-derived fuel in its own production facilities, but it also offers engineering consulting services for feasibility studies that might lead to the production of refuse-derived fuel for burning in other types of heat exchangers, including the facilities of its competitors throughout the world.

For developing countries, perhaps the most useful experience transferable from the efforts of European authorities to improve solid waste disposal through recycling is the burning of refuse in cement kilns. Kilns exist all over the world. They are generally located close to population centers, and hence are close to the points of refuse generation.

Of concern in many developing countries is the trade-off between moisture level and the amount of fuel that can be burned. As stated earlier, moisture is an economic debit. When the waste is very wet, as it is, particularly at certain times of the year, in many developing countries, conceivably all, or nearly all, of the energy value of the refuse-derived fuel could

be consumed in evaporating the moisture it contains. Drying may be necessary, if it can be done economically. Cement-making installations have rather large quantities of low-level energy available which might be used. This is the energy inherent in the off-gases produced by the cement-making process. This energy is usually dissipated in the atmosphere as there is no effective use for it. It appears worthwhile to investigate the economic viability of utilizing this heat to dry the refuse-derived fuel before it is injected into the kiln.

This could represent a relatively significant capital outlay for the drying equipment. It could also have corrosive and other negative effects on the air pollution control equipment and other aspects of the cement-making process. Nevertheless, and in particular for those countries which must use scarce foreign exchange to pay for imported energy, the investigation of the use of the kiln's excess heat for drying of a prepared refuse-derived fuel seems warranted. Electricity-generating facilities also have considerable quantities of excess low-value energy. One could conceivably use this heat for the drying of the refuse-derived fuel. This also appears to merit consideration. There is not as much tolerance for low-quality fuel in the generation of electricity as there is for the production of cement. Therefore, the best combination may be to use the off-energy from the electricity production to dry the refuse-derived fuel, which would then be burned as a supplementary fuel in the production of cement.*

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* The Blue Circle Cement Company also has a cement production facility that is burning discarded automobile tires to provide 10 to 15 percent of the energy normally provided by coal in a dry kiln process. As with the ash from the municipal refuse burned at the Westbury works, the ash including the metal from the steel belts is incorporated into the cement clinker.

Contacts

Dr. Colin A. C. Haley
Commercial and Planning Manager
Blue Circle Cement Industries PLC
Blue Circle Technical Consultancy Division
Blue Circle House, New Road
Gravesend, Kent DA11 0AT,
England
Ph. (0474) 64366
Telex. 965175

E.D. Knights
Works General Manager
Blue Circle Cement
Production Division
Westbury Works, Trowbridge Road
Westbury, Wilts BA13 4LX,
England
Ph. Westbury 0373822481
Telex. 44116

5. MADRID: ENADIMSA RECYCLING PLANT (SPAIN)

The plant in Madrid is one of approximately two dozen projects of the ENADIMSA organization.* ENADIMSA is a research group concerned primarily with mining and minerals processing. It is partly public and partly private, as is the custom of Spanish economic organization. This arrangement has made it possible for a number of recycling research and demonstration projects to be included in the national government's long-term energy plan. ENADIMSA carries out these projects. The Madrid plant, which is described here, is the major effort.

The plant started up in 1981 with a ten-month shakedown period. At present, the plant is operating on a regular basis. It is one of the few "operating" plants worldwide that separate materials, other than ferrous metals, for reuse. However, it is still a demonstration plant, and, in spite of its consistent and technically successful operation, its scale is too small for commercial viability. Also its location in the Madrid area, which is fine from a demonstration standpoint, is too far from the markets for the recovered materials, which are mainly on the Mediterranean seacoast. From an operating standpoint, the plant has a 75 percent availability rate. The products recovered are listed in Table 21.

Table 21. Products Recovered

<u>Material</u>	<u>As-Received Basis</u>
Compost	30.12% (30% moisture)
Paper/cardboard	17.38% (50% moisture)
Tin cans and bottle caps	2.04%
Light plastic	0.83%
Heavy plastic	0.61%
Rejects	33.48%
Water balance & fermentation losses	15.54%
	<u>100.00%</u>

Source: ENADIMSA, Process Description, p. 12.

The plant is carefully engineered and represents a considerable amount of development work, taking off from earlier activity of the United States Bureau of Mines. However, the plant

*ENADIMSA stands for Empresa Nacional Adara de Investigaciones Mineras, S.A.

bears little resemblance to the original plans put forth by the Bureau of Mines for resource recovery facilities in the United States. The unit processors that are incorporated in the Madrid plant represent the broad spectrum of separation principles applied in plants throughout the world. The operations include shredding, mechanical and pneumatic classifications, magnetic and galvometric separations, and other aspects of differentiation between physical properties (for example, adhesion as a function of moisture level). The concentrations accomplished on site result in a paper-cardboard fraction, plastic films, heavy plastics, heavy ferrous metals, tin cans, and organic matter that is made into compost. Interestingly, the revenues derived from the sale of materials, in spite of the scale and poor geographical location of the plant with respect to its markets, are sufficient to cover the operating costs of the plant, although they are not extensive enough to cover the investment made in constructing the plant and the costs incurred in start-up.

Description of the Plant and Operations

The unit processes that are incorporated in this demonstration plant recover between 70 and 75 percent by weight of the feedstock. Table 22 gives the refuse composition for Madrid. The remainder is landfilled on site. This is feasible as the facility is located at the principal landfill site for the municipality of Madrid. Flow schematics for the plant are shown in Figures 6 and 7.

Table 22. Refuse Analysis

<u>Material</u>	<u>As-Received Basis</u>
Organic matter	53.60%
Paper cardboard	19.10%
Ferrous	2.24%
Light (film) plastics	1.67%
Heavy plastics	1.07%
Others (wood, textile, leather, rubber, glass, ashes, etc.)	22.32%
	<u>100.00%</u>
Average moisture	48.00%
Specific gravity in the reception bin	430 kg/m ³

Source: ENADIMSA, Process Description, p. 12.

Figure 6. Madrid (ENADINSA) ADARO Facility

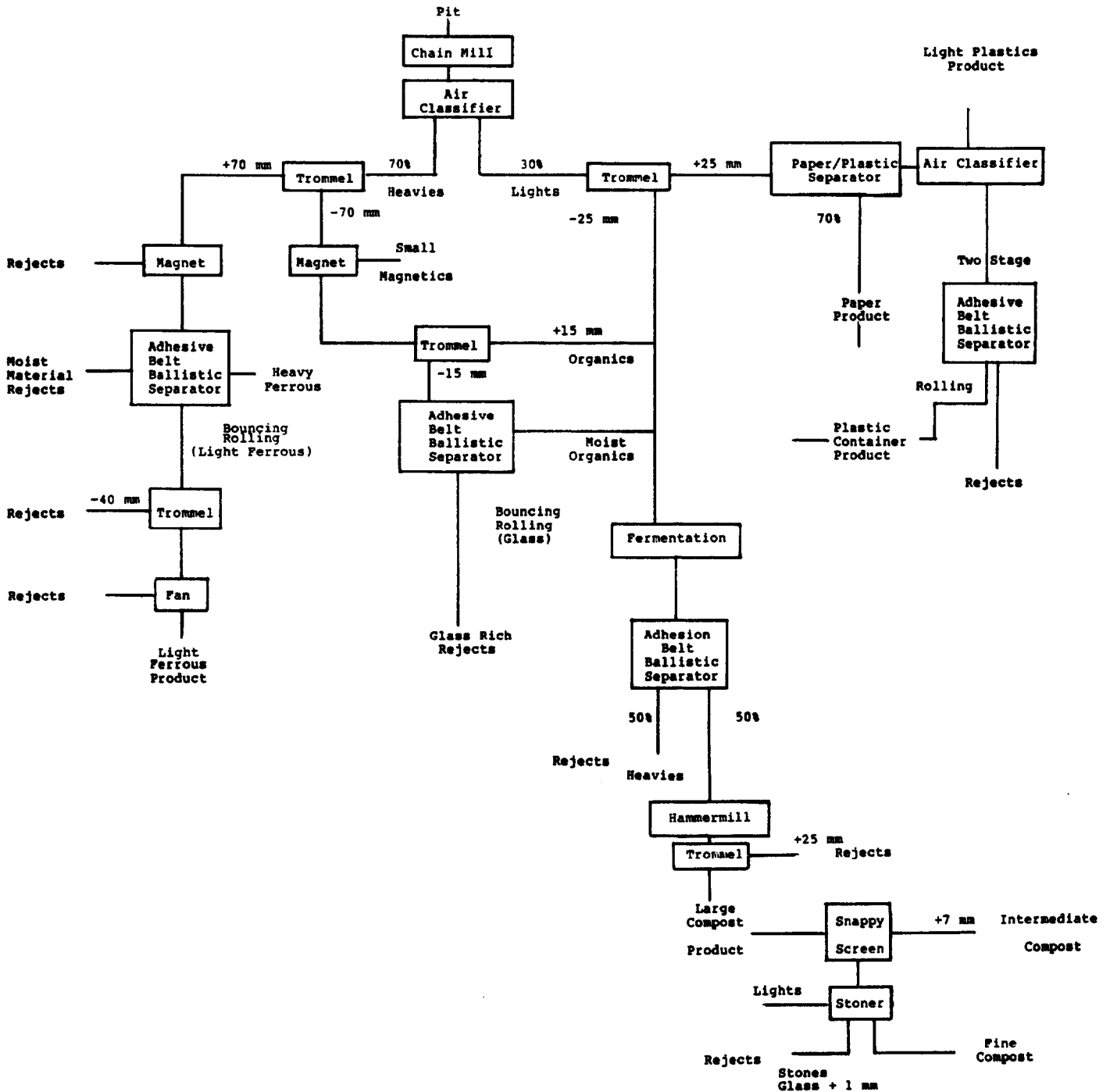
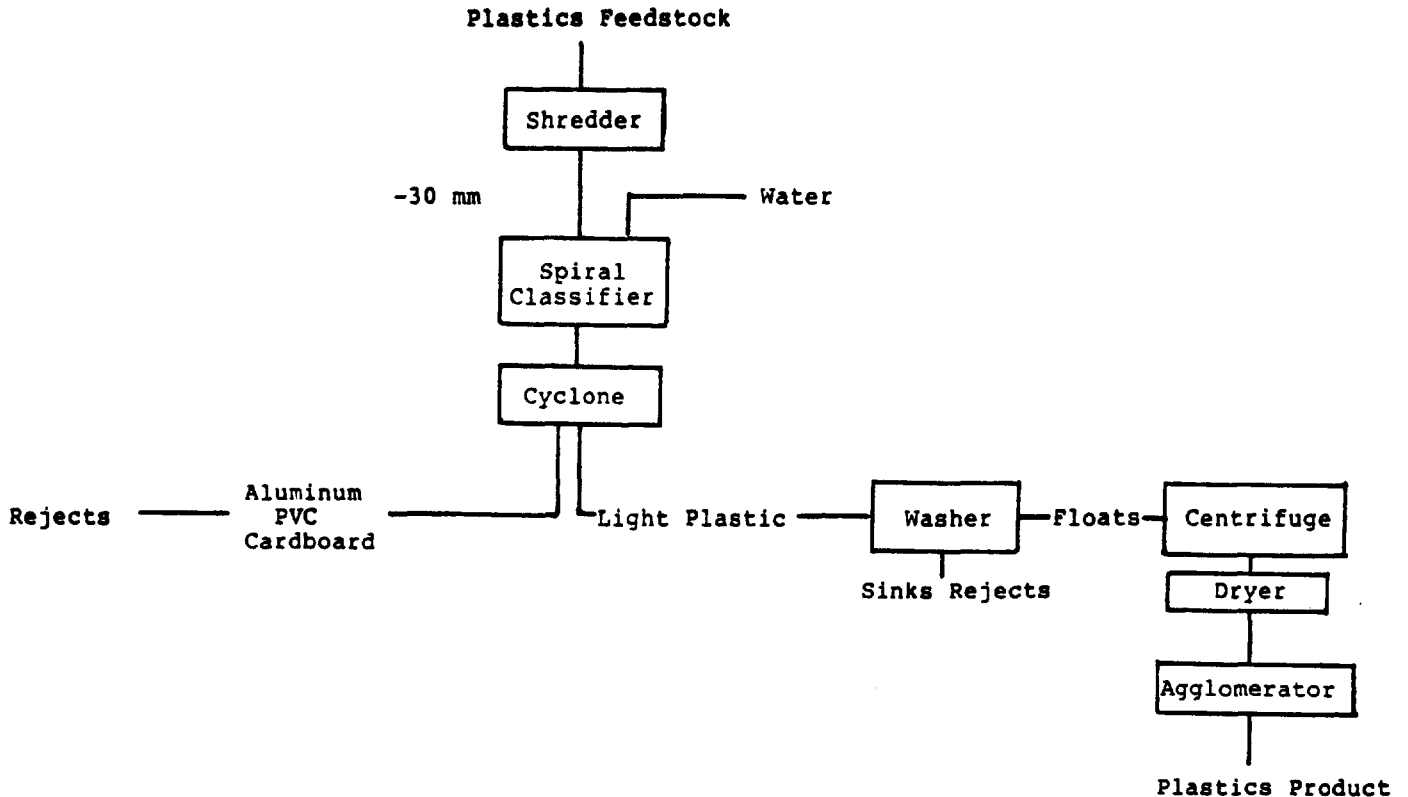


Figure 7. Madrid (ENADIMSA) Facility: Plastics Clean Up



Whenever refuse is needed to provide a supply of waste, refuse transport vehicles discharge into the facility's receiving pit. The waste is removed from the pit by a grappling arm that can also be used to segregate materials which are not amenable to processing by the plant's installed equipment, such as white goods. A variable feed conveyor transports the waste to the first unit process in the system. With adequate operator attention, a steady feed can be ensured. The first unit process is a chain mill operated by two motors of 50 hp each.

The flails that both break open the bags (within which much of the refuse is delivered to the site) and accomplish the size reduction are similar to bicycle chains. At the end of each there is a hook that grabs and tears at the refuse. The mill operates at a rate of 15 ton/hr. Because of the high velocity of the flails, the glass is shattered into particles less than 15 mm in size. There are no grates in the device; there are 72 flails. Rotation is over the top and toward the middle. The machine draws 30 amps and it operates at 380 v.

Contrary to what one might expect, the maintenance and replacement on the flails and the hooks is very low. Replacement or positioning changes are necessary every 500 to 1,000 hours. Maintenance, when necessary, takes about 4 hours.

After discharge from the flail mill the material passes under an air-sucking device (air classifier) that operates like a vacuum cleaner and sucks up the light paper and plastic. Because the flail mill tends to fluff up the waste, the air classifier is able to liberate 80 percent of the newspapers. Even Tetrapak-type containers go to the lights. Plastic bottles fly as well. In fact, given the characteristics of Madrid waste, and the action of the flail mill, 30 percent of the incoming material is sucked up by the air classifier.

After deentrainment in a cyclone, the lights are transported to a trommel screen with holes of 25 mm. The purpose of this screening step is to remove fine material, most of which is organic material. In addition, some fine glass that is attached to paper fragments is tumbled loose and screened out. The oversize from the trommel screen is then subjected to a separation step that involves the addition of moisture. It is known as a semiwet separation step. The device used here has rotating blades within a stationary screen with 35 mm holes. The rotation of the blades forces much of the moist paper through the holes in the screen. Approximately 70 percent of the paper in the feed goes through the holes at an average moisture content of about 50 percent. The material left in the device, which comes out as a reject, is mainly plastic.

The light plastics are sucked off by another air classifier. The mixture of wet organics and plastics, primarily plastic bottles, is ejected onto a ballistic separator, which is an adhesion belt with a distinctive downward slope. Any materials that roll or bounce fall back down the belt. Those that are moist adhere to the belt and are conveyed upward and are discharged. Those that fall backward are mainly containers of various plastic polymers and of various colors (Table 23). A hand separation by color is made. The white material is picked off the discharge belt and becomes a product of the plant. The remaining mixed plastics stay on the belt. Depending on the market, either the white or mixed plastic can be shredded and then containerized for sale as described below. It is primarily the white plastic that finds a ready buyer.

Table 23. Heavy Plastics

<u>Property</u>	<u>Composition</u>
Quality	97.5% polyethylene
Moisture	less than 5%
Granulometry	less than 30 mm
Color	white and colored
Density	250 kg/m ³

Source: ENADIMSA, Process Description, p. 16.

The plant has ample equipment for the handling and cleaning up of the film plastic. After deentrainment from the air classifier, the light plastic material is shredded to a size of less than 30 mm. It is then transported to a washing circuit where the washing is accomplished in a spiral classifier. Two sequential steps then separate the heavy plastics from the light. The first is a cyclone and the second a sink/float tank in which the material is circulated. This step, with its recirculating circuits, separates light plastics from any pieces of heavy plastics that may be present. Next, a centrifuge is used to eliminate much of the water and other impurities. From the centrifuge the plastic (which has about 5 percent moisture) goes to a hot air drying system. After drying, the material is pressed together by corrugation, which increases the specific weight. At this point the material is ready for market (see Table 24). As mentioned above, the heavy plastics are also shredded, in this case to less than 25 mm. The washing, cleanup and drying circuit just described can also be used for the heavy plastic material. Interestingly, the plant operations currently feel that plastic film with up to 20 percent impurities can be commercialized. This eliminates the need for washing.

Table 24. Densified Plastic Film: Madrid

<u>Property</u>	<u>Composition</u>
Quality	95% polyethylene
Moisture	less than 5%
Granulometry	less than 30 mm
Color	grey
Specific weight	300 kg/m ³

Source: ENADIMSA, Process Description, p. 16.

Returning now to the initial air classifier, which is the unit that is used immediately after the flail mill, it will be recalled that at this point 30 percent of the materials goes off to the lights while 70 percent is delivered to a trommel with 70 mm holes. The oversize material from this trommel is taken to a magnet, which picks up the ferrous material and deposits it on a ballistic separating belt. The light ferrous rolls and bounces down the belt while the heavy material is conveyed upwards and into the container for the heavy iron fraction. The split here is about 90 percent light ferrous and 10 percent heavy ferrous. Therefore a concentration of the light ferrous is achieved during this step.

This light ferrous is discharged into another trommel screen, whose rotating action helps clean the cans; in particular it serves to remove the paper labels and to liberate materials trapped within the cans. The residence time for the cans is between 5 and 15 minutes. The liberated material is screened through the holes in the trommel, but some still adheres to the cans. Upon discharge the material goes through an air knife that blows off the bulk of the remaining organics. The resulting ferrous product is as clean as that from any other resource recovery plant. It may, in fact, be the best ferrous product produced anywhere.

This set of unit processes is able to produce a ferrous fraction that has less than 5 percent contamination in part because the cans are not crushed during initial size reduction. The flail mill, although it operates at a relatively high velocity, is more gentle with the cans than the traditional hammermill. Rather than crushing, it simply beats them. In the Spanish marketplace this cleanup doubles the value of the recovered ferrous metal compared with that obtained from ordinary magnetic separation. In fact, the material is clean enough for detinning, which is not the case with the ferrous recovered from most municipal waste-recycling plants.

The heavies from the initial air classification, meanwhile, are conveyed to a trommel with 70 mm holes. The overs go to the magnetic separation circuit just described. The unders, that is, the -70 mm fraction, pass by a magnet that extracts ferrous material, mostly bottlecaps. The remainder is conveyed to another trommel with 15 mm holes. The overs from this trommel are an organic concentrate, and the material passing through the holes is mostly inorganic, principally glass. The overs join with the -25 mm fraction from the trommel previously described located in the paper and plastic recovery circuit.

This organic material is the feedstock for the compost operation and thus is transported to an outdoor fermentation area. It takes about 120 to 150 days, depending on the weather, for the material to become compost. During this time the material is turned over five times. When fermentation is complete, the material is picked up by a front-end loader and placed onto another ballistic separator belt, which makes a split of approximately 50-50. Half the material is heavy and bouncy and is discharged from the lower end of the belt. The lighter organic material is conveyed upwards and into a hammermill. Here it is shredded to a fine size, and then it is conveyed to a trommel with a hole size of 25 mm to obtain fine compost. The material that was not cut to this size, particularly plastic and pieces of wood, stays in the trommel. These rejects (overs) go to landfill or to incineration, while the material that passes through the holes is the semifinished compost.

Next, the compost is processed by a vibrating screen, one with a flexible, snappy rubberized deck with 7 mm holes.* It is sized to -7 mm and 7 to 25 mm. The 7 to 25 mm is a medium-grade compost. Most of the glass that is carried over from the other unit processes is in the -7 mm fraction. This mixture is further classified in a device known as a stoner. It produces a light product, an intermediate product, and a heavy product. The heavy product contains the bulk of the glass. The light product contains the organics, and, as can be expected, the intermediate product is the refined compost.

However, the lights can also be used as compost and after deentrainment in a cyclone may be added to the fine compost material. The three compost products, then, are large compost, intermediate compost, and fine compost. The intermediate and fine compost are derived from the large compost by means of the processing steps described. The quality of the refined compost is described in Table 25.

Table 25. Refined Compost

<u>Quality</u>	<u>Composition</u>
Moisture	25%
C/N ratio	12 to 15
Field capacity	188%
Total organic matter	55-60% (dry basis)

Source: Correspondence with Plant Engineers.

As far as the paper product is concerned, the moisture, as already stated, is approximately 50 percent. The physical characteristics of this material are said to exceed that of much of the secondary paper used for the production of grey cardboard. The physical characteristics of this material after drying are listed in Table 26. The average length of the fiber is 1.04 mm (58% long fiber and 42% short fiber). The percentage of fines is said to be relatively low.

The plastic film is an important output of the process. This material can go into injection molding, which is used in the manufacture of various articles such as plastic buckets, toys, plastic covers, and so on.

*See the illustration of this type of screen (flip-flow) in the section describing the ESMIL facility.

Table 26. Paper Product

<u>Composition (Dry)</u>	<u>Percent</u>
Fibers	67.1
Fines	8.9
Inerts	17.2
Rejects	<u>6.8</u>
	100.0
Moisture	50

Source: ENADIMSA, Process Description, p. 15.

Economics, Manpower Required, and Energy Use

The market prices in pesetas (Ptas) received for the recovery material are: plastic (white) 35,000 Ptas/ton; plastic (colored) 27,000 Ptas/ton; film plastic 11,000 Ptas/ton, baled; ferrous metals (cans) 5,000 Ptas/ton, loose; compost 1,700 Ptas/ton. The prices cited are FOB the plant in Madrid. The cost of the plant in 1981 terms was 260,000,000 pesetas. Start-up cost an additional 60,000,000 Ptas. The operating costs are currently 990 Ptas/ton of waste (input basis). The income is 390 Ptas/ton of waste received as a tipping fee plus 660 Ptas/ton of input waste derived from the sale of the recovered products. Revenues cover operating costs, with a little to spare, but they do not cover the prior capital outlays, including the start-up costs.

The plant operates on two eight-hour shifts per day. This requires nine production workers per shift and one staff person per day. The plant processes 250 tons per day. This is an average figure and takes into account the dead time required for maintenance and cleaning operations. The energy consumption is 17 kwh/ton of waste treated (electrical) and 0.4 kg/ton of waste treated (fuel). The water consumption is 2 m³/hr of operation.

Summary

Even though the plant cannot repay the capital cost and its start-up expenses, the fact that it somewhat more than covers its operating costs means that it can generate some cash flow to continue test and evaluation activities and to carry out equipment modifications. In this sense it can be considered a

successful demonstration undertaking. In contrast, many other demonstrations around the world require an operating subsidy in addition to the capital grants that provided for construction and shakedown.

The important features of the Madrid plant are the initial flail mill, the adhesion belt ballistic separators, the ferrous metal clean-up system and the composting operation. Recently, it has been decided to produce and RDF fraction from the plant rejects (33.48%, see Table 21). It is expected that this will reduce the 33.48 percent figure to the range of 12 to 15 percent. The combustible product is expected to have a lower heating value of 3,200 Kcal/kg and sell for 1,800 p/ton.

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Contacts

Martin M. Cavanna
Empresa Nacional ADARO
de Investigaciones Mineras
Serrano 116
Madrid 6,
Spain
Ph. 262 41 10 or 797 34 00

Higinio Garcia Ramirez
Empresa Nacional ADARO
de Investigaciones Mineras
Serrano, 116
Madrid 6,
Spain
Ph. 797 34 00

6. ROME: SORAIN CECCHINI (ITALY)

Waste recycling is probably nowhere more comprehensive than in the city of Rome. For a number of years four recycling plants have been in operation there. At first they belonged to three different companies, but then were consolidated as a result of a joint venture between the companies Sorain and Cecchini.* More recently, with the changing of the municipal government in Rome, the plants have been sold to the city and are currently operated by municipal employees. Sorain and Cecchini supplies technical and engineering assistance and marketing expertise, and has the responsibility for the sale of a portion of the recovered products.

The equipment described here is the most recently modified line in the Rome East recycling plant, which was originally built in 1967. The capacity of the plant -- 1,200 tons per day overall -- is based on two shifts per day. The facility is as complete a recycling plant as can be found. The products are ferrous metals, paper pulp, compost (occasionally), film plastic, and -- on a pilot basis -- a refuse-derived fuel. Bulky combustible refuse and the nonreclaimed fine material is incinerated on site as a means of generating heat for various processes. Table 27 shows Rome's waste composition. Note in particular the high moisture level.

Description of the Central Processing Plant

The process flow of this plant is a complex one (Figure 8). Also, it is difficult to evaluate the effectiveness of the unit processes because of the proprietary nature of the effort. The paragraphs that follow are as complete a description as appears in the literature.

Rome's refuse is contained mainly in polyethylene bags. It is collected daily during a six-day week without much compaction and is delivered to the plant. The receiving pits at the plant are equipped with overhead cranes and electrohydraulic grapples to move the refuse. The pits are capable of receiving and storing up to two days of refuse, thus allowing for plant shutdowns over one-day holidays and necessary large scale repairs.

The material is conveyed to the first unit process, which is a bag opener. This consists of a number of relatively slow-moving arms that push the bags down through a series of stationary jaws. The bags are too large to pass through the jaws without being ripped and torn and this action liberates the contained materials. Large materials such as cardboard boxes are also cut into smaller pieces by the rotating action of the arms. The bag breaker operates at 12 RPM.

*SORAIN stands for Societa Riutilizzazione Agricola Industriale.

Figure 8. Rome Sorain Cecchini Facility Flow Diagram

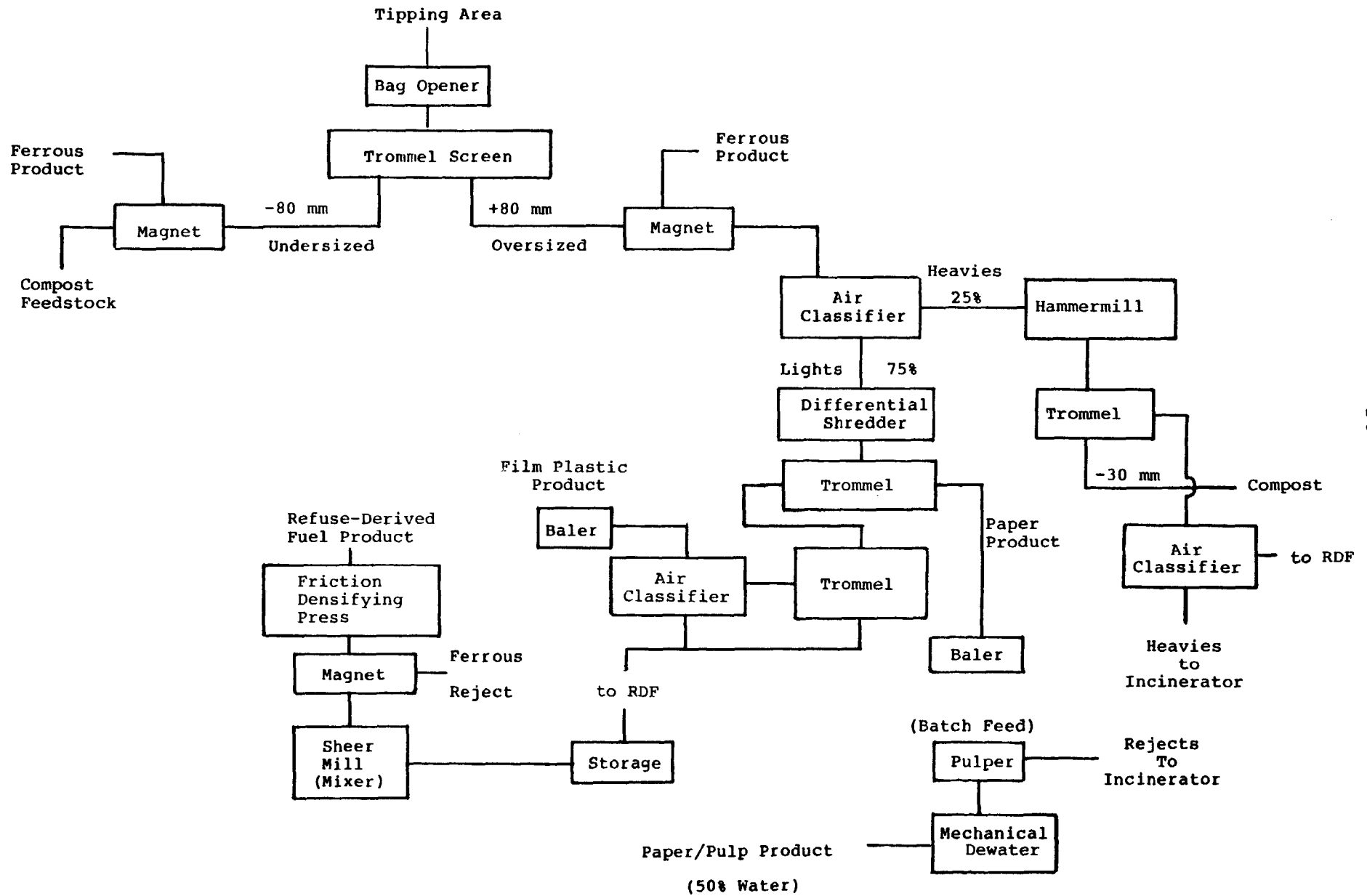


Table 27. Refuse Analysis

<u>Component</u>	<u>Percent</u>	<u>Moisture (average)</u>
Paper and cardboard	25	20-22
Film plastic	3.5	0-5
Hard plastic	2.5	0-5
Textiles, wood and other combustibles	3	10-15
Organic	50	80-85
Ferrous metal	2.5	-
Glass and inerts	13	40-45
Total	100	
Average moisture content		45-50%

Source: Sorain Cecchini, Corporate Brochure, p. 1.

Next, the material is conveyed to a trommel where material less than 80 mm is screened out. Much of this material is organics; some is glass. Magnetic metals are separated from this stream. Other inerts include ash, rocks, and stones. The oversize from the trommeling step -- and this trommel is operated at a rather light load to ensure effective screening -- goes to a magnetic separation unit and then on to an air classifier that blows the lights from the heavies. After deentrainment the light material, which is mainly paper and plastic, is subjected to differential shredding. The device used here cuts the paper but not the plastic. The differential has a ratio of approximately 3 to 1.

The heavies from the air classification step, which amount to 250 to 300 tons per day, are further processed in a hammer-mill, followed by a trommel with 30 mm holes. The unders are a compost feedstock. Overs are air classified with the lights going to RDF while the heavies are incinerated on site.

A principal objective of the operators of the plant is to improve the composition of the compost produced, and thus its salability. The next few paragraphs describe the new composting operation installed in 1983 and in shakedown at the time the site was visited.

This system utilizes a large mobile machine called a BIORAPID rotor unit. The organic matter, which is the feedstock for the compost portion of the operation, is deposited in a number of composting basins, each of which holds approximately 2,200 tons (short) of material; its residence time in the basins is, as mentioned above, four weeks. The bottom of each basin is covered with gravel. The gravel overlies a number of ventilation pipes connected to an air supply fan that provides the air for the aerobic compost process.

The BIORAPID unit rides on rails fitted to the sides of the composting basins. The unit weighs approximately 40 tons. This unit turns over the material that is composting to ensure mixing and aeration. It moves through the material, starting with that closest to the discharge end and then moves along the rails to the infeed end. After a complete run along the entire length of the basin, the material that is composting will have been moved about 4 meters from feed to discharge end.

The unit looks like a large birdcage lying on its side; not parallel with, but across, the basin that contains the material being composted. That is, the axis of the cylinder is across the basin. The rotation is in the direction of the material movement. As the rotor moves through the material, spring-loaded spikes fitted on the outside of the rotor surface move and mix the material, fragmenting the organic matter, oxygenating the mass, and freeing water vapor. At the end of a working run, the rotor is raised, and the entire unit travels back to the discharge end, where either a new cycle is started or the unit is transferred to another basin.

One unit can service up to six basins with a daily capacity of 550 short tons per day. The diameter of the rotor is 6.3 m and its length is 10 m. The machine is driven from a control cabin hung on a side frame. Hydraulic power is used for both the rotation and the movement of the rotor along the basin. The material discharged by the composting unit is screened and air classified. The latter steps are necessary if a marketable compost material is to be produced. From information received, it is not clear that composting operates on a day-by-day basis. There may be marketing difficulties.

Back in the main processing line the ferrous metal from the magnetic scalping is purified and partly detinned in a rotary kiln by sweating at 450 to 600o C. Organics are burned off. The clean scrap is baled and sold to a ministeel mill for the production of reinforcing bars.

The light fraction from the first air classification step in the main processing line goes through the differential shredding process mentioned earlier. This step -- which, it will be recalled, cuts the paper but not most of the plastic -- is followed by a sequence of two trommeling steps designed to separate the larger from the smaller pieces of paper and plastic.

The oversize for the first trommel holes is a plastics-rich fraction. The smaller pieces (85% to 90% paper) go through the trommel's holes and are baled for later pulping. The latter reduces the nonpaper content to less than 1 percent. The oversize material, i.e., the plastic concentrate, is trommelled again. This trommel's overs (the plastic fraction) is then air classified. The lights are 90 percent film plastic, the main contaminant being paper. The trommel unders and the air classifier drop is RDF feedstock.

The plastic film is about 90 percent low-density and 10 percent high-density polyethylene. This polyethylene plastic concentrate is baled. The plastic is taken off site to another plant for further processing. As mentioned, the paper is pulped on site and the rejects from the pulping process are incinerated in the units that are part of the plant's overall solid waste disposal capability.

The RDF fraction from the various trommeling and air classification steps consists of about 80 percent paper and 20 percent plastic. As mentioned briefly and described later in this chapter, this fraction is made into a refuse-derived fuel called CALURB.

The batch pulper that treats the paper concentrate removes over half of the plastic contraries. The pulp is dewatered and processed through a screw dryer; the moisture level here is about 65 percent. It is then transported to a nearby paper mill. The primary feedstock for this mill is straw. The semidry pulp from the recovery plant is blended with the straw in the production of grey cardboard. The output of the plant is used for tablet backings and other low-grade cardboard.

This plant has a number of processing lines that have been upgraded to better accommodate the separation goals of the operation. These have changed over the years and emphasis now is placed on the production of refuse-derived fuel rather than paper and plastics recovery or the animal feed that was once a feature of the plant. The newest line processes 20 to 22 metric tons/hr. The primary trommel here rotates at 12 RPM. It has both square

and round holes, designed to place the maximum amount of material less than 80 mm into the undersize. The trommel sends about 60 percent to the unders and 40 percent to the overs. The ferrous material removed represents about 2 1/2 percent of the raw waste.

Refuse-Derived Fuel (CALURB)

The refuse-derived fuel RDF production unit is the newest experimental, pilot addition to the plant. A special effort has been made to minimize the amount of energy needed to produce the fuel product.

There are five steps in the production process: feeder, shearmill, conveyer, magnet, and densifier. It is said that the shearmill actually does very little except mix the material. The densifier is a press, perhaps a roller press, which produces pieces of material that have a sponge-like consistency. The RDF, held together by friction, is approximately 1/8 in thick and less than 1 in in its other dimensions. Less than 20 kwh/ton are utilized in the processing steps just mentioned.

One user of the refuse-derived fuel produced by the plant is a nearby cement kiln where it is burned as an auxiliary fuel. Transportation takes place in ordinary packer trucks. The refused-derived fuel has a higher heating value of 6,500 and 6,800 BTU/lb, with a moisture level of 18 and 22 percent. The residual ash is about 15 percent, sometimes lower. The cement kiln that utilizes the CALURB fires coal as its primary fuel. The RDF is blown into the kiln.

In recent months the SORAIN CECCHINI Company has disclosed additional information about the characteristics of CALURB. The amount that will be produced from a given raw refuse composition depends on whether or not paper and plastics are also recovered. They have also given more information on the energy required to produce the fuel. However, little detail beyond that given above has been revealed about the production process itself.

Table 28 shows the chemical composition of CALURB produced at the Rome plant. The ash content is approximately 15 percent, of which roughly 40 percent is SiO (glass). The melting point of the ash is between 1920o and 2010o F. If a plant, like the one just described, were to be configured without the recovery of plastics and paper, devoting these fractions to the CALURB feedstock, the results would correspond to data given in Table 29. Compare this with the data in Table 30 on the current input and output of the Rome plant, which, it will be remembered, recovers both paper and plastic. The overall energy consumption of the Rome plant -- taking into consideration the newest line or, perhaps better, its possible replication -- is given in Table 31.

Table 28. Percentage Presence of Certain Chemical Elements in Calurb (Dry Basis)

<u>Element</u>	<u>Percent</u>
C	47
H	6.4
N	0.70
S	0.19
Cl	0.087

Source: Carrera and Dunin, Energy Recovery, p. 51.

Table 29. Refuse-Derived Fuel (CALURB) Without Plastics and Paper Recovery

<u>Waste Composition</u>	<u>Percent</u>	<u>Recovered as Percent of</u>	<u>CALURB Composition</u>
Paper/cardboard	25.0	21.0	71.2
Film plastic	3.5	3.3	11.2
Hard plastic	3.0	0.9	3.0
Ferrous metals	2.5	-	-
Textile/leather/wood	3.0	1.9	6.5
Organic matter	53.0	2.1	7.1
Glass/inerts	10.0	0.3	1.0
	100.0	29.5	100.0

Quantity of CALURB obtainable: 29.5%

Higher Heating Value (HHV):	MSW (H ₀ = 47%)	2040 Kcal/kg 3675 Btu/lb
	CALURB (H ₀ = 24%)	3605 Kcal/kg 6490 Btu/lb

Source: Carrera and Dunin, Energy Recovery, p. 48.

Table 30. Refuse-Derived Fuel (CALURB) With Plastics and Paper Recovery (Rome)

<u>Waste Composition</u>	<u>Percentage</u>	<u>Recovered Paper Percentage</u>	<u>Recovered Plastic Percentage</u>	<u>Recovered Combustible Components</u>	<u>CALURB Composition Percentage</u>
Paper/cardboard	25.0	16.0	-	5.0	56.8
Film plastic	3.5	0.8	2.1	0.4	4.5
Hard plastic	3.0	0.4	-	0.5	5.7
Ferrous metals	2.5	-	-	-	-
Textile/leather/wood	3.0	0.2	-	1.7	19.3
Organic matter	53.0	1.1	-	1.0	11.4
Glass/inerts	10.0	0.1	-	0.2	2.3
	100.0	18.6	2.1	8.8	100.0

Quantity of CALURB obtainable: 8.8%	
Higher Heating Value (HHV): MSW (H ₂ O = 47%)	2040 Kcal/kg 3675 Btu/lb
CALURB (H ₂ O = 25%)	3605 Kcal/kg 6490 Btu/lb

Source: Carrera and Dunin, Energy Recovery, p. 52.

Table 31. Energy Consumption from Start of Processing Through RDF Production: Rome

<u>Cycle Steps</u>	<u>KWh x ton MSW</u>
1-Bag opening and cardboard breaking	3.5
2-Separation of organic fraction	0.3
3-Ferrous recovery	0.1
4-Separation of heavy fraction	4.1
5-Separation of film plastic	8.2
6-Separation of paper/cardboard	0.6
7-Homogenization	2.7
8-Densification	9.6
9-Auxiliary consumptions	2.4
Total	31.5

Source: Carrera and Dunin, Energy Recovery, p. 61.

Plastics Upgrade and Use

The waste processing plants of Rome (daily capacity 1,800 tons of refuse) as well as several other sources provide baled plastic film to the Sorain Cecchini plastics upgrade, plastic bag manufacturing, and plastic pipe production plant. This facility is located in the suburbs of Rome. The composition of the plastics found in Rome's waste is shown in Table 32. It consists mainly of polyethylene, and most of this is low density. The reason for this is that most of the city's refuse is contained in plastic bags.

The plastics upgrade and manufacturing plant's flow sheet is given in Figure 9. No attempt has been made to recover the thermosetting material that makes up 15 percent of the plastics. Thermoplastic is the target for reuse. First, the baled plastic is fed to a shredder, and then it passes through a "safety" magnetic separator (not shown). The first washing step comes next. This is also a float/sink process that separates heavies in the feed from the lights. A system of flush and counter-flush enhances the cleaning action. Plain water -- no detergents -- is used.

Dewatering is done on a vibrating screen. A second wash is carried out to eliminate the paper residue. The material is next treated in additional vibrating separators. The plastic product is centrifuged to remove additional moisture and it is then dried with hot air and blown to storage silos.

Discharged from the silos, it is melted at a temperature of 220° C and extruded. On extrusion, the softened polymer passes through an automatic double-screen filter that removes impurities greater than 50 microns. The product discharge is cooled and granulated. The product is 90 percent low-density polyethylene with a melt-index of 1.3 to 2.0.

The plant is capable of handling 500 kg/hr of baled plastic-rich feedstock. From this it produces 425 kg/hr of plastic granules. The daily input/output relationship is 12,000/10,000 kg.

The recovered polymer is converted mainly into plastic film that is made into plastic refuse bags. The production rate is 300,000 bags a day. Although the bags could be made of 100 percent recycled plastic, the mix used is 70/30 in favor of virgin material since many of the bags will come back after their next household use. While the loop is not closed completely, about half of the bags sent out will be recovered by the refuse-processing facilities and will be returned to the bag-manufacturing plant. Mixing the virgin and recycled plastic allows the bags to be made of film of 60 microns, but if the bags were 100 percent recycled material they would have to be thicker (150 microns). Plastic pipe is also made from the material. This process uses 100 percent regenerated plastic.

Table 32. Average Composition of Polymeric Substances Present in the Waste of the City of Rome

<u>Thermoplastic (85%)</u>		<u>Thermosetting (15%)</u>	
Subdivided as Follows (%)		Subdivided as Follows (%)	
Polyethylene, low density	61	Phenoplastic	25
Polyethylene, high density	12	Aminoplastic	23
Polyvinylchloride	17	Polyurethane	16
Polypropylene	3	Polyester	7
Polystyrene	6	Polyacrylic	15
Others	1	Others	14

Source: Recovery and Reutilization of Plastic.

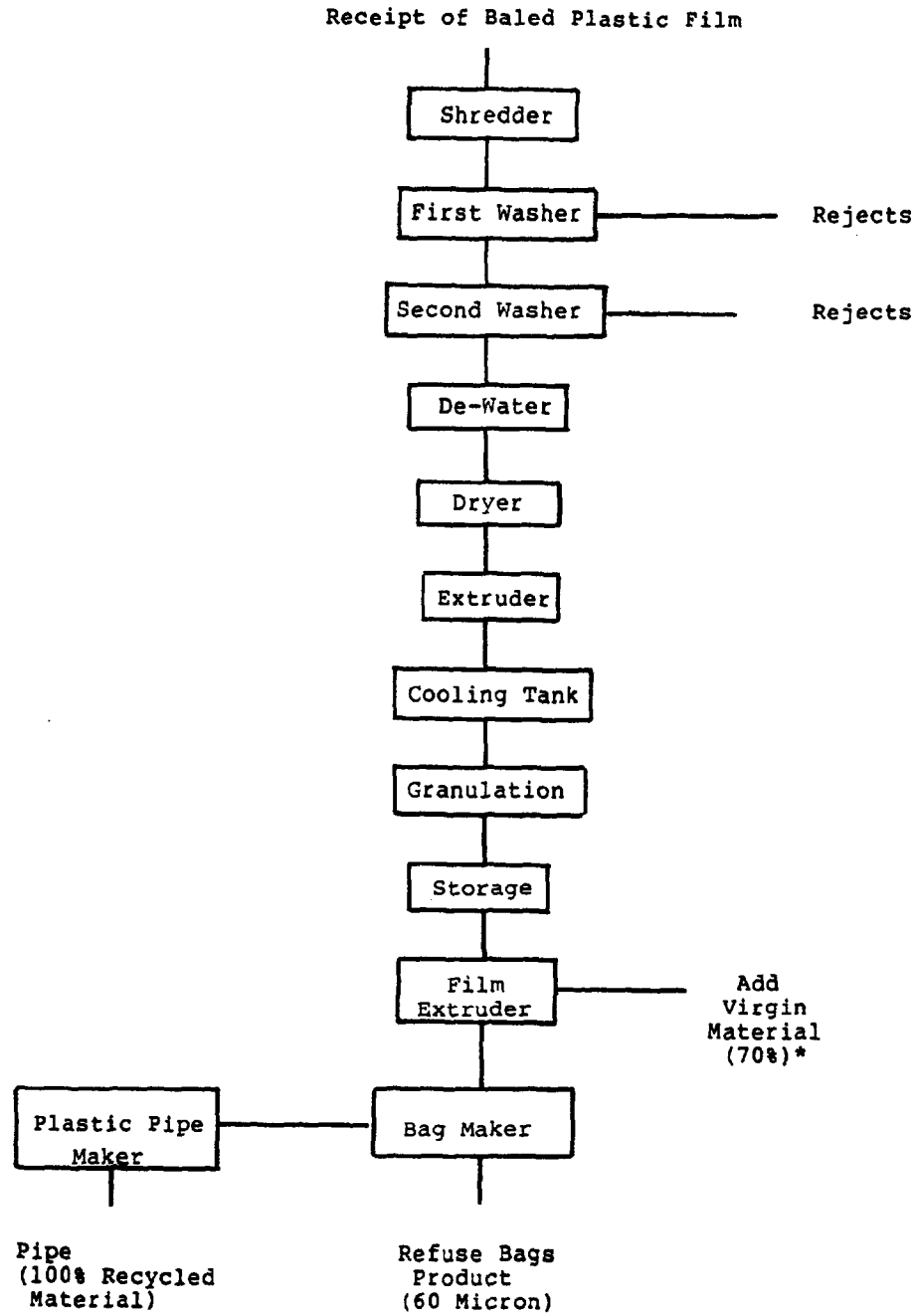
About 50 percent of the plastic in the household waste picked up by the city's trucks is recovered and baled according to the process previously described. Essentially, this material is 89 percent plastic (see Table 33).

Table 33. Impurities Present in Polyethylene Recovered Prior to Transfer to Off-Site Plastics Upgrade and Manufacturing Plant

<u>Impurity</u>	<u>Percent</u>
Paper and cartons	4
Polyvinylchloride and other polymers	5
Organic Substances, silica, clay and others	2
Wood, rope, rags, etc.	0.2

Source: Recovery and Reutilization of Plastic.

Figure 9. Rome Sorain Cecchini Plastic Upgrade Plant



*With Thickness of 150 Micron or Better, 100% Recycled Plastic.

Summary

The Sorain Cecchini plants in Rome certainly have the greatest number of operating hours and tons processed in the world. By whatever measure that might be used, this organization has unquestionably gathered a great deal of experience and know-how. Much has come about through trial and error.

As in the case of all waste-recycling facilities, modifications have been necessary to run the plants efficiently and to improve on operations. The most recent Sorain Cecchini flow sheet bears testimony to this. Particularly notable in this operation are the low-speed bag openers and the low-speed differential shredding unit processes.

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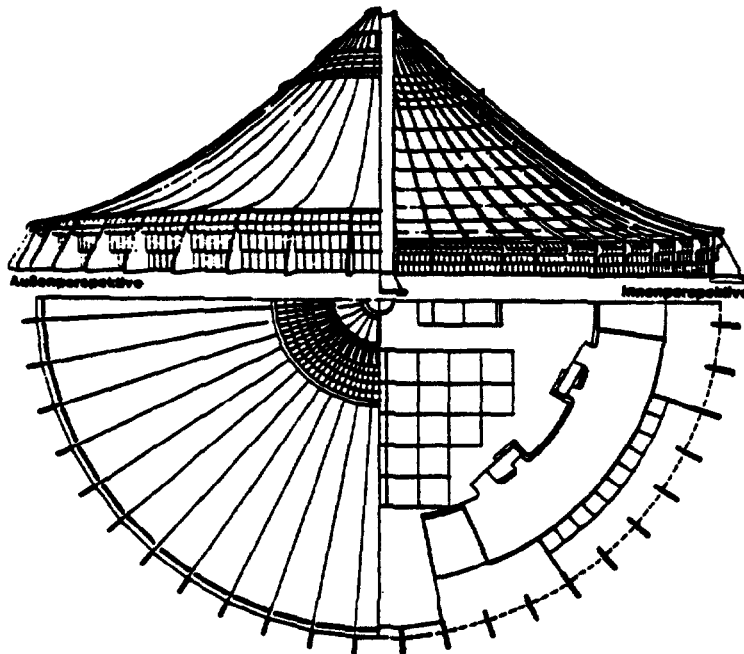
Dott. Ing. S. Dunin
Sorain Cecchini
Solid Waste Recycling Group
Via Bruxelles, 53
00198 Rome, Italy
Ph. (06) 860192 - 867031
Telex 611534 sorain I

Dott. Ing. Pietro Carrera
Sorain Cecchini
Via de R. Cencia, 301
00132 Rome, Italy
Ph. (06) 6181141

7. VIENNA: THE RINTER PLANT (AUSTRIA)

The Rinter Plant located in Vienna, Austria, is probably the most ambitious recovery effort that has been undertaken in Europe. This extends from the recycling objectives to the type of building erected. The latter, which looks like a single-poled tent, has a diameter of 170 m, a central height of 67 m and an overall facade height of 11 m. It has the world's largest hanging rib wooden roof (see Figure 10). The equipment originally installed takes up only half the interior of the building. Optimistically, room was left for additional processing capability. Actually put into place was equipment making up two parallel but independent running lines with a planned capacity of 20 tons of waste per hour each. In addition, there was one preparation line to produce fiber for fiberboard production and a preparation line to produce fiber for paper production. There is also plastics and ferrous metals recovery and, finally, there are two residues, one seen as a potential compost feedstock and another that was targeted for use in brickmaking.

Figure 10. Rinter Plant (Vienna)



Source: Bandion, "Recycling Plant in Vienna," p. 190.

Unfortunately, the plant in actual operation did not prove to be successful. It is said that 841 million Austrian shillings have been spent on the plant. Nevertheless, the ambitious plan to recover iron scrap at a rate of 1.5 tons/hr, bulk material at a rate of 6 tons/hr, organic fine fraction at a rate of 6.4 tons/hr, plastic foil at .9 tons/hr, organic heavy fraction for board fiber preparation at a rate of 11.2 tons/hr and a moist paper fraction for paper fiber preparation at a rate of 15.6 tons/hr simply did not succeed* (see Table 34 for waste composition). Some blame the company that did the design work -- Esmil, a Dutch firm. Some blame the equipment manufacturer -- Andritz, an Austrian company. Others blame the Rinter Company itself.

The contract with the city of Vienna apparently did not specify the extent to which materials had to be recovered from the waste. It only specified that the waste had to be accepted by the Rinter Company and for this acceptance a fee was paid. (This fee was in excess of the current cost of disposal of raw waste at local disposal sites.) Thus, an incentive was set up for the company to merely pass the material through the plant as quickly as possible and at as low a cost as possible. The material then could be landfilled at a net gain in income.

Those who fault the Dutch firm say that available figures on the bulk density of Vienna refuse were not taken into account in developing the dimensions of the equipment. The density of Vienna's refuse is much lower than for Dutch refuse. It is said that Dutch figures were mistakenly used and that, when equipment was put to the test on Vienna refuse, it proved to be undersized and unable to handle the design throughput tonnages.

In evaluating the Vienna situation, one must keep in mind that virtually all resource recovery plants have had significant shakedown problems. The scale of the Rinter plant simply amplifies this experience. For a time it seemed that agreements had been made among the principals, including the banks that financed the undertaking, to reconfigure the plant into a refuse-derived fuel production facility. This work was proceeding as an extension of the RDF concept that was incorporated into the system just before the plant was shut down. However, recently there has been another change in direction as a result of Rinter filing for bankruptcy (December 1983). The latest decision is to disassemble most of the equipment and to install a bulky waste treatment plant as an interim use for the facility.

*These figures include some water added during processing.

Table 34. Vienna Household Waste

<u>Component</u>	<u>Percent by Weight</u>	
	<u>Bulky Waste Included</u>	<u>Bulky Waste Removed</u>
Paper	27.52	28.12
Cardboard	11.96	12.24
Wood	2.72	1.94
Leather	0.20	0.20
Rubber	0.17	0.11
Bones	1.09	1.12
Textiles	5.64	4.69
Plastic Films	3.91	4.00
Plastic Containers	4.93	5.00
Vegetation	21.82	22.40
Small Iron	3.05	3.13
Large Iron	1.11	0.77
Nonferrous	0.97	1.00
Glass	7.84	8.05
Stones, Dirt, Ash	<u>7.07</u>	<u>7.21</u>
	100.00	100.00

Source: Vogel, Quantitative and Quantitative Analyse...
p. 60-61.

Description of the Plant and Six-Month Operating Attempt

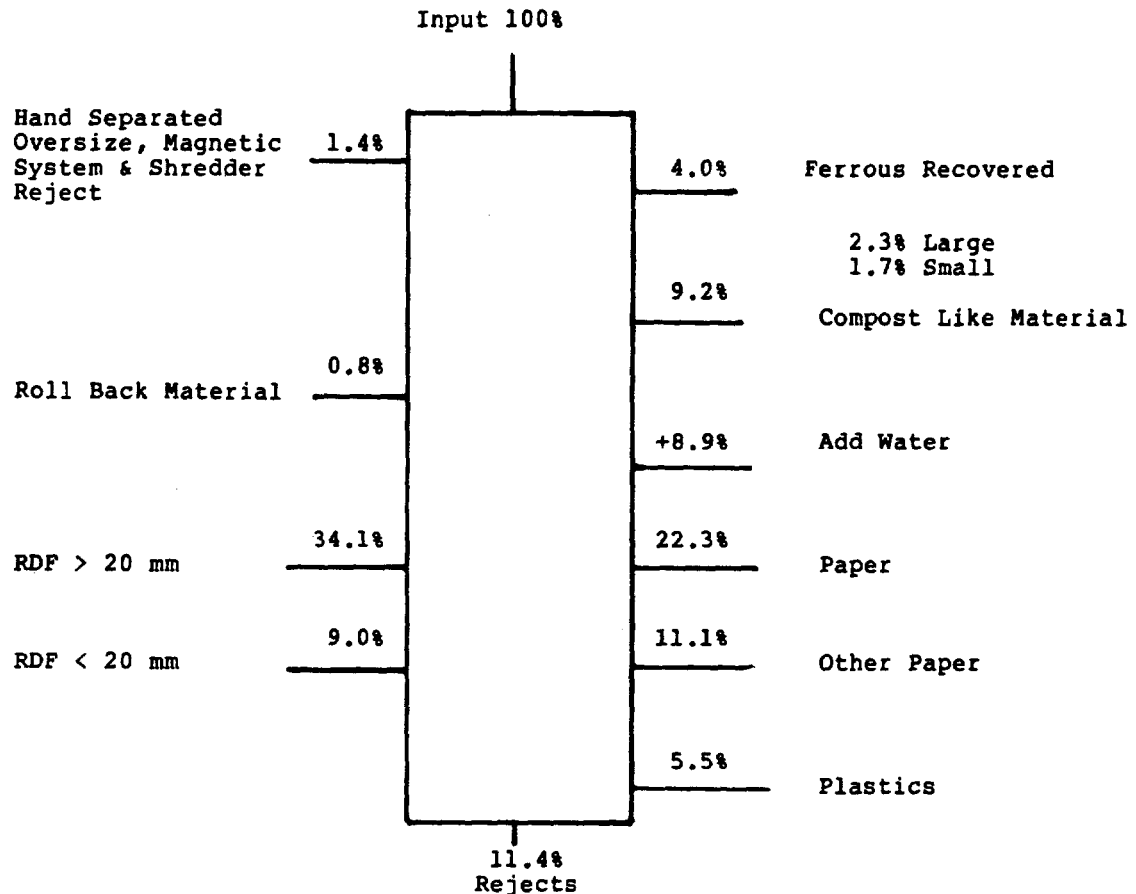
A schematic of the principal equipment operated during the six months that the plant was open is shown in Figure 11. The Figure simplifies the plant considerably. For example, it does not show the paper recovery operation. However, it serves to guide the description that follows. The waste is discharged from the collection vehicles into receiving pits similar to those used in most conventional incinerator plants. Two large grab cranes are used to load the feed conveyer. A bag opener is the first processing step even though trash cans are almost exclusively used in Vienna. Downstream processing equipment is protected by handpicking. There is also a smaller grab crane inside the processing area itself. This is used to separate oversized material, which includes bulky waste collected together with household and commercial waste, that was on occasion delivered to the plant. Examples are washing machines and refrigerators, tree trunks, and the like. (There is a controversy as to whether such deliveries were within the scope of the contract or not.)

The primary magnet comes next; after which food and beverage cans and large ferrous material are separated by air classification. The tin cans are shredded in a cutter. Once the ferrous is removed, the waste is conveyed to slowly running shredders that reduce it to a particle size on the order of 70 to 100 mm.

The shredded mixed waste is next air classified. Air classification takes place in two stages, with the lights from the first stage undergoing a second stage of separation. Both air classifiers are of the zigzag design. The light fraction -- consisting of paper, plastic foil, and small organic substances -- is transported to a cyclone, where it is separated from the transport air. The heavies from both air classifiers are combined and go to a hammermill. This material consists of wood, leather, rubber, textiles, bones, and heavy plastics, as well as glass, ceramics, sand, and stones.

Originally this shredder was supposed to reduce the material to a particle size less than 15 mm, and this material was then to be sieved at 5 mm. It was assumed that the -5 mm material would be basically inorganic and could be used in various building operations or for road construction. The +5 mm size fraction was assumed to be organic, and was to be the feedstock for fiberboard.

In early operations, this material was dried until its moisture content was 5 to 10 percent moisture. Drying was accomplished in a gas-fed rotating drum dryer. It was then sieved again and separated into a compost or RDF material (the smaller size) and feedstock for the fiber operation (the large-sized material). Using this fraction for fiber was abandoned quite early because of the quality of the material and material's handling difficulties. During most of the shakedown operations, all of the material was screened with overs going to RDF and

Figure 12. Vienna Rinter Plant - Materials Balance

Source: G. Vogel, "Quantitative and Qualitative Analyse . . .," p. 57.

fines to reject. The shredded heavy fraction was sized into three components: refuse-derived fuel larger than 20 mm, which was approximately a third of the overall input to the plant; a refuse-derived fuel less than 20 mm, which made up approximately 9 percent of the input of the plant; and a reject material, at 11 percent of the plant's input. Figure 12 gives the materials balance for the plant in this operating configuration.

The light fraction (paper, plastic foil, and some organic matter) is conveyed to a rotating sieve-drum separator. The plastic and paper stay inside the drum and are conveyed to the next step in the processing flow. The fine material, primarily organic, is considered suitable for composting. At this point, water is added to the mixture of paper and plastics to create a

differential density between the paper, which soaks up the moisture, and the plastics, which shed the water.

Next, a warm air classifier blows off the plastic foil and some of the light paper. The moist heavy paper falls. Additional moisture is added to the lights and the paper is separated from the plastic by being forced through the holes of a rotating screen, called a sieve-drum. This is mixed with the paper that dropped in the air classification step. The plastics, the overs from the rotating screen, are pressed into bales for use by the plastics industry. The plastic concentrate is 60 to 80 percent plastic.

The paper concentrate from these final steps in the plastic clean-up process is approximately 80 percent paper and corrugated. The heavy moist fractions are then processed together in the paper fiber preparation plant. This production line is similar to that used in the paper industry, and consists of pulpers, tubs, fiberizers, sieves, a thick matter cleanser, thickener, disperger, and double-sieve press. The product of these processing steps is in the form of pressed layers similar to cellulose stock (wet lap) produced by secondary paper processors for use by the paper industry.

Extensive papermaking equipment was installed in the Vienna plant because it was felt that the paper fraction from the household refuse should be processed to the point that it can be used directly by an actual paper or board mill plant. It should be the same as wet lap produced from source separated paper. It should not have greater amounts of fines or bacteria or be accompanied by an unpleasant odor. A twin pulp system was considered to be the best way to accomplish this objective. This is described at some length because of the several plants that are attempting paper recovery and the interest in this subject, since paper is generally the largest single component of municipal waste.

In a twin pulp system the pulper can be operated continuously. The stock enters the pulper through very large holes. This material is disintegrated further in a fiberizer, which is also provided with large holes. Most of the fibrous material returns via the perforated plate of the fiberizer into the pulper, whereas the impurities, including a small percentage of the fiber stock, are removed from the center of the fiberizer and pumped into a perforated drum. Rejects are washed out of the drum -- that is, the fibrous material is returned to the pulper with the washwater through the perforations of the drum, whereas the rejects, now freed of fibers, are separated out of the drum.

The pulp is further cleaned, first by screening through perforations and then by a subsequent screening through fine slots. Then it goes through a washing unit designed to process stock containing about 5 percent solids. A disperger is next in the process flow. After this step, the processed stock is

dewatered to a dry content of approximately 45 percent and piled on pallets by means of a layboy.

The stock-washing system is of interest. As is well known, considerably more fines adhere to the fibers of paper pulp derived from mixed waste than is the case with paper that is separated at the household. In papermaking terminology, this results in lower freeness, or a higher SR degree. A lower freeness means that the material will have poorer dewatering properties. This is not desirable in paper production and is one of the reasons why paper manufacturers are reluctant to use paper fibers that have been extracted from mixed household waste.

In Vienna, the cleanup steps involve the use of an Andritz double press that is used for dewatering fibrous materials from about 3 percent to 20-30 percent. The fines are removed by the slotted screen headbox previously mentioned. Here fines are dewatered from 1/2 percent to about 3 percent solids. At this point, undesirable fines, as well as a large portion of the additives along with what is called the white water, are extracted.

This white water flows to an effluent treatment plant that is also part of the installed equipment at the Vienna facility. Here the water is cleaned with additives and the fines removed in the form of sludge. The clean water is recirculated as feed water for the pulping of the fibrous stock. The sludge from the effluent treatment plant is dewatered in a continuous press filter. It was felt that this material might also be usable, for instance, as a porosing agent by the brick industry.

While the stock-washing steps just described are expensive, they can increase freeness by as much as 100 percent and consequently enhance the strength of the end product.

A second important processing step on site is that of hot dispersion at a temperature of 95°C. The stock (dryness of more than 20%), which is discharged from the double press in crumbs, is conveyed to the disperger by a conveyer screw, where it is heated by means of steam. A disperger has two important functions in the process flow. First, it distributes inseparable impurities such as adhesives and similar material to under the visibility limit; this greatly reduces impurity problems during the paper manufacturing process. Second, the number of germs are reduced by a factor of approximately 10 to the fourth power, a consequence of the heat and ensuing hygienization of the paper fiber stock. This means the product can be stored for at least a month.

Summary

Although it offered the prospect of being the crown jewel among the first generation materials-recovery-from-waste plants, Vienna has turned out to be the most prominent disaster. Other

facilities have failed to live up to their promises, but the promise of the Rinter effort was so large. It was going to do so much. Perhaps it is unrealistic to expect that such a total system can be effected except through an evolutionary process of growth, beginning with fairly simple processing steps and adding unit processes only after the rudimentary first steps are mastered.

The problem with this is that the materials products that emerge from these more simple, and therefore less difficult to accomplish, processes are generally unsalable, particularly if the overall world market for secondary materials is depressed, as it has been for the last few years. Few plants, especially those financed privately, have the necessary staying power to proceed stepwise toward marketable end products. Most have tried to do it all at once. Few have succeeded. Vienna is no exception.

A number of lessons are to be learned, particularly from the papermaking efforts undertaken at the Vienna plant. These lessons would be of particular value to facilities that are considering the upgrading of recovered paper on-site before it is sent to a papermaking plant. This step is being taken by the VAM Company for the facility that it is reconfiguring in Northern Holland. Also, the ESMIL Company, who designed the Vienna facility, has constructed a plant using some of the same technology at Zoetermeer in the Netherlands (see Chapter 11). As was the case in Vienna, this plant makes extensive use of zigzag air classifiers.

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Contact

Dr. Gerhard Vogel
Institut fuer Technologie
Wirtschaftsuniversitaet
Augasse 2-6
A-1090, Austria,
VIENNA
Ph (0222) 347547-807
Tx 347547

8. NANCY: REVALORD PROCESS (FRANCE)

This project is the first full-scale demonstration of the Revalord Process developed in France and Benelux by the French Companies TRIGA and Strival from experimental work performed by BRGM*. The Revalord process is one of the most comprehensive materials recovery approaches yet developed. The recovery targets are paper, cardboard, ferrous metals, glass and plastic. As one might expect of a system that is geared to such a broad range of materials, there is no initial shredding step. Instead, the focus is on separation into materials-rich streams (concentrates) as early as possible in the process flow. Care is taken to minimize breakage and mixing beyond that effected by the householder or caused by the collection vehicles. More breakage and mixing would make the separation even more complex than it already is.

In the mid-1970's the urban district of Nancy was faced with a waste disposal capacity problem. The population had grown, and solid waste generation had increased to the point that the mass burning, water-wall energy recovery incinerator, operated by the urban district, was at its capacity. This led in 1978 to investigations of the alternatives available. One option was to expand the existing incinerator. A second was to build an entirely new disposal unit on a different site. A third was to implement some form of front-end recovery system for the purpose of reducing the tonnage of materials that would have to be burnt in the existing incinerator. The first two alternatives were ruled out because of space and political limitations, and because of the cost of investment. The feasibility study of the third alternative looked favorable, particularly from a siting standpoint. After a series of pilot plant sorting tests and an assessment of the likely revenues to be gained from the recovered materials, it was decided to move ahead with the front-end sorting system option, which showed economic potential in terms of the expected sale of the recovered materials and the savings in incinerator costs.

Reproduced in this section are a number of tables describing the characteristics of the Revalord process. For the most part, these data are from the operation of a pilot plant at BRGM headquarters in Orléans. Comparable data for the Nancy plant itself are not yet available.

*TRIGA stands for Traitement industriel des Gadoues; Strival is the Société pour le tri et la valorisation; and BRGM is the Bureau de Recherches Géologiques et Minières.

The Nancy materials recovery plant is designed to recover about 20 percent of the incoming waste. The processing capacity is 128,000 tons per year. As constructed, the plant includes three parallel sorting lines for the concentration of the materials targeted for recovery. They have a combined infeed capacity of 22 tons/hr. As concentrates are produced, the flows from the three "initial processing" lines merge. To reach its capacity, the plant must operate 20 hours per day, 6 days a week. At present, the plant is in a second shakedown period. The first efforts to operate the system indicated that a number of modifications were needed and this necessitated a shut-down period. These modifications have now been made and the plant restarted. Figure 13 shows the current configuration of the process flow.

Shakedown Operations

Collection trucks tip the waste into a large receiving pit. From the pit the municipal refuse is fed by a crane to the feed hoppers for each of the individual sorting lines. Table 35 gives the composition of typical French waste. An apron feeder delivers the refuse to the first stage of concentration. This is a primary trommel. It serves four purposes. First, it empties collection bags or boxes and separates agglomerated items in the first stage of the device. Second, the trommel screens out materials smaller than 200 mm. This is the size of the holes in the central zone of the trommel screen. The first zone has no holes. Third, the trommel removes two-dimensional elements such as newspapers, magazines, and flat cardboard, which pass through the openings in the third section of the trommel. This section is of a squirrel cage design. Fourth, the trommel conveys as oversize any objects that pass through the trommel and have not gone through any of its openings. Much of this material consists of three-dimensional boxes. The entry to the trommel serves as a bag opener of sorts in that it is equipped with a spike that tears at the bags as they fall into the device.

The squirrel cage at the end of the trommel consists of a series of bars on 180 mm centers. Each is covered with a tube that is free to rotate. Textiles, which would normally wrap around immovable bars, cause the tubes to rotate and, rather than being caught, they are directed into the appropriate product. The 200 mm holes in an earlier section of the trommel are also somewhat self-cleaning in that a bar welded outside on the trailing side of the hole makes it more difficult for textiles and stringy plastic to be caught and retained rotation after rotation, causing a blockage of the holes and thereby decreasing screening efficiency. Approximately 90 percent of the material, by weight, goes through the 200 mm holes.

Figure 13. Nancy Revalord Process

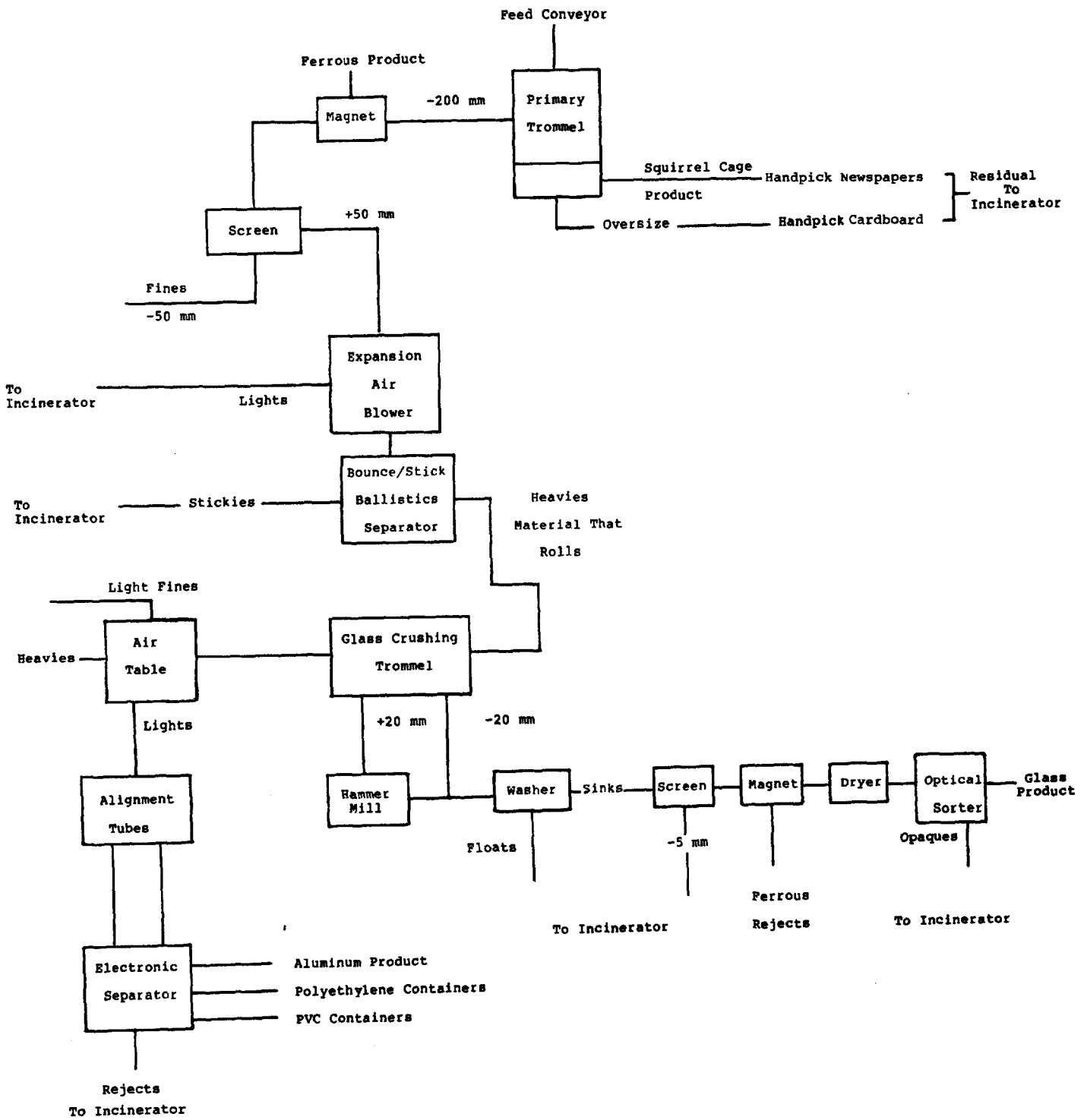


Table 35. French Waste Composition

	<u>Percent</u>
<u>+200 mm fraction:</u>	
Cardboards	4.4
Newspapers, magazines	6.6
Plastic bags	1.0
Flexibles	1.2
Mix materials	<u>1.0</u>
Subtotal	14.2
<u>-200 + 50 mm fraction:</u>	
Ferrous scrap	3.3
Nonferrous metals	0.3
Glass	7.0
PVC containers	1.3
PE containers	0.3
Mixed light materials	8.6
Mixed organics materials	<u>34.0</u>
Subtotal	54.8
<u>-50 mm fraction:</u>	31.0
Total	100.0

Note: Moisture level = 30%

Source: Giloux and Gony, "Revalord Process...", p. 1.52.

Table 36. Recovery Targets and Effectiveness
(Average per Hour Outputs of Recovered Materials)

<u>Target Recovered Products</u>	<u>Average Output/Hour</u>	<u>Recovery Efficiency (%)</u>
<u>+200 mm fraction:</u>		
Cardboards	800 kg/h	90
Newspaper, magazines	1,300 kg/h	90
<u>-200 +50 mm fraction:</u>		
Ferrous metals	700 kg/h	90
Nonferrous metals	40 kg/h	65
Glass cullet	1,300 kg/h	85
PVC containers	200 kg/h	75

Source: Giloux and Gony, "Revalord Process...", p. 1.52.

The oversize fraction is conveyed to a handpicking station where the corrugated fraction is picked out of the flow of the materials, dropped into a chute, and baled. The squirrel cage product is also conveyed to a handpicking station. It was hoped that the contraries could be picked out of the flow of materials, and that a salable paper product would remain on the belt for baling. This has not been the case; instead, the handpicker selects clean newsprint and drops it into a chute, after which it is baled for sale in the secondary paper market. The residual on this belt and that on the squirrel cage product belt is conveyed to the adjacent incinerator and combusted as a fuel.

It had been expected that the initial trommel step could also remove some of the flexibles (textiles and stringy plastics). These were to be collected on a conveying device that ran along the inside top of the trommel from beginning to end, somewhat like a clothesline. However, as was the case in the Doncaster plant in the United Kingdom, this device did not prove to be effective. It simply did not work and has been removed.

An interesting aspect of the trommel is that the inner lifters have rubberized ends in order to prevent, or rather minimize, the breaking of glass in the device. The objective is to minimize the glass fines that are produced by a shattering of the friable glass during trommeling. This allows the glass to be broken more systematically at a later step.

The undersize fraction from Nancy's initial trommel step is the material that passes through the 200 mm holes of the central zone of the trommel. This material then passes under an overband magnet that extracts most of the ferrous material, which is shredded and then subjected to a second magnetic scalp in order to improve its marketability. The product is baled for shipment to steel mills or iron foundries.

Having had the magnetics removed, the -200 mm fraction is fed to a one-deck vibrating screen with 50 mm openings. The -50 mm fraction is conveyed through the disposal circuit to the incinerator. Unfortunately, about 30 percent of the glass in the incoming waste is lost at this point. In spite of the precautions taken in the trommel to avoid the shattering of glass, there are still more small pieces (fines) created than expected. As a result, the -50 mm fraction is about 15 percent glass.

The +50 mm fraction falls through an expanded air blower that blows off light elements. These too are conveyed to the incinerator and burned. They are mostly combustible. The expanded air classifier is an interesting device. Near the nozzles is a high dynamic pressure that quite forcefully blows the material. However, the pressure reduces very rapidly in the expansion area, allowing for a natural setting of the blown-off fractions.

The next step is a ballistics separator, which is a moving belt that catches the heavier elements from the +50 mm fraction. The glass and the plastic bottles bounce off the belt downhill against the direction of movement. The uphill movement carries away the moist and damp elements that stick to the belt. This is mainly soiled paper, kitchen waste, and various vegetable matter. The sticky elements join the disposal circuit and are taken to the incineration plant. The ballistic separator is a differential rebound adhesion sorting device made from two belt conveyers, the upper feeding the lower. The wet material sticks to the lower belt and is conveyed upward and out to the reject area.

The bouncing elements are regrouped on a single conveyer. This material is conveyed to the glass-crushing trommel. The material first passes through an entrance zone that has no holes, but rather has lifters that pick up the glass and drop it to produce a selective breaking. The openings of this trommel are designed to screen two different size ranges. The first, a fine fraction, which is also the most important in weight, passes through the 20 mm holes that cover the first two-thirds of the trommel screen. The second size is a coarse product that falls through 40 by 90 mm holes. These occupy the last third of the device. The material that passes through these holes consists essentially of larger pieces of glass such as bottle necks and bottle bottoms. These fall into a small hammermill where they are reduced to a size generally below 20 mm.

Joining the previously described -20 mm glass-rich concentrate, this material flows to a water elutriator. This device washes out very fine and light (both floatable) contaminants and these float off. The elutriator heavies (which sink) are screened to eliminate residual fine impurities (less than 5 mm) and coarse ones (more than 20 mm). The plus 5, -20 mm glass concentrate goes to a magnetic pulley that extracts the remaining ferrous particles. It then goes to a dryer for which the energy is supplied by steam from the adjoining incinerator. Finally, the material is subjected to an optical sorting step that ejects the opaque pieces of ceramics, stones, earthenware, and so on. This is a multichanneled Sortex, one-pass slide system.

The optical sorter's feedstock has about 1 to 2 percent ceramics and other contraries. The objective is to reduce this to 0.05 percent in the product. However, results to date indicate that the reduction is only to about 0.1 percent. In order to improve the efficiency of the Sortex, a new screen will be added to the process flow before the optical sorter. This screen will divide the feedstock into a +5 -10 mm fraction and a +10 -20 mm portion. Several channels will be dedicated to the smaller size and several to the larger size. It is hoped that this step will enable the device's sensors to distinguish between opaque materials and glass more effectively. Particle size plays a role in this and the sensors can be selectively set according to the mean particle size that they expect to see. The capacity of the Sortex machine is approximately 1.2 tons/hr.

The oversize from the glass-crushing trommel consists mainly of plastic and aluminum containers and various pieces of paper, or paper and plastic combination containers. This fraction feeds two pneumatic tables that separate the lights from the heavies. Actually, the heavies, which consist of shoes, pieces of rubber, some glass and vegetable matter, walk up the table as a result of the vibrating action. The plastics, paper, and aluminum containers go down the table and fall into a series of rotating tubes separate from the table itself. The air, forced through the table from below, picks up fine material, primarily organics, which are exhausted through a hood.

The purpose of the rotating tubes, which receive the container-rich material, is to align these items one by one. This fraction contains about 40 percent PVC bottles, 25 percent polyethylene bottles, 14 percent polystyrene containers, 20 percent cardboard containers, and 6 percent aluminum containers. However, the amount of aluminum has decreased recently as some containers (particularly spray cans), are being made of steel.* Once aligned, this mixture is carried to a set of parallel belts. Each performs the same function.

*For Nancy the PVC content may be as high as 80 percent.

Sensing is initially effected by two eddy current devices. The first detects metal in mass such as in an aluminum can. Once sensed, the container is blown off the belt into a hopper. The second sensor is set to detect lesser masses of metal. In France, polyethylene containers generally have metallic rings or staples. These are sensed here and blown off the belt. PVC containers have no metallic parts or caps and hence pass through. The remaining task of this separating device is to distinguish between PVC and paper and cardboard. This is done by means of an infrared sensor. The sensor reacts to the relative level of opacity.

The PVC is clearer than the paper and the cardboard; therefore it is blown off the belt. The paper and the cardboard travel on, and are discharged onto, another conveyer, which carries them to the incinerator for combustion. One problem with infrared sensing based on opacity is that it can be defeated by the paper labels on certain PVC containers. Overall, the device is about 60 percent effective. The recovered PVC material is shredded, bagged, and sent to market.

A knife shredder is used to cut the aluminum containers into smaller pieces. However, in present operations the aluminum product also contains a fair amount of aluminum foil, which tends to foul the machine. Although little shredded aluminum concentrate has been obtained, what has been recovered meets the target specifications for reuse in cast and secondary aluminum alloy products.

Since there is no initial shredder, the energy required to operate the plant is relatively low (about 60 kwh/ton of refuse).

Economics

The targeted recovery percentage was 20 percent, but the performance through the early shakedown period was only 10 percent, broken down as follows: paper 2 percent, cardboard 3 percent, glass 3 percent, ferrous metals 2 percent, and PVC 0.2 percent. The revenues derived have been: paper, 170 francs per ton; cardboard, 320 francs per ton; glass, 274 francs per ton; FOB glass plant; ferrous, 150 francs per ton; and PVC, 600 francs per ton. Table 36 shows the target for recovery and the expected recovery efficiency. Table 37 gives the recovery tonnage expected.

Capital costs expressed in 1979 values are provided in Table 38, which shows a total cost of 17.2 million francs. However, with the modifications that have been made, the costs have risen to 20 million francs. The anticipated operating costs are shown in Table 39. At present, the plant is operating at less than the 100,000 tons per year assumed in the calculations shown in the table. Operating costs are actually closer to 10 francs per ton.

Table 37. Recovery Tonnages: Nancy
(Annual Streams of Recovery Materials)

<u>Target Recovered Products</u>	<u>Annual Production Tonnage</u> (2 Shifts/Day)
Glass	6,000
PVC	1,000
Newspapers, magazines	6,000
Cardboards	4,000
Ferrous metals	3,000
Aluminum	200
Total	20,200

Source: Giloux and Gony, "Revalord Process...", p. 1.52.

Table 38. Nancy Plant (Sept 79) Capital Costs

	<u>ME</u>	<u>%</u>
Digging and Foundations	2.7	15.7
Buildings	2.2	12.8
Sorting	4.2	24.4
Cleaning and conditioning	4.8	28.5
Electrical equipment	0.9	5.2
Handling	2.3	13.4
Total (Without taxes)	17.2	100.0

Source: Giloux and Gony, "Revalord Process...", p. 1.55.

Table 39. Plant Operating Costs
(September, 1979 basis)

<u>Cost Category</u>	<u>Amount</u> <u>MF</u>
Labor	2.35
Maintenance	0.30
Provision for equipment change	0.45
Power	0.35
Miscellaneous expenses: insurance, overhead, technical assistance, etc.	0.35
Total	3.80

Note: 100,000 t/year, 2 shifts, 6 days a week.

Source: Giloux and Gony, "Revalord Process...", p. 1.56.

This should be compared to the cost of incineration. The average cost of incineration, net of the sale of the steam, is 72 francs per ton. It is probably safe to assume that average costs are equal to marginal costs, given that the incinerator plant operates at capacity. Indeed, if new investment were required to expand the existing incinerator -- or in line with the other option considered, to construct an entirely new plant -- the cost picture could be considerably different than that based on the costs of a plant built some years ago. The per ton cost of a new plant would probably be much higher.

Operating at 50,000 tons per year (the current recovery rate) removes 5,100 tons from the waste stream. The revenue according to the sales figures given above is approximately 1 million francs per year. Using a figure of 10 francs per ton of material processed, the net loss for the year is slightly over 2 million francs. It would require an additional cost avoidance of 418 francs per ton to justify this loss. The same calculation done for 100,000 tons per year, with the actually experienced reduced recovery rate of 10.2 percent, would require an additional operating cost for incineration capacity of 124 francs per ton to make the effort economically justifiable. If the forecast recovery rate were to be achieved (20%), then a 50,000-ton-per-year processing level would require only a 75 franc per ton increase in the cost of incineration to make the recovery approach a break-even proposition. An incremental cost increase

of 75 francs per ton is probably a plausible figure if one were to build a new incinerator at today's prices. However, moving to a figure of 100,000 tons per year processed (and 20% rate), the net saving is 1,500,000 francs per year. This is a savings of 75 francs per ton, measured against the current average cost of disposal via the already built, and at least partially paid for, incinerator. Calculations such as this are sensitive to the market value of the materials. Nevertheless it seems that the addition of the upfront separation facility would be economically validated if the processing level were 100,000 tons per year, and the recovery rate were in the neighborhood of 15 to 18 percent (or some combination of processing level and recovery rate within these bounds).

The planned for revenues that were used to calculate the potential for the plant are shown in Table 40. Note the difference between these revenues and those actually achieved in the marketplace. If the planned for figures could be achieved, revenue would be 57 francs per input ton of waste. Note that a comparison between these figures in francs and in U.S. dollars can be misleading. At the time that these figures were generated, it took only 6 or less francs to buy a U.S. dollar. Converting at today's exchange ratio can give a very misleading picture. Currently, it takes about 8 francs to equal 1 U.S. dollar. This is a significant change and illustrates the problem of making comparisons between currencies.

Table 40. Plant Revenue Planning Factors
(September, 1979 basis)

	Annual Throughput		Unit Value (F/t)	Annual Income	
	%	Quantity (t)		Total Value	%
Glass	6.0	6,000	170	1.02 MF	17.8
PVC	1.0	1,000	650	0.65 MF	11.3
Ferrous metals	3.3	3,000	88	0.26 MF	4.6
Papers	6.0	6,000	300	1.80 MF	31.4
Cardboards	4.0	4,000	400	1.60 MF	27.9
Aluminum	0.2	200	2,000	0.40 MF	7.0
Total		20,200		5.73 MF	100.0%

Source: Giloux and Gony, "Revalord Process...", p. 1.56.

Summary

The Nancy plant is an extremely interesting scale-up of a pilot effort. The plant has benefited from much more than the average amount of research and development prior to full scale implementation. A number of innovations bear watching, particularly the squirrel cage configuration of the primary trommel. Also, the ballistic-adhesive belts are of interest. If efficient, these represent a relatively inexpensive way of accomplishing the desired separation. Nancy has no air classifier, a rarity among materials separation plants in operation today. The eddy current separators with the PVC infra-red feature are also of interest. Overall the plant is a full-scale test bed for many recovery technologies. The rest of the world, both developed and developing countries alike, stand to learn a great deal from its continued shakedown and operation.

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Contacts

F. Clin
Bureau De Recherches Géologiques
Et Minières (B.R.G.M.)
Department Mineralogie
B.P. 6009
45060 Orléans CEDEX
France
Ph: (38) 63.80.01 ext. 36.25
Telex: BRGM A 780 258 F

A. Marchand,
Directeur General des Services Techniques
du District Urbain de Nancy
5400 Nancy, France

9. HERTEN: RZR RECOVERY CENTER RUHR
(FEDERAL REPUBLIC OF GERMANY)

The resource recovery plant located in Herten is currently in shakedown. This is a very large plant designed to process 300,000 tons of municipal solid waste per year. The technology has been developed by the MVU Corporation.* The principal recovery objective of the plant is a refuse-derived fuel trademarked ECO-BRIQ. The new plant is a scale-up of a pilot that has been running in the city of Herne since April 1979. The capacity of the pilot is 5 tons/hr. The fivefold scale-up has provided the new plant with two lines, each sized at 25 tons/hr.

The development of this process was supported by the Federal Ministry for Research and Technology of the Federal Republic of Germany. The RZR facility has two incineration lines at the same site, one for municipal refuse and one for industrial discards. The energy from the burning of these wastes is used to produce electricity. Therefore, the ECO-BRIQ process, located at the same site is, in a sense, a substitute for a second co-located municipal incinerator. However, the energy value of the pelletized waste will be realized off-site. Raw refuse, being perishable, must be burned within a short period of time. As in other briquetting (pelletizing) projects, the ECO-BRIQ method of processing the waste into a fuel increases its storability. It can be stored for a relatively long period before it is used. Being fairly dense, it can also be more economically transported for some distance. A third enhancement to its fuel value, compared to raw waste, is that the process increases the heating value per unit of weight and obviously of volume. In the instance of Germany, the heating value of the ECO-BRIQ fuel is 16 GJ/T which corresponds to the heating value of lignite. Table 41 shows an average waste composition for Germany. Figure 14 is the flow diagram for the plant.

Technological Description

After being discharged from the transport vehicle, the material is conveyed to the first separation device. This is a large trommel screen with 60 mm holes. The -60 mm material, which includes most of the glass in the refuse, thus bypasses the primary shredder, as only the +60 mm oversize is shredded. The oversize, after shredding, is combined with the -60 mm material and passes under a magnet, which extracts the ferrous fraction. Up to this point, the process is fairly conventional. However, it is said that the primary trommel contains some special fittings that selectively reduce the size so that most of the plastic, particularly streamers, stays in the overflow so that it will be shredded in the hammermill. Conversely, the big pieces of glass are broken in the trommel so that they will pass through the 60 mm holes.

*MVU stands for Mannesmann Veba Umwelttechnik GMBH.

Figure 14. Herten: Recovery Center Ruhr MVU ECO-BRIO Process

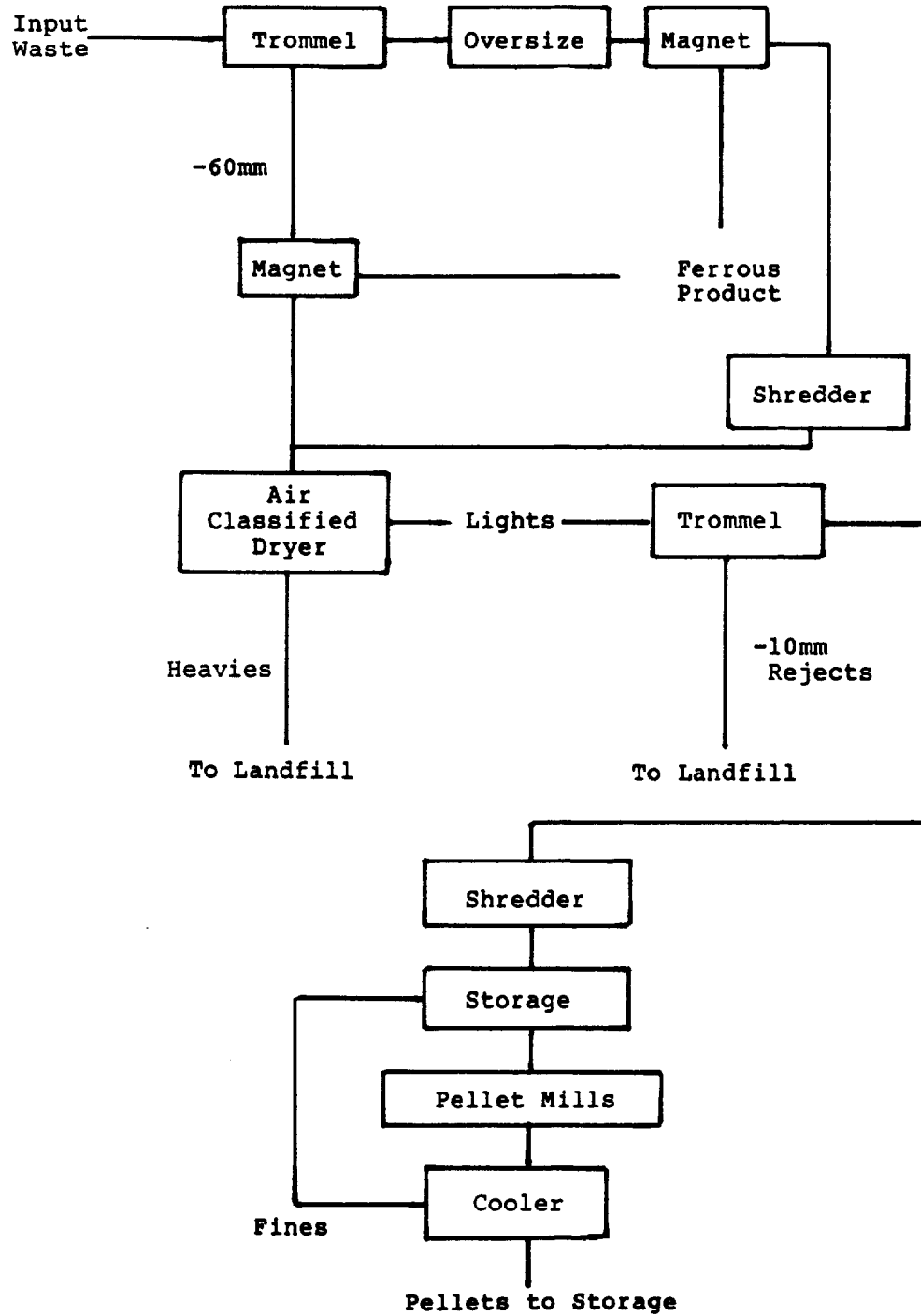


Table 41. Average Composition of German Waste

<u>Waste Components</u>	<u>Percent by Weight</u>
Paper, cardboard	28
Wood	5
Vegetables, garbage	16
Yard rubbish	2
Plastics, rubber, leather, textiles	7
Glass, ceramics	16
Metal (mostly Fe)	5
Fines, others	21
Total:	100
Moisture content:	25-40%

Source: Handout of MVU (undated, no page numbers).

What is unique about the MVU process is the combination of air classification and drying, which occurs after magnetic separation. Fed to the air classifier dryer by an auger airlock, the material, which has an initial moisture of about 35 to 40 percent, is dried to 10 to 15 percent. Simultaneously, the light fraction is separated from the heavy fraction. The inlet temperature, as far as the drying air is concerned, is between 250° and 300° C. As installed in the Herten plant, the air classifying drying device is almost four stories tall. It is perhaps the tallest air classifier in the world.

The heavy fraction is drawn off from the bottom of the air classifier through a rotary valve into a residual material bunker. This fraction is transported to landfill. It consists largely of inorganic waste, or of materials high in water. A cyclone filters the light material from the classifying air. The exhaust air is filtered in order to remove dust and then is partly recirculated to the air heater in order to conserve energy. The light fraction after the deentrainment is again trommel-screened. The hole size in this trommel is 10 mm. At this point, the plant produces a fluff RDF in the size range plus 10 mm - 60 mm.

This material undergoes a second shredding step. The shredded light fraction goes to a storage bunker, from whence it is conveyed to a series of pelletizing mills. These are Kahl presses. The MVU Company selected the Kahl mill after having tested four different types of pellet mills. The presses are rated at 6 tons/hr. After pelletizing, the material enters a cooler and then is conveyed to storage. A certain amount of flaking takes place in the cooling process and this fine material is recycled back to the storage hopper and then to the pelletizer.

It has been found that the 10 mm undersize from the secondary trommel contains 2,000 to 2,500 kcal/kg which is too high to discard. As a consequence, a provision is made to screen this material at 4 mm and to recycle the oversize into the pelletizing process. Table 42 shows the expected outputs for the plant and Table 43 the characteristics of the ECO-BRIQ.

Table 42. Herten Plant Outputs

<u>Product</u>	<u>Percent by Weight</u>
ECO-BRIQ	45
Ferrous scrap	5
Residues (15% by volume)	30
Moisture, driven off during drying process	20
Total	100*

*Figures are approximate.

Source: Handout of MVU (undated, no page numbers).

The energy for the air classifier dryer and the electricity to run the various motors in the plant are supplied from the on-site incinerators and their installed electricity-generating equipment. Actually, one-half of the energy used in the drying comes from the steam from the incinerators. The other half of the energy comes from direct fuel firing. The steam is used to initially warm the recycling air, and the fuel oil is used to bring it to the required temperature. The steam required for this operation is at a pressure of 30 bars. Hence it is not a giveaway commodity; a charge is made to the ECO-BRIQ process for its use. The operators of the MVU processing plant continue to look for an inexpensive furnace to generate hot gases for the dryer that will use the reject organic fraction from the process itself.

Table 43. Properties of ECO-BRIO Fuel

Calorific value (LHV)	:	14.600 - 18.800 kJ/kg (3.500 - 4.500 kcal/kg)
Volatile constituents	:	55 - 65 % by weight
Ash content	:	10 - 20 % by weight
Water content	:	8 - 12 % by weight
Chlorine, total	:	0.2 - 0.6 % by weight
Chloride	:	0.05 - 0.2 % by weight
Sulphur	:	0.2 - 0.45 % by weight

Melting characteristics of the ash in an oxidizing atmosphere:

Fusion point	:	1,180o C
Hemisphere point	:	1,250o C
Flow point	:	1,290o C
Bulk density	:	approx. 600 kg/m ³ (with approx. 20 mm diam., 50-70 mm length)
Specific weight	:	approx. 1,200 kg/m ³

Source: Schmitt, The ECO-BRIO Process, p. 10.

Energy and Economics

Overall, the process is an energy-efficient one. After deducting processing losses and the losses involved in converting the ECO-BRIQ fuel to electricity, the net yield is a positive 26 percent taken in relation to the energy value of a ton of input waste. This is shown in Figure 15. Figure 16 shows the corresponding 15 percent yield for a mass burning municipal waste incineration. The energy required for the processing of 1 ton of waste was expected to be about 90 kwh of electric power and 0.9 GJ of processed heat (see Figure 15). If all the fuel produced were converted to electricity, the energy used in production would amount to 63 percent of the net electricity produced. In actual practice, it is reported that the electric power requirement ranges between 70 and 80 Kwh/ton for the ECO-BRIQ process. This further enhances the energy balance.

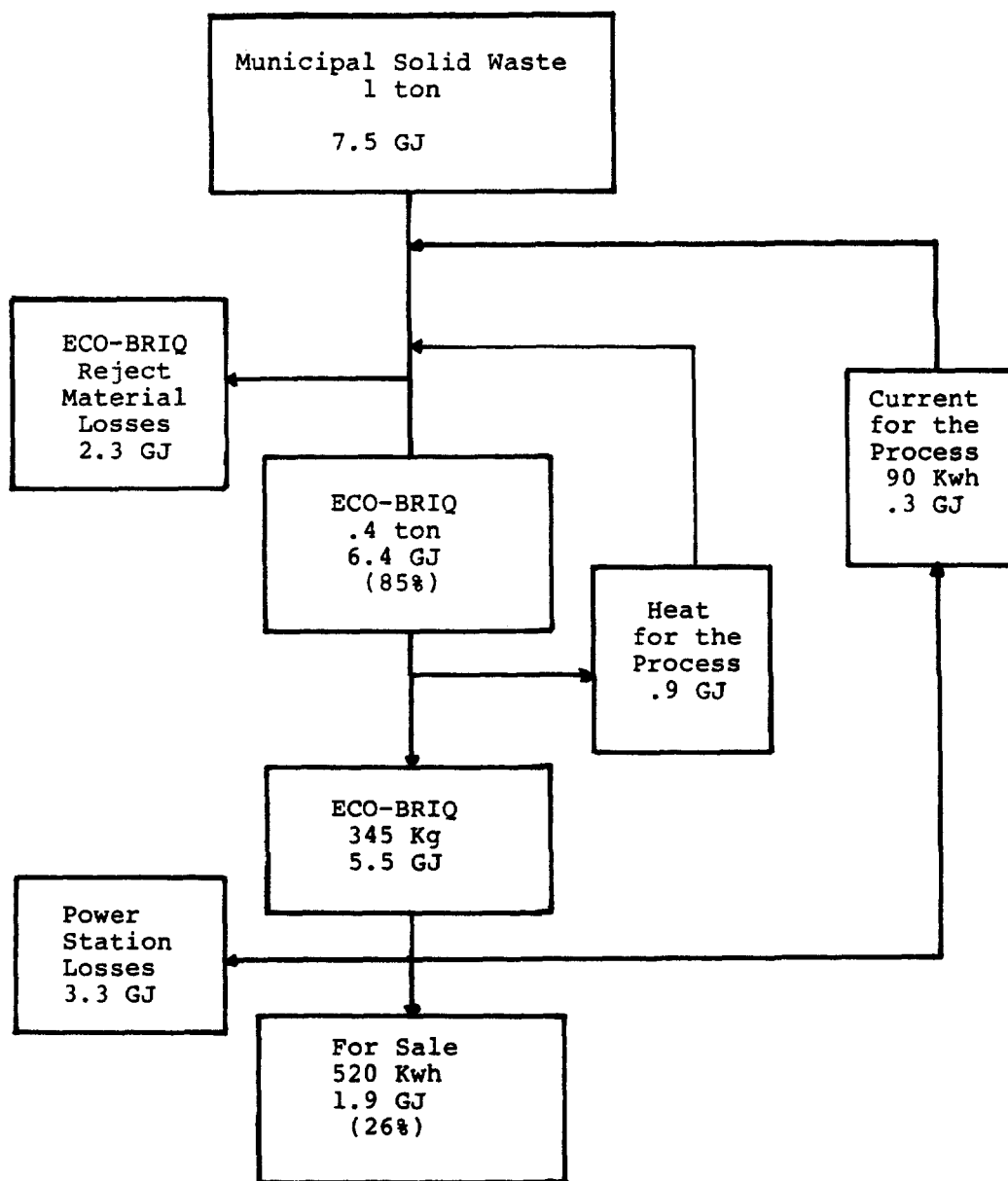
The capital cost of the Herten plant was 320 million Deutsche Marks, of which approximately 30 percent went to cover the cost of the ECO-BRIQ plant and its related civil works. MVU Company brochures cite a price of 55 to 70 Deutsche Marks per operating ton for plants from 300,000 tons per year down to 100,000 tons per year. According to the company, this cost includes the service of capital for a turnkey plant; all costs for repair, maintenance, personnel, auxiliary materials, energy, insurance, taxes; along with provision for the disposal of the residual materials. This figure takes into account the sale of the ECO-BRIQ and the ferrous metal. The company claims that such sale can be guaranteed; it expects a yield of approximately 52 Deutsche Marks per ton for the recovered ferrous material.

Summary

Several other sections of this report have described processes for producing a pelletized refuse-derived fuel. The advantages of this fuel are its storability and transport ability. In the first instance, only direct exposure to moisture need be avoided in storing the pelletized refuse-derived fuel. In the second, the high density of the fuel, in comparison with fluff RDF, makes transport more economical. In research on the long-term storage capability of ECO-BRIQ, it was found that for periods up to 12 months, with layer heights of 15 m in an enclosed silo, no alterations showed up in the stability, moisture content, or heat value of the fuel; nor was there temperature increase in the material in storage. Finally, there appear to be no problems with odor, either on transport or during the storage of the fuel.

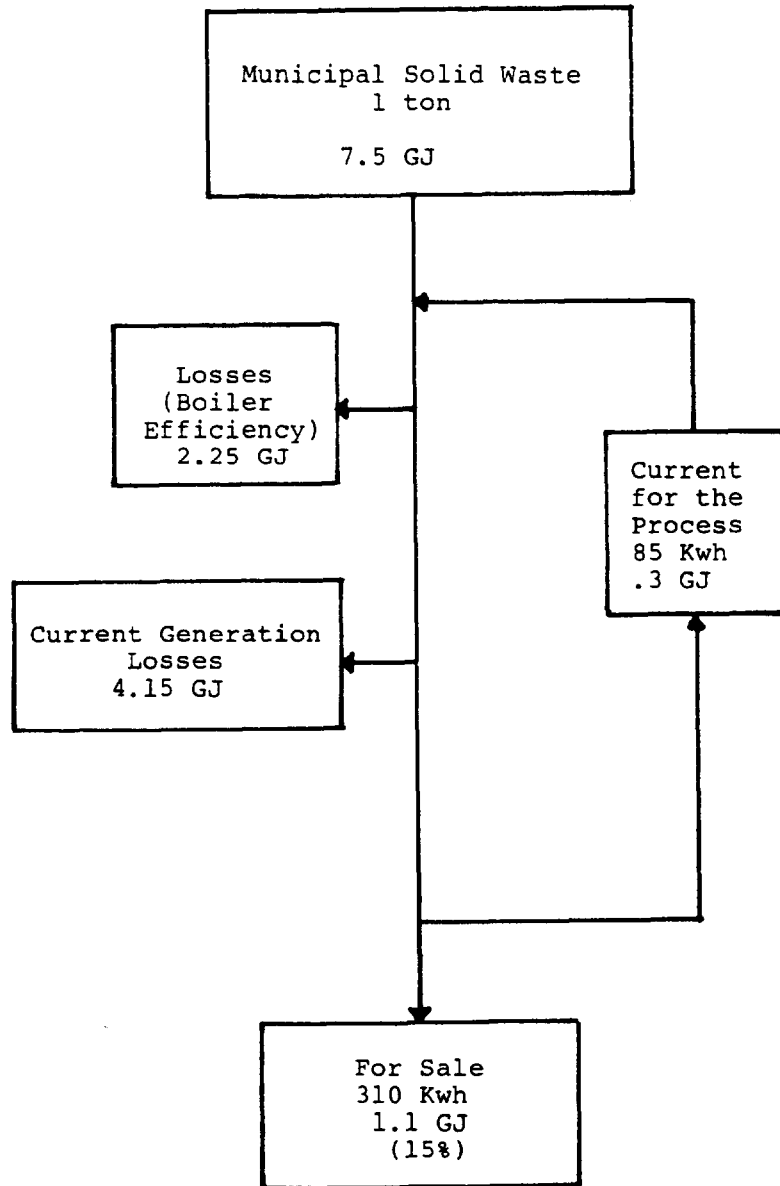
The plant is currently being brought on the line and the briques produced are being used by a nearby cement kiln. The pelletized fuel is introduced at the halfway point in the kiln to provide a slow-burning source of heat. This plant shows great promise and it is hoped that it will prove to be an operating

Figure 15. ECO-BRIKETT Technology Including Electricity Generation
Energy Diagram



Note: Process energy in relation to net electricity produced:
 $1.2 \text{ GJ} / 1.9 \text{ GJ} = 63\%$

Source: Bracken and Sonnenschein, "Storable Energy from MSW," p. 6.53.

Figure 16. Incineration Plant: Energy Diagram

Source: Bracken and Sonnenschein, "Storable Energy from MSW," p. 6.54.

success. The combined drying and air classification process is of particular interest especially if a means is found to utilize low quality waste, not suitable for pelletizing, to raise the heat for the drying step.

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Contact

Peter Schmidt
Diplom-Ingenieur
Marketing Und Verkauf
Mannesmann Veba Umwelttechnik GMBH
Sudstr, 41, D 4690 Herne 2
Ph. 023 25/4 30 01
Tx. 820377

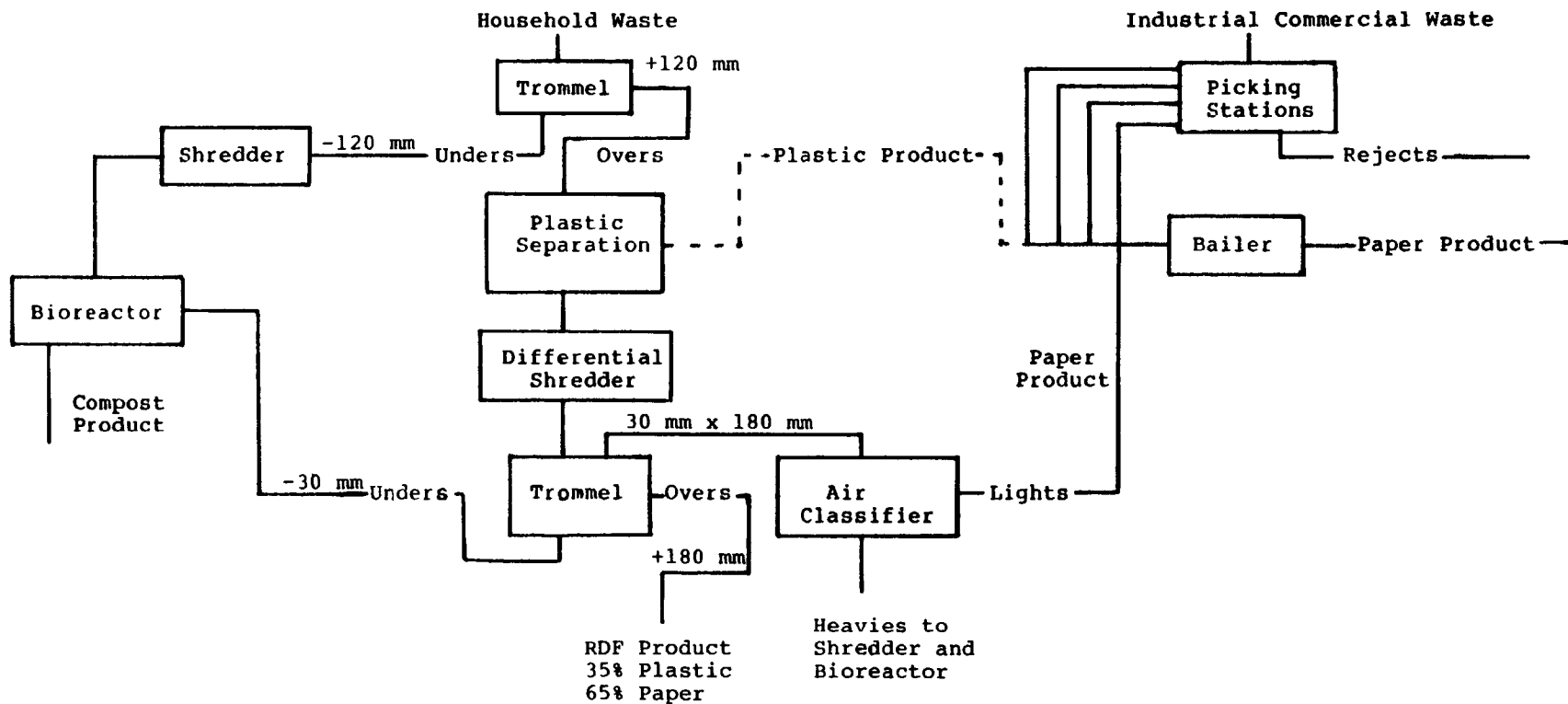
10. NEUSS: TRIENEKENS PLANT (FEDERAL REPUBLIC OF GERMANY)

This facility, which was built in 1978, is a combined household and industrial/commercial waste-processing plant. It is located adjacent to a landfill. The throughput capacity of the plant is about 60 tons/hr of household waste and 6 1/2 tons/hr of industrial/commercial refuse. The products are film plastic (perhaps now discontinued), paper, cardboard, ferrous metals, and compost. (See Figure 17 for the flow diagram). Nonferrous metals are handpicked as are portions of the paper and cardboard. The plant cost 13.5 million Deutsche Marks, which included a 5.05 million Deutsche Mark grant from the Federal Ministry for Research and Technology and the Federal Bureau of Pollution Control. The plant building is 60,000 square feet.

The incorporation of both a household waste sorting facility and one for industrial/commercial waste allows for the blending of the fibrous material extracted from the household waste with the higher quality product taken from the industrial/commercial waste. The industrial and commercial waste is handpicked from a belt. There are six picking stations. The rejects are allowed to stay on the belt until they are discharged. The various grades of paper and corrugated that are picked reside in large live-bottom bins until they are transported selectively to a paper baler. The belt that conveys this material to the baler is also fed from the product belts of the household waste separation portion of the plant.

In addition to processing waste, the Trienekens Company has been collecting, sorting, and selling used paper for more than 25 years. In fact, this is its primary business. The company is a major force in the northern European secondary paper industry. Perhaps because it knows the market, reinforced by the ability to blend, it is able to market a fairly large portion of the fiber extracted from the household waste processing portion of the plant. What is too contaminated to sell into the secondary fiber market is sold as RDF to the waste incineration plant in nearby Dusseldorf. Here it is used as a supplemental fuel to burn the high-moisture content refuse collected by the city. Because of the wetness of the ordinary household refuse in Dusseldorf, it is usually necessary to utilize a supplemental fuel, generally oil, in order to complete the combustion of the trash. Hence, there is a ready "fallback" market. In fact, the equipment has been reconfigured somewhat from the original suit so that it now maximizes an RDF product, which is approximately 35 percent plastic and 65 percent paper. As fuel, this material sells for 70 Deutsche Marks per ton. Its moisture content is between 15 and 20 percent.

Figure 17. Neuss: Trienekens (Germany)



Description of the Plant

The industrial/commercial refuse handled in the plant consists mostly of packing material. After being dumped on the tipping floor, it is loaded onto a belt conveyer that transports it past the picking stations. The sorting/picking operation takes place as described, with the materials stored in what are called bunker conveyers, after having been picked out of the mixed industrial/commercial waste.

The household refuse is also dumped onto the tipping floor, but in a separate area. A front-end loader pushes it onto a conveyer. The first separation process is a rotating trommel with 120 mm holes. The -120 mm material from the initial trommeling stage is magnetically scalped and then shredded. This shredded fraction goes directly to the compost bioreactor. The oversized material is passed under a magnetic separation, and then into a second trommel with two segments. The first has holes of 30 mm; the second 180 mm. The overs are a paper/plastic RDF. The +30 mm -180 mm material from this second trommel is air classified. The lights generally consist of approximately 90 percent paper. The heavies from this process along with the -30 mm material from the second trommel stage are used to feed the bioreactor. The heavies join the -120 mm unders from the first trommel and are shredded prior to being fed to the bioreactor.

The shredding step that occurs in the +120 mm line consists of a differential size reduction. Differential here means that the paper is cut into smaller pieces than the plastic material. The latter tends to go into streamers that are longer, and perhaps also narrower, than the pieces of paper. As a result of this step, the air classification tends to blow the smaller, lighter paper away from the larger, heavier plastic material in the +30 mm -180 mm fraction.

As mentioned earlier, compost is a product of the plant. In the bioreactor, between 20,000 and 25,000 tons of compost are anaerobically produced yearly. This material is used for cover on the landfill. The heat produced by the biological decomposition is used to heat the workrooms of the plant, the offices, and adjacent buildings on the nearby landfill. Furthermore, this energy is used to support direct evaporation of the leachate water from the landfill. At present twenty workers are involved in the operation of the plant. This includes the drivers and the handpickers.

Summary

The facility in Neuss is truly an operating plant. It produces products that find a use. Although not as much of the paper is sold as is desired, its use as RDF provides a fallback. The fact that some paper is sold is an achievement, particularly in the current worldwide recession, which has a magnified influence on the secondary materials market.

The Trienekens Company is offering its expertise to municipalities interested in conducting feasibility studies, or in the design, construction and/or operation of a facility similar to the one in Neuss. The Trienekens company also offers assistance in the marketing of the secondary materials recovered. Because of the proprietary nature of the system, few details are available about the specific characterization of the equipment and operating results.

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Contact

Dr. Hans Flender
 UTG - Gesellschaft fur
 Umwelttechnik GmbH
 Postfach 100764
 D-4060 Viersen,
 West Germany
 Ph. 02162/370280
 Plant Ph. 02101-8661

11. ZOETERMEER: ESMIL (NETHERLANDS)

The ESMIL Company has been active in the recovery of resources from waste since the middle 1970s. Its first plant was a pilot operation in Haarlem in the Netherlands. The development work carried on here led to the contract to design the Vienna Rinter plant. Earlier technical work had been conducted by TNO, a research organization connected with the Dutch technical university in Eindhoven. (TNO stands for the Central Technical Institute of the Netherlands Organization for Applied Scientific Research). The TNO approach makes extensive use of zigzag air classification.

The early TNO work, in which they were later joined by ESMIL B.V., began with a 100 Kg/hr laboratory scale operation, scaled to a 1 t/hr pilot in 1973, superceded by 5 t/hr and 15 t/hr prototypes in 1975 and 1976. The latter were located in Haarlem, The Netherlands. In 1976, ESMIL took over this aspect of the TNO work and continued independently with the development of an industrial scale waste processing plant. ESMIL delivered the basic engineering and some equipment for the Rinter, Vienna plant described elsewhere in this report.

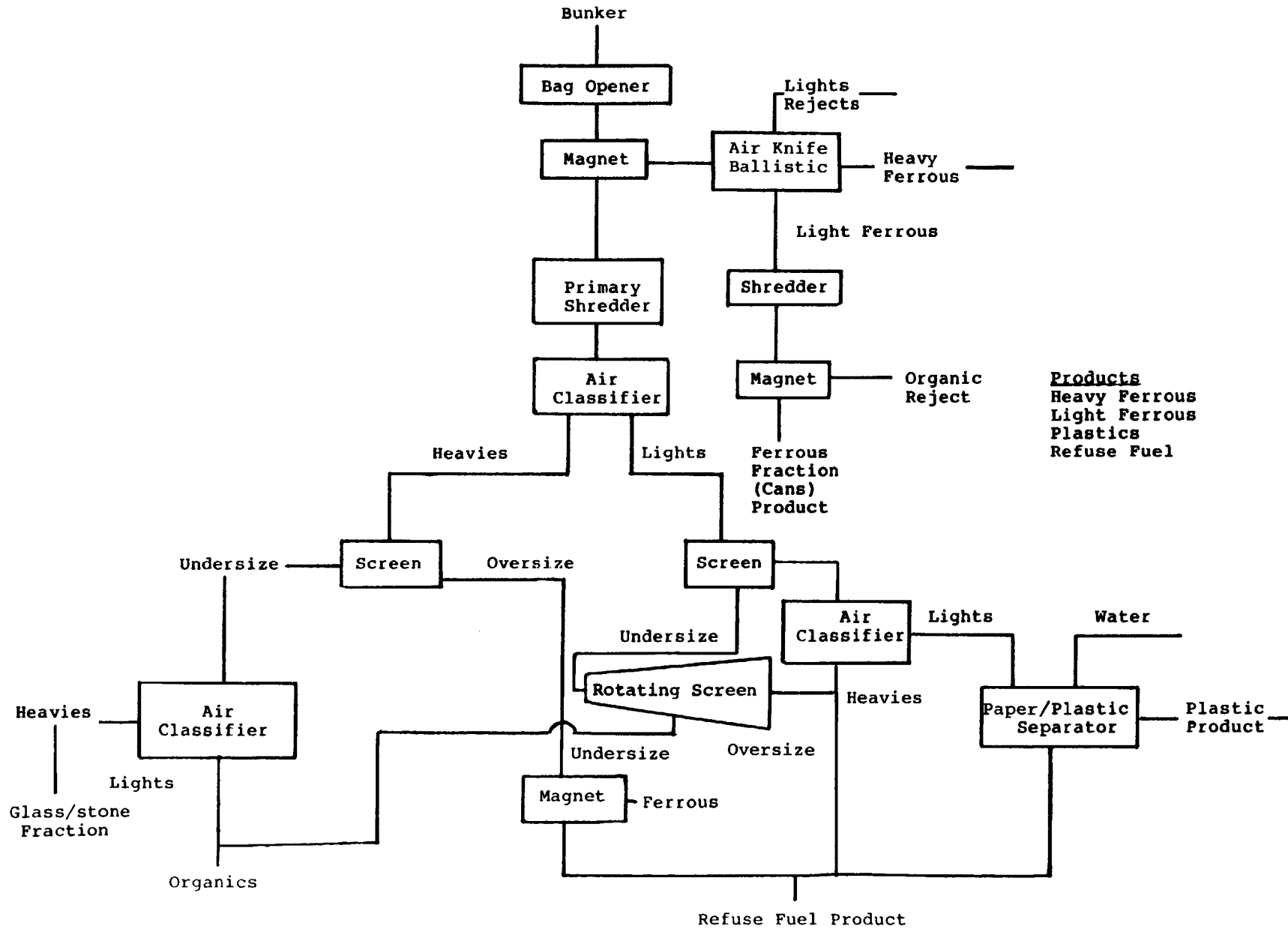
The Zoetermeer plant is one of two currently being constructed and undergoing shakedown operations by the ESMIL corporation. Zoetermeer is a suburb of the Hague in the Netherlands. The other plant, considerably larger than Zoetermeer, is being built near Liege, Belgium*. The capacity will be 250,000 t/yr. Zoetermeer is 65,000 t/yr. The Zoetermeer plant consists of one line rated at 20 t/hr. It has three air classifiers and two different and unique separators to divide the municipal waste, essentially a paper, plastic, and organic feedstock into its constituent parts. The products of the plant are heavy ferrous (1.5%), light ferrous (1.5%), plastic foils (2%), a refuse-derived fuel (48%), and a glass and stone fraction for use in road construction. The remainder (38%) is an organic waste fraction. If there is a viable market, the facility can also produce a paper fraction. At present, this material is added to the RDF.

Figure 18 shows the equipment flow. This plant is owned jointly by three partners: ESMIL, V and D (which is a large retail store and warehousing company), and a consortium of construction companies.** There is some question as to where the

*The owner of this plant is "Association Intercommunale de Traitement des Dechets de la Région Liegeoise" - INTRADEL, Rue Sur-les-Foulons 11, 4000 Liege, Belgium.

**Recycling Zoetermeer B.V. is owned by ESMIL Recycling B.V., and NEMCO Recycling V.O.F.

Figure 18. Netherlands ESMIL (Zoetermeer) Facility



refuse-derived fuel is going to be burned. The ESMIL Company would like to see a fluidized bed combustion system, which is a proprietary development of their company, installed at the site. As mentioned, the plant is designed to operate at 20 tons/hr and to process 65,000 tons annually.

Technological Description

The facility at Zoetermeer, which began its shakedown in the mid-summer of 1983, is a rather sophisticated undertaking. The waste is discharged from the collection vehicles into a bunker. There is some presorting of oversized bulky waste. The first unit process is a bag opener as most of the household waste is delivered to the facility in plastic bags. Magnetics are extracted from the discharge from this device. Ferrous material represents about 3 percent of the incoming waste. An air knife and ballistics separator blows off light organics and separates the tin cans away from the heavier ferrous material. The cans are then shredded; next, the material undergoes a second step of magnetic separation.

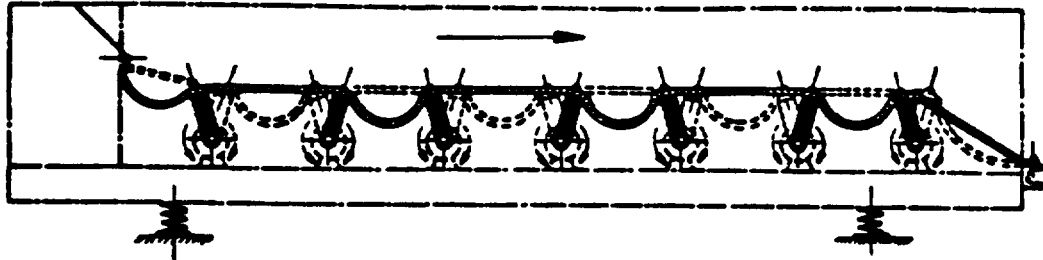
The nonmagnetic material from the first ferrous extraction step falls into a 360 kw hammermill and then is conveyed to an air classifier, the first of three. The waste is metered into the classifier by a rotary valve. The lights are deentrained in a cyclone while the heavies fall on a flat deck screen. The unders from this screen are conveyed to another air classifier, which again separates heavies from lights. The heavies in this instance are mainly inert material such as small pieces of glass and stone. The lights consist mainly of organic materials. The oversize of this first screening step, after magnetic scalping, is the first stream of material that makes up the refuse-derived fuel product. The remaining three originate from the lights of the first air classification step.

The lights from the first air classification step, after deentrainment, are conveyed to a second flat deck screen. The flat deck screens used in this facility are of the "snappy" variety. Also called "flip flop," the deck is made of a flexible rubber-like material that snaps up and down, as shown in Figure 19.

The unders from this screening step are conveyed into a rotating screen of expanding dimensions similar to a cone, fed at the smaller diameter end. The organic material passes through the holes in the screen, while the paper and plastics are discharged from the wide diameter end. The organic material is a reject suitable for composting.

The paper-plastic material is the second of the four streams of material that combine to make up the refuse-derived fuel produced by the facility. The final two streams originate with the oversized from the second flat deck screen in the system. This oversized material is fed to yet a third air classification step. The material that flies here is the "lightest" of the lights. It

Figure 19. Scheme of Movement of a Flip-Flow Screen



Source: Hobert and Julius, "Unit Operation in Refuse Separation," MEI, p. 4. (Originally from a corporate brochure of Hein, Lehman, AG, Dusseldorf.)

is primarily a mixture of paper and plastics, the plastics being predominant. The heavy fraction from this air classification step is largely a mixture of paper and plastics with paper forming the majority. This mixture is the third stream of material that makes up the refuse-derived fuel product.

The light material from this third air classification step travels through a screw conveyer of some considerable length. Water is sprayed into the conveyer. This moistened material is discharged into a paper and plastics separator. The shell of this device is a horizontal cylinder with holes. Inside there is a high-speed rotor. The action of the rotor forces the paper through the holes. The plastic material is sucked from the inside of the device by a fan. After discharge through a rotary valve, it becomes the plastic foil product of the plant.

The moist paper that has been forced through the holes is the fourth stream of material that makes up the refuse-derived fuel product. The material that is forced through the holes in this last device has a maximum moisture content of about 40 percent.

Summary

It is too soon to be able to comment on the effectiveness of the Esmil equipment suit in obtaining the targeted products. Presently, energy utilization is approximately 500 kwh for the 20 ton/hr throughput. The plant cost 14,000,000 Netherlands

guilders to construct, not including land. Six million of this is in the building, and 8 million was spent for equipment. This total sum does not include spare parts for the plant. The tipping fee is 80 Netherlands guilders per ton (2200 pound tons). The expected revenue is 25 Netherlands guilders per input ton. If the revenue from the sale of the recovered products exceeds this amount, the excess is to be shared with the local community. The contract length between the plant owners, and operators, and the community is ten years. It was expected that 60 percent of the input waste would emerge in the refuse-derived fuel fraction at a moisture level of 32 percent. This RDF was expected to have an energy value of approximately 8.4 MJ/kg. Based on current operating experience, 48 percent of the plant's input is recovered as RDF. The RDF has an energy value of 10.45 MJ/kg.

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Contacts

G.R. Westra, General Manager
ESMIL Recycling VB
Postbus 7811
1008 AA Amsterdam,
Netherlands
Ph (202) 5411054
Telex. 10295 nl

J.G.M. Thelen
Proposal Manager
Esmil Recycling BV
De Boelelaan 7
P.O. Box 7811
1008 AA Amsterdam,
Netherlands
Ph. 020-541 10 54
Telex 10295 esml nl

12. STOCKHOLM: PLM SELLBERGS (SWEDEN)

PLM Sellbergs AB has developed a proprietary process known as the BRINI system. There are currently five operating plants in Sweden. The plants vary in the amount of processing that their equipment undertakes. The most complete system is installed at Kovik near Stockholm. Here municipal waste is pulverized and sorted before being compressed into pelletized fuel. Undersized screen fraction is used for the production of compost. Magnetic separation also takes place. About 90 percent of the input waste is recycled in the form of fuel pellets, compost, or scrap metal.

Central to the processing is a unique proprietary ballistic classifier, which accomplishes the same separations as an air classifier and a screen. However, it uses only a fraction of the energy required by an air classifier standing alone.

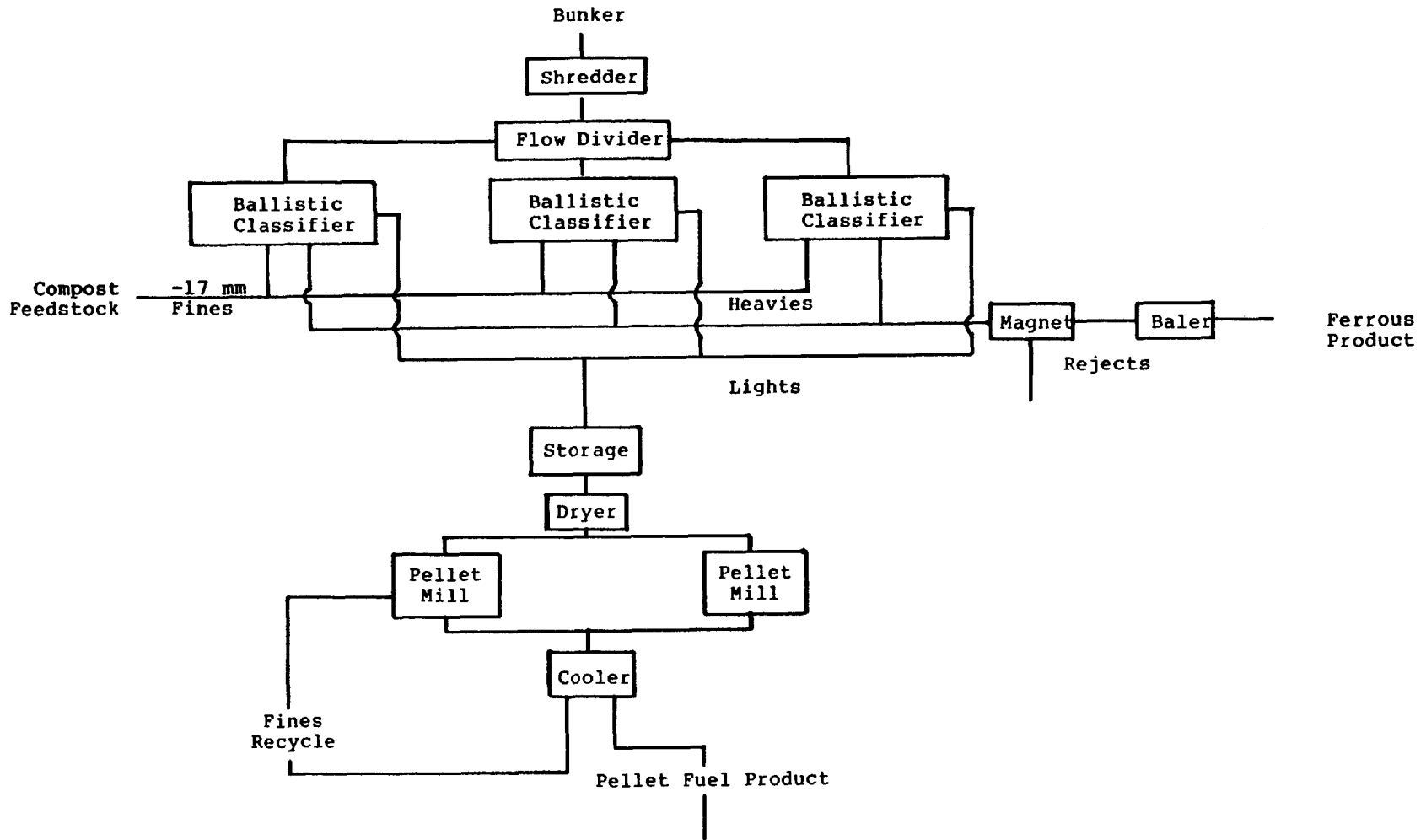
The processing capacity of the Kovik facility is 27 tons/hr. On a single shift basis, a total of 40,000 tons of waste can be processed annually with full utilization of the plant's capacity. For each 100 tons of waste input, the plant produces 40 tons of pellets.

Description of the Plant and Operations

A flow chart of the plant operation is shown in Figure 20. Waste is discharged from the refuse trucks into a bunker. An overhead crane fitted with a grab transports the waste from the bunker to the size-reduction feed conveyer. The size reducer (the pulverizer), which comes next in the process flow, is a Tollemache 1500 operating at 735 RPM and 355 hp. This is the same machine that is manufactured in the United States by the Heil Co. It is a vertical-axis hammermill with no grates. It is probably among the family of shredders that are on the low end of the energy utilization curve. It requires 7-8 kwh/ton to effect the size reduction. This machine produces material that is 80 percent less than 50 mm.

In developing the ballistic classifier mentioned above, it was decided that the optimal capacity of each device would be 10 tons/hr. The machines constructed were sized accordingly. As a result, after size reduction, the feedstock at Kovik must be divided into separate flows. Splitting a waste flow is a difficult process because the flexibles and the long stringy material tend to catch on the dividers. The Kovik plant has a unique arrangement of conveyer belts and chutes that appear to split the waste fairly evenly and are not susceptible to blocking and jamming. Each of the three separate waste streams (three ballistic classifiers are installed) falls from the splitter belt into distributors. The cross section of each distributor, at its inlet, measures 1.7 m. A vibrating action spreads the waste out to 2.5 m as it travels down the distributor device. The flow distance is 2 m.

Figure 20. PLM Sellbergs Stockholm (KOVIK) Facility



The more even the feed, the more efficient the operation of the ballistic classifier, which is the next unit process. Here the waste is mechanically separated into three fractions: lights, fines, and heavies. The first is mainly combustible material, which is concentrated into the light fraction. In the main, this consists of paper, textiles, and plastics; the emission generators (metals and PVC) are largely absent from this fraction. The second separation sorts smaller organic materials as well as sand and pieces of glass, which are concentrated into the screen fraction (the fines). This material is used for compost. The screen holes are 17 mm. The third, or heavy fraction, contains the ferrous metals as well as other heavy residual materials such as shoes, pieces of rubber tire, PVC, and the like.

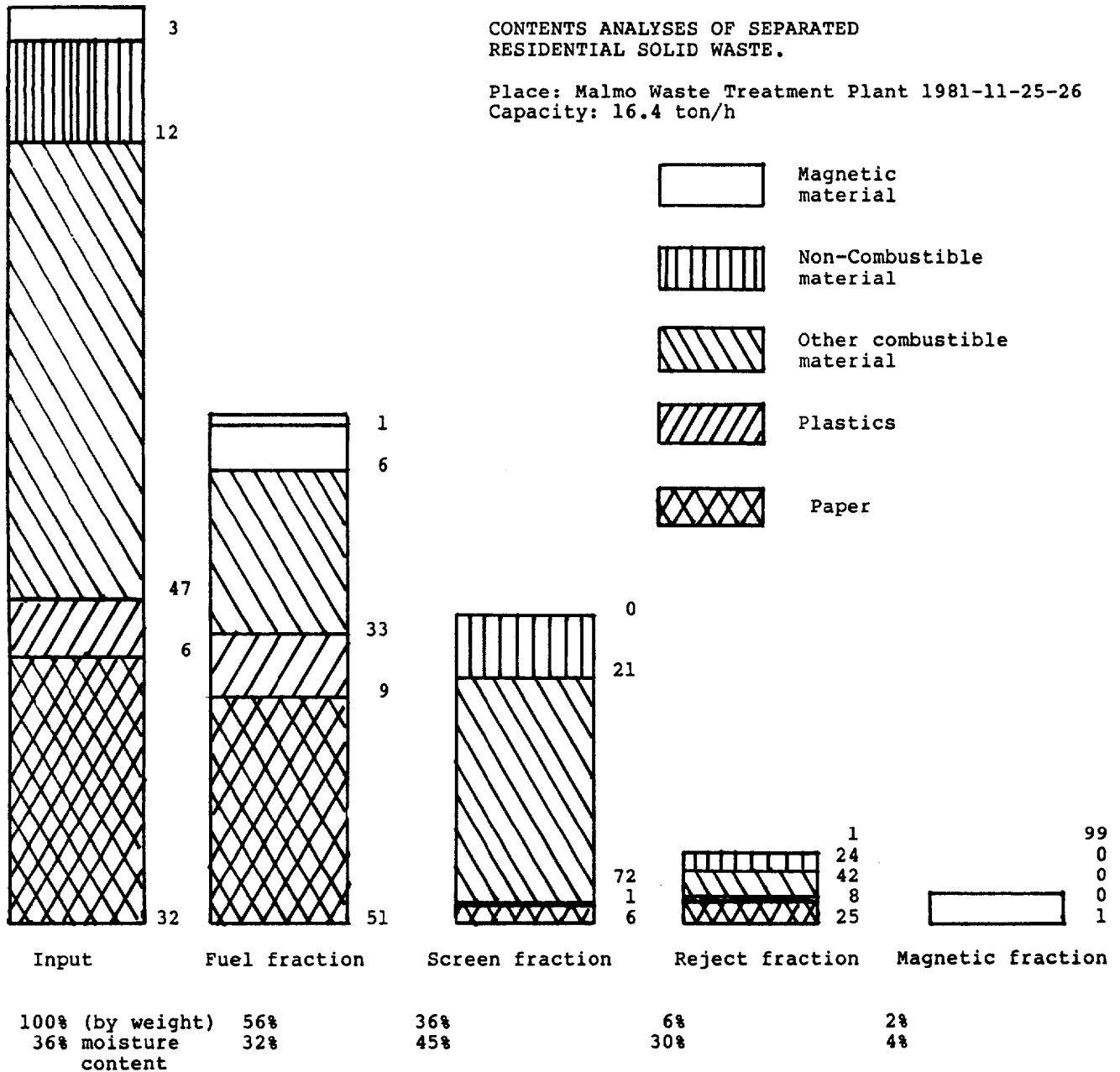
Figure 21 shows the materials balance for the plant. From the ballistic classifier, 56 percent of the material goes to the lights. Fines make up 35 percent. The heavy fraction consists of 2 percent magnetic metals and 6 percent other heavy material.

The ballistic classifier unit consists of an inclined perforated table divided into vibrating segments (Figure 22). Vibration in the device is actually a rather large amplitude rotation, uphill, which is the direction of flow. The shredded waste is fed to the table at the lower end. It may (1) fall back down the table and into the heavies discharge, (2) ride up the table as light fraction, or (3) pass through the screen holes into the compost feed fraction.

The data in Figure 21 are taken from another PLM Sellbergs plant in Malmo. There the holes in the screen are 10 m. The incline movable table of the ballistic separator consists of 10 segments, each having a width of 2,500 mm and a length of 5.6 m. These segments are attached to rotating crankshafts. The movements of the segments are displaced in relation to each other so as to induce a stirring action. This stirring action lifts the light material. The speed of the bar and its rotation are faster than the freefall of the material. As a result, the lights just flow up the screen. They are essentially moved from one position to another, each position being ahead of the former on the screen. Eventually the material is discharged at the high end of the screen. Because of their higher specific weight, the heavy materials rebound backwards when they hit the screen deck. They are propelled backwards and discharged at the lower end of the screen.

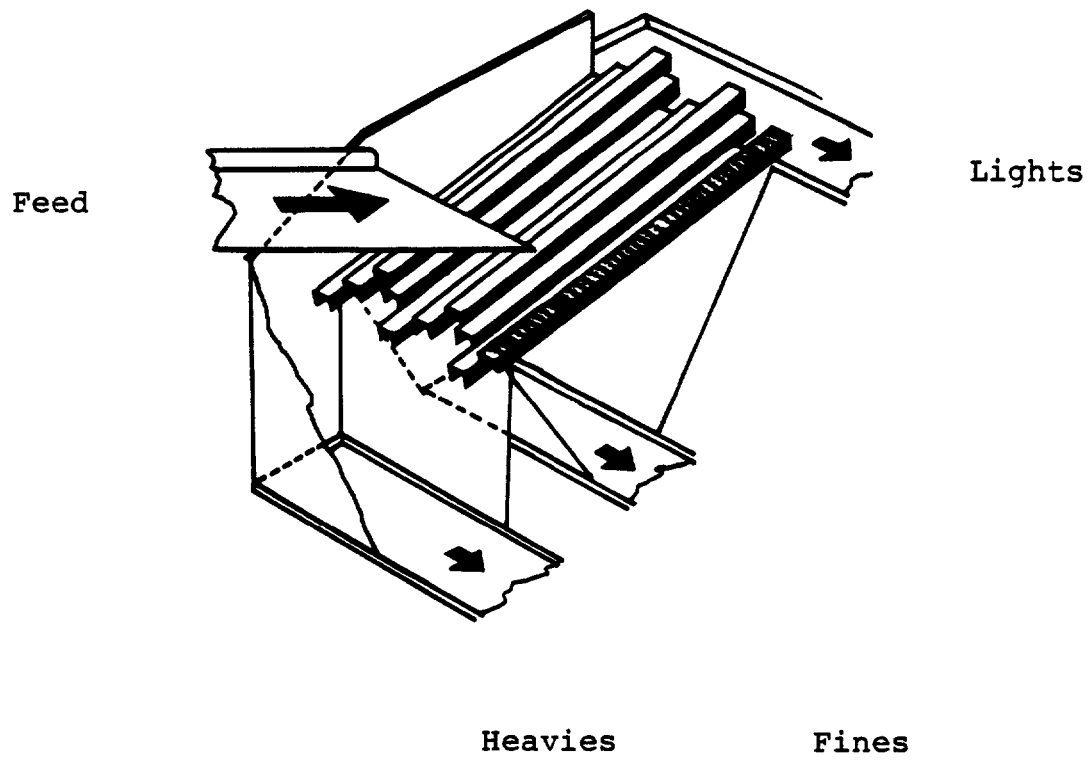
The optimal speed of the device is a question of composition of the waste. One wants to hit the heavy material with sufficient impact to propel it backwards. Therefore, if the machine senses a more rapidly accumulating burden of material, more energy, hence a higher speed, must be given to the impact. Also, by changing the inclination of the vibrating segments, it is possible to control the proportion of the materials that report to the light or the heavy fraction. For example, if there is a relatively large amount of cardboard, which should ideally go to

Figure 21. Materials Balance: PLM BRINI System (Malmo)



Source: Selberg and Edner, "Combustion of Solid Waste."

Figure 22. PLM Ballistic Separator



Source: PLM Corporate Promotion Brochure.

the light fraction, then the incline of the device would be reduced. The power necessary to run the ballistic classifier is 5 horsepower (it takes roughly 75 horsepower to operate an air classifier). The device costs approximately US\$100,000.

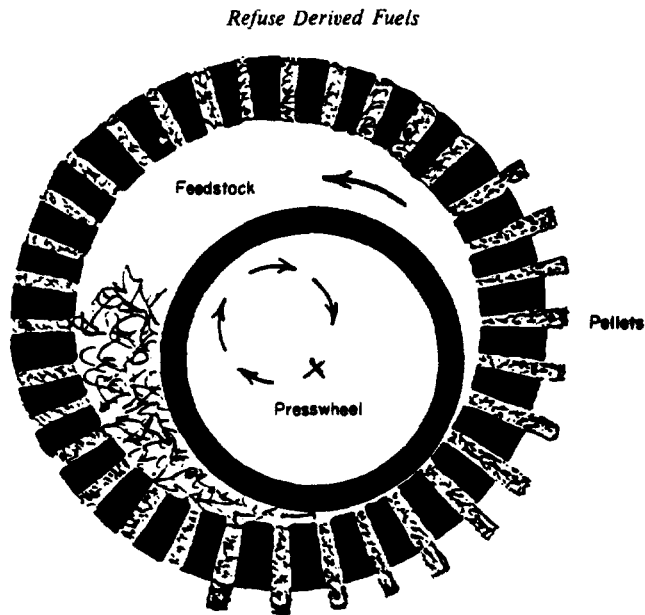
In the recovery circuit at Kovik, the light fraction is composed of 9 percent plastics, 51 percent paper, 33 percent other combustibles, 6 percent noncombustibles and 1 percent metal. This light fraction is transported to a buffer storage unit, the purpose of which is to ensure a uniform flow of material to subsequent processing stages. From this storage hopper the material is fed to a dryer. A paddle wheel leveler is situated between storage hopper and dryer. On average the moisture content of the input waste is about 36 percent. After separation, the moisture level of the light fraction is about 32 percent. As can be seen, there has been some reduction, but the waste is still too moist to effect pelletization. Thus the drying step is needed to produce pellets with sufficient integrity to be both storable and transportable.

The storage bin has a capacity of 200 m cubed. It has an interesting feed splitter that consists of a rotating drum (vertical axis) positioned over the horizontal feed belt. When rotating clockwise, the splitter pushes the waste off the belt into the right side of the bin. When it rotates counter-clockwise, just the opposite occurs. Echosounds tell the rotating device where to position itself on the belt and in which direction to rotate. Positioning is a matter of depth sensing.

Drying to approximately 15 percent moisture is accomplished in an air-swept dryer with resident times of 10-15 seconds to several minutes depending on the material. The dryer is a rotating device deriving its energy from an oil-fired furnace. Part of the drying air is recirculated. Fresh air is preheated. Preheating takes place as a by-product of the pellet cooling step that occurs later in the process. Exhaust air from the dryer is also used to provide space heating. At the inlet side of the dryer, the temperature ranges from 225o C to 250o C.

A certain amount of deragging is accomplished at the point where the live bottom storage interfaces with the conveyer that feeds the material to the dryer. Rags tend to ball at this transition point although they do not impede the feed movement. They are cleaned out at the end of each shift. Two pelletizers with circular die presses are installed in the plant. Figure 23 is a cutaway view of the type of pelletizer used. The pellet mill itself is an adaptation of a John Deere agricultural pelletizer. Portions of these modifications were accomplished earlier by PapaKube, a U.S. company. John Deere no longer makes the devices; however, the PLM company is going to have them manufactured in Sweden on subcontract.

The die is vertical. Its internal diameter is 800 mm. The holes in the die wheel are square with an area of 32 by 32 mm. The die is stationary. A press wheel rotates counter-clockwise

Figure 23. Papakube Densifier

Source: Porteous, A., Refuse-Derived Fuels. London: Applied Science Publishers Ltd., 1981, p. 50.

around the inside circumference of the die. An auger feeds the light fraction that is to be pelletized. At each pass of the press wheel, an additional amount of light fraction is pushed into the die holes. A shield breaks the extruded material at a length varying from 20 to 50 mm. The pellets are essentially small cubes. Dies are changed when 2,000 tons have been pelletized.

Each machine produces about 4 tons of pellets per hour and utilizes 90 kw. The bulk density of the pellets is 450 kg/m cubed. On discharge from the pellet mill, the cubes have a temperature of about 500 C. They are cooled in a cooler/conveyer to ambient temperature. The hot, moisture-laden air is used as preheat air for the dryer, as mentioned previously. A screen in the cooler serves as a discharge point to extract small flakes and various fine material. This is primarily organic, and it is recirculated to the pellet mills. The pellets have an ash content of approximately 10 percent and a heating value of 4,000 kcal/kg. BRINI fuel data are given in Table 44.

Returning to the heavy fraction from the ballistic classifier: it consists of metals and other heavy material and is transported to a magnetic separator. After extraction, the ferrous metal is baled to a density of 1500 kg/m cubed.

Table 44. BRINI Fuel Data

<u>Pellets</u>	<u>BRINI Fuel in Bulk</u>	<u>BRINI Fuel</u>
Effective heat value	13MJ/kg	17MJ/kg
Bulk density	50 kg/m ³	450 kg/m ³
Moisture content	30%	< 15%
Ash content	< 10%	< 10%

Source: Selberg and Edner, "Combustion of Sorted Waste."

The third fraction obtained from the ballistic classifier step is the "unders" or screen fraction. It is conveyed to the compost operation where it is mixed with sludge and nightsoil. This mixture (raw compost) is spread out on a composting pad. It takes about 10 weeks to obtain a final compost. This is used as cover material in the adjacent landfill. The steel scrap is used for re-bar manufacturing. The revenue derived from the sale of ferrous is 300 Swedish kronor per ton.

Fuel Characteristics

Since 1978 a large number of tests have been conducted burning the BRINI process fuel, both fluff and pelletized (see Table 45). Pellets were burned along with coal on a chain grate boiler. Pellets were also burned in a fluidized bed boiler at a district heating plant. Fluff fuel has been burned alone, and in combination with wood chips, in a furnace at a waste treatment plant in Malmo, Sweden. In all cases, the tests showed that sufficient combustion was achieved. In most cases, the environmental benefits from burning the RDF fuel, in terms of the combustion emissions, were improved. This, it is claimed, is particularly true in relation to the combustion of untreated municipal waste.

Economics

The economic advantages claimed for the BRINI process are shown in Table 46. Here a fluidized bed boiler is used for combustion and energy recovery from PLM fluff fuel. This is compared with the ordinary approach to incinerating municipal waste, that is, a standard type of mass burning, waterwall, solid waste incinerator. Note that the fluff approach saves approximately 25 percent in costs. This would be further increased if credit were given for the sale of ferrous material or for the possible, but perhaps unlikely, sale of the compost.

Table 45. Combustion Tests of BRINI Fuel

Inclined Grate

HSB Industrier BoroHus, Landsbro, Sweden.
 (BRINI pellets mixed with bark and wood shavings.)
 Fiskeby, Skarblacka, Sweden.
 (BRINI pellets mixed with bard.)

Step Grate

Orebro Pappersbruk, Orebro, Sweden.
 (BRINI pellets)

Chain Grate

Sockerbolaget, Arlov, Sweden.
 (BRINI pellets mixed with coal.)

Fluidized bed (Furnace)

G.A. Serlachius OY, Tammerfors, Finland.
 (BRINI pellets mixed with fiber sludge.)
 Eksjo Energiverk, Eksjo, Sweden.
 (BRINI pellets and BRINI fluff.)
 Ahlstromslaboratorierna, Karhula, Finland.
 (BRINI pellets)

Source: Selberg and Edner, "Combustion of Sorted Waste."

A BRINI plant is not particularly labor-intensive. In fact, it takes only five people to operate the Kovik facility. Two of these work inside as observers. One is in the workshop and one is a free person who handles the containers outside the building. The fifth person of the regular crew runs the control room.

In spite of the benefits claimed for the burning of the pelletized waste, it has been difficult to obtain a ready market for the material produced by this plant, partly because of the high seasonal variation in the fuel needs in Sweden, and partly because of a wide variety of alternative fuels that are available there. These include Polish coal, Swedish peat, and various types of biomass, such as straw. Government subsidies are even available for the construction or modification of boilers to burn the locally produced peat.

When sold by the Stockholm plant, the revenue from the refuse-derived fuel is tied to its energy value, and amounts to approximately 6 Swedish ore/kwh. On a 2,200 lb/ton basis this is 250 to 280 Swedish kronor per ton, or approximately 30 to 40 U.S. dollars per ton.

Table 46. Economic Comparison

Capacity	60,000 ton	
Fuel output after sorting (2/3 of input)		
Depreciation		
Buildings	20 years	
Boilers & mechanical equipment	13 years	
Mechanical equipment sorting	10 years	
Interest	14%	
	<u>Solid Waste: Incineration</u>	<u>RDF: Sorting + Fluidized Bed</u>
Effective heat value	10 MJ/kg	13 MJ/kg
Average annual efficiency	0.70	0.80
Operating time/boiler	7,750 h	8,030 h
Heat generated: Total	108,700 MWh	115,600 MWh
Heat generated: Per ton fuel	1.94 MWh	2.89 MWh
Boiler capacity (ton/h)	2x9.7 MW (2x5 ton)	2x8 MW
Investment:		
Machinery (sorting plant)	-	14 million
Machinery, boiler	57 million	39 million
Buildings	17 million	21 million
Total	74 million	74 million
Gross annual operating cost for waste treatment	18.6 million	18.0 million
Income		
(sales of energy) 110 SEK/MWh	12 million	12.7 million
Net cost annual operating	6.6 million	5.3 million
Net cost per ton	110 SEK	88 SEK

Source: Selberg and Edner, "Combustion of Sorted Waste."

Summary

The BRINI process is perhaps the most fully developed of the European energy-from-waste processes. This statement applies to those that separate and beneficiate the combustible portion of household discards. The BRINI approach is relatively simple. Unlike many of the facilities described in this report, the concept has been operationalized, not only in one, but in several locations. The ballistic classifier warrants special attention as a relatively inexpensive method of accomplishing the separations generally requiring a more complex air classifier taken in combination with a screening step.

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Contacts

Carl-Goran Carlson
Project Manager
PLM Miljoteknik AB
Sturkogatan 2
S-211 24 Malmo,
Sweden
Ph. +46 40 209000
Telex. 335 41 Pmt s

Elmar Forslund
Project Manager
PLM Miljoteknik AB
Box 19605
S-10432 Stockholm
Sweden
Ph. +46 8 151620
Telex 108 31 sellcon s

13. STOCKHOLM: FLAKT RRR LOVSTA PLANT (SWEDEN)

The Flakt Resource Recovery from Refuse (RRR) System was developed with the financial support of the Swedish technical development board. A particular target for recovery was the paper and cardboard constituent of the solid waste. A basic assumption of the technology was that a dry system would be preferable because it would probably simplify upgrading of the paper fraction and fit the air technology background of the Flakt Corporation. Also, it would avoid the problems that can arise in treating the wastewater from wet processing. The paragraphs that follow report on the plant built at Lovsta, which is a part of the Stockholm metropolitan area.

In addition to recovering ferrous material, the plant puts out a light paper fraction, a heavy paper fraction, film plastics, and compost. An earlier version of this plant was constructed in the Netherlands and is described in Chapter 14. The Lovstra plant operated quite well with good throughputs. Nevertheless, market conditions dictated that operators be at least temporarily terminated at the end of 1983. Whether or not the plant will reopen is currently under discussion.

The Flakt plant in Stockholm consists of three basic units: the front end, consisting of a primary shredder, trommel (drum) screen, air classifier, magnetic belt separator, secondary shredder, and secondary trommel screen; the back end, consisting of a flash dryer; and the upgrading unit, which consists of an air classifier and trommel. Figure 24 shows the process flow. Tables 47 and 48 give the input-output relationships.

Table 47. Flakt Plant Refuse Design Analysis - % wt. wet

<u>Material</u>	<u>% Wet Weight</u>
Paper	50
Ferrous	5
Plastics	8
Food wastes	20
Remainder	17
Moisture	22
Bulk density: kg/m ³	125

Source: Mowle, "Flakt RRR," p. 4.

Figure 24. Stockholm Flakt Facility at Lovsta

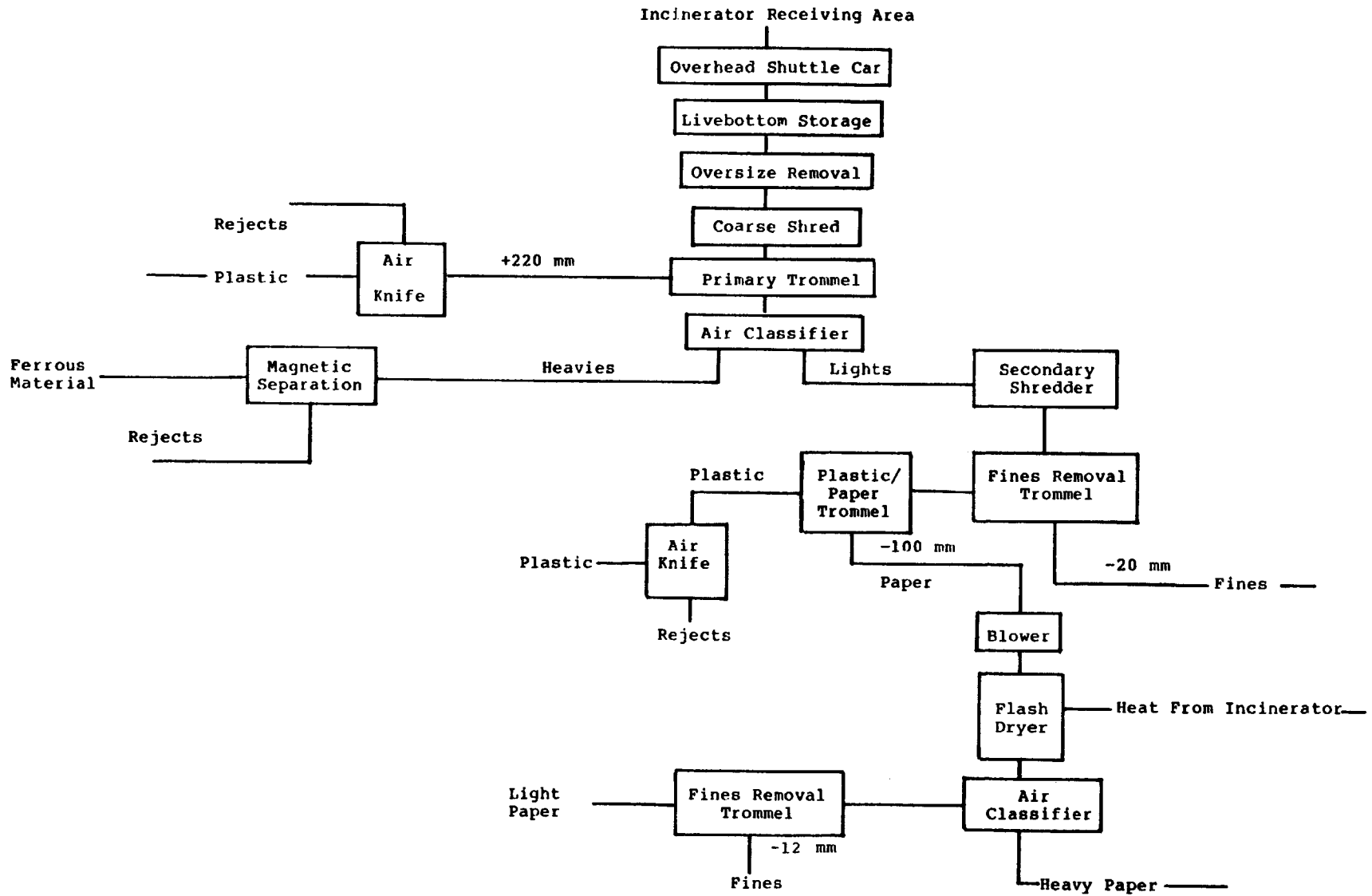


Table 48. Flakt Plant Targets for Recovery - Ton/Year

Paper (dry)	17,500
Ferrous	2,500
Plastics	3,300
Compost	12,000

Source: Mowle "Flakt RRR," (1982) p. 4.

Description of the Plant and Operations

The plant in Stockholm has been constructed adjacent to a municipal incinerator that is used solely for volume reduction. The waste collection vehicles empty into the pit of the incinerator. From there the feed for the RRR plant is loaded by the incinerator crane operators into an overhead shuttle car. This driverless vehicle carries loads of municipal waste to the adjacent Flakt plant. The car is rotated, discharging its contents into a live-bottom bin. There is a mechanical arm that the control room operator can use to pick oversize objects out of the bin if necessary.

The Flakt process does not begin with the hammermill that is found in most resource recovery plants. Rather, the incoming material is coarsely, and somewhat gently, shredded in a special flail mill. This equipment has two high-speed rotors with flexible flails that rip open sacks and bags to expose their contents. There is no grid in this machine. The gentle shredding is intended to minimize the grinding and pounding of dirt into the materials targeted for recovery. The objective is to initially achieve some size reduction without excessively contaminating the paper or losing fiber owing to excessive shredding.

The low-power consumption of this machine is a further important factor. Larger items like car mufflers and tires are passed through the machine without shredding as the flails fold away and can let objects over 0.5 m in size pass by. This machine also minimizes the generation of additional fines, particularly from the glass in the waste, which will require ultimate extraction if they are not to contaminate the paper or plastic products.

The shredder is followed by a rotating trommel screen, which is used to screen out excessively large items, particularly plastic film and textiles. The trommel device also provides a buffering action, and various materials tend to be fluffed up in

the shredder. Because the trommel screen has a certain accumulation capacity, it evens out the volumetric flow to downstream units and in so doing can enhance the performance of the plant. The primary trommel operates at 17 RPM. Seventeen RPM is approximately 70 percent of the critical speed. The device is rather lightly loaded. The holes in the trommel are 220 mm.

The material that is confined within the trommel and leaves the trommel as oversize contains a high proportion of plastic in sheet form. This material is passed through an air knife that blows off a proportion of the film plastic, which, after further processing, is a product of the plant. The less than 220 mm undersized material is taken to an air classifier of the zigzag type. This configuration was chosen because the changes in direction inherent in the zigzag patterns enhance the classification process and contribute a battering effect, which further exposes and helps to separate the material.

In this type of classifier, a rising air stream of controlled velocity transports the lighter fraction upwards, while the heavier materials fall through the air stream to the bottom. In the Flakt version of a zigzag air classifier, air is introduced into the unit at high velocity through a horizontal slot (air knife). Heavy material falling through the air curtain is exposed to this strong current of air. Light materials adhering to the heavy material are blown away and transformed to the light fraction. Because closed air circulation is employed, only a small proportion of the air (about 10%) is discharged to the atmosphere after going through a filtering step.

The air classifier is constructed with two parallel shafts. This was the result of a somewhat conservative approach to scale-up. Since the pilot plant was considerably smaller, it was considered best to use two smaller air classifiers rather than one large device. A vibrating table splits the feed material into two flows. Twin rotary feeders direct the material into the air classifiers. This splitting and feeding is a critical point in the process because long rods tend to jam the system here. However, problems have not been as great as was anticipated. Only one or two blockages occur per shift.

The heavy fraction provides the feedstock for the magnetic separation, which is accomplished with an overhead belt magnet. It is reported that the contamination of this material does not exceed 5 percent. The remainder of the heavy fraction is discharged to landfill. An advantage of the flail mill for the initial size reduction step is that the ferrous material tends to be flattened to some extent, but is not nuggetized, as is the case when it passes through a high-speed hammermill. Therefore, the product of the flailmill is more suited to detinning and can result in material of a higher value.

The light fraction from the air classifiers is deentrained, passing through rotary feeders. It is then blown via another pneumatic system through a single secondary shredder. This secondary shredder is quite expensive to operate because of heavy wear. Various materials have been tested for use in the construction of the hammers. Nevertheless, the problem of hammer wear plagues this facility, as it does most sites that use hammermills.

The next process represents a modification to the original set of equipment installed in the plant. One lesson learned from the earlier operation of the plant is that trommels are difficult to scale up and small trommels (pilot size) are relatively more efficient than big ones. At first, only one trommel, divided into one fine and one coarse section, was installed. The device was overloaded and screening efficiency suffered accordingly. Therefore, a second trommel was added. The first trommel (20 mm holes) is now dedicated to the extraction of organic fines. The second trommel (100 mm holes) makes the separation between a plastic-rich concentrate and a paper fraction.

The paper fraction passes through the 100 mm holes. The plastic-rich concentrate stays in the trommel and is ejected as product. This material, along with that blown off by the air knife from the primary trommel step, is conveyed to a baler for possible sale. The recovered plastic did not generate any direct commercial interest, although tests were undertaken. It should be noted that the undersize from the first of this set of two trommels is a feedstock for a possible composting operation.

It has been found that rotational speed significantly influences the efficiency of the trommeling step. In this plant the first of this tandem set of trommel screens is run at a much higher speed than the second.

The paper produced from the second trommel is pneumatically conveyed to a flash dryer. Because some impurities in the paper-rich fraction become tacky when heated and therefore give rise to deposits within the system, it is necessary to avoid high surface temperatures and low velocities within the pneumatic system. By and large, a flash dryer overcomes these problems.

Drying occurs in two stages; the first dries the material to virtually zero moisture content, with the moist air discharged to atmosphere; the second ensures retention of the material at a sufficient temperature for sterilization purposes, with the hot air being recirculated through the drying stage. The material inlet section of the drying stage includes an expansion section to allow heavier items such as an occasional piece of textile to drop out of the air stream. The drying stage also changes the physical properties of any light plastics that are carried over with the paper fraction. Light plastics tend to shrink owing to the heat, and thus become more amenable to separation in the stages of the process flow that follow.

Drying is quite energy-intensive. Apart from drying, the system consumes about 70 kwh/ton of raw refuse. Drying adds 120 kwh/ton. The total electric power consumption in this plant is about 900 kw. The dryer alone has an additional heat consumption equivalent to 2,500 kw. However, in this particular plant, the heat recovery system is based on the excess energy from the incineration plant next door. An economizer placed in the flue gas channel of the incinerator heats thermal oil to 280° C. The hot oil is pumped over to air heaters at the dryer. The heat demand for the dryer as well as for the heating of the plant is accommodated in this manner.

A problem common to this and other plants employing pneumatic conveying has been that fines have caused excessive wear in some sections of the pneumatic conveying system. In this plant it was therefore necessary to transfer the conveying fans from suction to pressure side -- that is, to locate them on the clean side of the conveying system. Linings have also been added to most bends in the pneumatic conveying piping system to protect the pipes from erosion as the fine material, often fine glass, tends to rapidly erode the metallic bends. One bend just before the flash dryer has been lined with ceramics containing aluminum oxide.

After drying, the material being processed is pneumatically conveyed to a secondary air classifier of the zigzag type. The heavies, mainly paper, are discharged through a rotary valve to a scraper-type conveyer feeding a baling press. The light paper is pneumatically conveyed through yet a fourth trommel where screening at 12 mm removes most of the impurities that have been freed through the agitation resulting from the processing steps just described. This light paper is a product of the plant and is baled for sale.

From the dryer on, a principal objective has been to achieve a marketable paper fraction. To do this, the system divides the paper into two fractions, one heavy and one light. The lights are the superior product. In the air classification and screening steps just described it is hoped that most of the plastics, which have shriveled up in the drying process, will either fall with the heavies or pass through the holes in the screen and therefore become rejects, rather than staying with the overflow and becoming a contaminant in the better paper product.

The drying process helps to reduce the decayability of both paper products. Table 49, which summarizes test results from pilot work on this process, shows the bacteria count in the paper samples taken before and after the flash dryer. Note that the reduction is generally higher than 90 percent.

Table 49. Test Results from Pilot Work

<u>Test</u>	<u>Number of Bacteria/g of Paper</u>		
	Before heat treatment	After heat treatment	Reduction
Heterotrophic bacteria, total	72,000,000	3,100,000	96
Coliform bacteria	12,000,000	340,000	97
Enterobacteriaceae	8,900,000	520,000	94
Acinetobacter	23,000,000	1,900,000	92
Staphylococcus	5,500,000	790,000	86
Bacillus	650,000	51,000	92
Salmonella or Shigella	0	0	
Yeast fungi	1,900,000	81,000	96
Mildew fungi	560,000	22,000	96

Note: Bacteria counts in paper samples before and after heat treatment. Incubation temperature: 35o C.

Source: Mowle, "Flakt RRR," p. 40.

While the light paper fraction has only 5 to 7 percent contraries, the heavy paper has about 25 percent impurities. And, the heavier paper fraction contains high-quality strong fibers from brown papers which have considerable value. Nevertheless, paper in a mixture such as this can only be separated from the contraries by machinery using gentle pulping. These processes, however, have not been installed in northern European papermaking plants. With the overcapacity that exists at the present time, there is little desire to invest in new capital equipment, no matter how inexpensive the feedstock may be.

Thus, until a market capable of utilizing this heavy paper fraction appears, the product -- regardless of its potential material value -- serves only as a fuel. However, with the high cost of fuel, and hence relatively higher revenue for this product as a fuel fraction, this is not necessarily an inferior outcome from an economical standpoint.

The recovery efficiency for paper fibers -- output paper taken in relation to incoming paper content -- is about 70 percent, which is roughly in line with the expectations of the plant owners. However, it should be noted that the paper content of the input waste was about 50 percent five years ago and now it has dropped to approximately 35 percent. The paper is also more difficult to clean. Where 5 percent impurities in the light fractions was expected, it is now more likely to be 6 to 7 percent. Another contributing factor to this change is the increased use of light nonwoven textiles and wet strength paper.

An early concern was that the heat treatment implicit in the processing for this plant would seriously damage the quality of the paper fibers recovered. However, it has been found that the gentle and quick drying does little to decrease quality.

The plant is highly automated and one operator is able to handle the control panel. Two additional personnel take care of the outgoing material, the balers, and the containers, while a fourth man is constantly surveying the equipment spaces. This crew of four men, plus the supervisor in the incineration plant, is all that is required to operate the facility. The plant has been built with an attractive operating environment.

Special precautions were taken to keep noise and dust down. The shredders, for example, are placed in a separate sound and vibration chamber of insulated concrete. Other noisy equipment is in special enclosures and the effective noise level at the general exposure in the machinery area is 85 db. In the control room, where the operator sits, it is 50 db. All conveyers are covered with canvas to control the dust. A special enclosure and air evacuation occur at every transition point where dust is generated. The air is transported to a central bag filter where the extracted dust is conveyed to the organic fraction for possible use in composting.

The primary trommel has a friction drive. The other trommels in the plants have a central shaft and spoke with a belt drive.

Summary

The Flakt Company has invested a great deal of time and money attempting to perfect a materials recovery system based on air handling technology and flash drying, both of which represent the particular engineering expertise of the firm and both of which also use equipment manufactured and sold by Flakt. Paper has been the principal recovery target.

In addition to a Stockholm pilot plant and then the Lovsta facility described here, a plant was constructed at Wijster in the Netherlands. The Stockholm pilot plant was disassembled and shipped to Japan, where it was reassembled for use as a demonstration. However, with the current depressed state of the

secondary materials markets, Flakt's future interest in municipal waste recycling is not clear. Most observers expect that Flakt will reduce activities to a maintenance level until the market for paper extracted from waste improves -- although it is not simply a marketing problem. Materials recovery cannot compete with inexpensive forms of waste disposal. It will only find its economic place when municipalities find they have exhausted their less expensive options. Then they must pay the tipping fee or underwrite the capital costs associated with equipment-intensive processing such as that used in the Flakt plants. This, in concert with a higher level of demand for secondary fiber, would again offer an opportunity for the Flakt approach. In reality, the paper product is quite good, and an increased overall level of economic activity could provide a market for it.

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Contact

Bengt Citron
Project Manager
Solid Waste Management
Flakt Installator AB
Box 81051
S-104 Stockholm,
Sweden
Ph. +46 8 714 42 09 Ope. 7144000
Telex. 10430

14. INTERNATIONAL ORGANIZATIONS AND OTHER RECOVERY ACTIVITY

Commission of the European Economic Community (EEC)

EEC's interest in the recycling of urban waste, which goes back a number of years, is evident from the several studies on secondary raw materials published during 1978 and 1979. One of particular interest is the volume on household waste-sorting systems published in January 1979 by DGXII-Research, Science, Education. This volume comprises four reports, each one prepared under contract with EEC: the first one deals with household waste-sorting systems in general (it was prepared by the Warren Spring Laboratory in the United Kingdom); the second is a study of the disposal of urban waste in Italy; the third has to do with waste-sorting systems in the Federal Republic of Germany; and the fourth deals with household waste-sorting systems in France.

With this as a starting point, EEC interest in the recycling of urban waste has expanded into a number of studies and scientific investigations. The effort is known as the Recycling of Urban and Industrial Wastes (Secondary Raw Materials) Research and Development Program. A directory published in February 1982 shows the extent of the effort. The directory lists the projects undertaken under three main headings: (1) sorting of household waste; (2) thermal treatment of waste; and (3) fermentation and hydrolysis. In addition to the projects listed in this report there are twenty-five other contracts covering a wide range of subject matter.

Since 1979, DGXII has been renamed the Directorate General for Science, Research and Development. The reader interested in the research and development efforts in this area should contact the EEC. A conference focused on its efforts was held in Luxemborg, September 24-27, 1984.

At present the EEC is funding two overview studies. The first of these is a combined effort between Dr. D. V. Jackson of Warren Springs and Dr. A. Buekens of the Free University, Brussels. Together they are looking at the sorting of household waste (Jackson) and thermal treatment of waste (Buekens). In addition, Mr. Cowin Parker of Environmental Research Associates, London, is conducting an inventory of existing plants for DGXII. This is the Directorate General for Environment and Protection of Consumers. Finally, DGXII is funding demonstration projects in this area. Altogether, the scope of the EEC resource recovery effort is quite broad, more encompassing than that being conducted in the United States under the auspices of the federal government and perhaps even more extensive than the Japanese activity.

Organization for Economic Co-operation and Development (OECD)

At present little work at OECD is being directed to the mechanical sorting of household waste. Their main interest is on separation in the home. There have been several studies of household separation published. See the listing at the end of this chapter.

United Kingdom

In addition to the Byker, Doncaster and Westbury (Blue Circle) facilities described earlier in this report, several other mechanized waste-sorting facilities are in operation in the United Kingdom. A refuse-derived fuel production facility with ferrous metal separation has been operating for a number of years at the Witton (Birmingham) plant of Imperial Metal Industries. It uses refuse-derived fuel as a supplement to coal in two stoker-fired boilers, each having a steaming capacity of 100,000 lb/hr. A second facility is a pelletizing plant at Eastbourne in East Sussex County. Originally this was a privately developed plant using the Buhler-Miag system, which is a Swiss process. The project is currently being operated by the East Sussex County Council.

An interesting pilot plant exists at Bristol. This is an undertaking of the WMC Resource Recovery Ltd. The breaking down of the solid waste occurs in a low-speed (1 RPM) trommel-like device (a Vickers Sear drum). At a later point sewage sludge is blended into the material being processed. The three main products are: a horticultural material for use as a growing media; a fibrous material that is said to be suitable for the fabrication of chipboard, hardboard, plasterboard, fiberboard, and so on; and a fuel fraction that is said to have an energy value in the range of 50 to 75 percent of that of solid fossil fuel. While some data are available, the process is proprietary, and most information is closely held.

Italy

In addition to the Sorain Cecchini plant described elsewhere in this report, another plant has been constructed by the same company in Perugia. Note should also be taken of the plant in Milan constructed by the De Bartolomeis Company. This plant is designed to separate five basic materials: ferrous metals, organic fraction, cellulose products (paper and board), plastics, and glass. The company is actively marketing the process throughout Europe. Finally, a study group operating on behalf of the Italian federal government is looking at the overall energy situation. One subcommittee is concerned with energy from waste. The names and addresses of the chairman of the overall energy board and of the subgroup dealing with waste energy are recorded in the contacts list at the end of this chapter.

Austria

A rather extensive recycling study and research agenda is being undertaken by the Austrian federal government. In 1979 ten working parties were formed to study various raw materials such as glass, plastics, pulp and paper, and so on, and also various sectors of the economy such as agricultural, forestry, and waste recycling. Under the auspices of these working parties, a number of research and demonstration projects have been undertaken. These include the burning of tires in cement kilns, the use of waste materials in road construction, several pyrolysis efforts with solid waste as the fuel feedstock, and the burning of refuse as a fuel for power plants.

The cement kiln project is located near the city of Linz. About 20 percent of the energy used by the kiln is derived from the tires. This represents a combustion of approximately 2 tons of tires per hour. Both cut and whole tires have been used as fuel. It has been found that the cut tires work more satisfactorily. The same plant is experimenting with the burning of the residue waste from car shredding after magnetic separation. However, there appears to be a potential problem with metallic elements in the combustion emissions.

The government publishes a listing of its recycling research projects (see reference list).

Federal Republic of Germany

As in Austria, the central government in Germany has played an active role in the development of recycling research and demonstration agendas, and in the funding of specific pilot and demonstration projects. A volume listing these projects has also been published (see the reference list). The aims of this program are to reduce waste at both the production and consumer levels, increase waste utilization, and enhance the environmentally safe disposal of waste.

Waste utilization by material separation, a subcomponent of the program, consists of material separation at the source, that is, separate collection; material separation after conventional collection in centralized plants by hand sorting, and/or mechanical sorting and processing; and waste utilization by material conversion, for example, generation of products of transformation (solids, liquids, and gaseous products) for use as raw materials or as fuel. Also included as program components are the recovery of energy liberated through the transformation process; thermal transformation (pyrolysis and gasification); and finally, biotechnical/chemical transformation such as fermentation, hydrolysis, and biogas generation.

An experimental mechanical separation plant was constructed with financial help from the federal government of Germany in Ludwigsburg (Lemberg). This plant, which employs fairly

rudimentary mechanical processing steps, aims at increasing the recovery of recyclable raw materials at existing landfills with minimum capital and operating expenses. Other pilot plant work has been undertaken by universities, such as the technical university at Aachen, and the technical university in Berlin. Both have undertaken extensive investigations of unit processes for the separation of materials from mixed household waste.

Some years ago, the Krauss-Maffei Company in Munich devised a process known as the R-80 System. The pilot plant constructed in Munich was later scaled up to a full-sized, 8 ton/hr plant commissioned in 1979 at Landskrona, Sweden. This plant, which has paper and plastics recovery as an objective, operated for a number of years, but the quality of the materials recovered was not sufficiently high to find a ready market either in Sweden or at economical transport distances in northern Europe. As a result, the plant is now closed and undergoing modification.

Another full-sized project is the energy-from-waste plant at Bielefeld. The incinerator itself is the typical heat recovery type of installation found throughout Europe. Of interest is the fact that the waste is first processed in two large ball mills before it is burnt. These machines are used mainly in the mining industry. They process 8 tons of refuse per hour. The purposes of the ballmilling process are size reduction and homogenization. In addition to household waste, sludge is also disposed of by this system. It is added to the waste at the ballmilling stage. The reputed advantage of ballmilling is that it enables a relatively smaller incinerator to be constructed. It also allows for a reduction in the size of the air clean-up system. Accordingly, it is said that a 4 million Deutsche Mark investment in the ball mills saved 12 million on the cost of the incinerator and its associated air handling devices, which in this case includes wet scrubbers. Lower operating costs for the incineration phase of the process are said to more than offset the costs incurred to initially process the waste in the ball mills.

The German program is broad in scope, ranging from pyrolysis scale-up projects now being undertaken to pilot work on the separation of plastics that have been obtained in a mixed and contaminated form as waste products from industrial processes. The project listing previously cited is 179 pages in length. Mainly, each page describes a separate research or demonstration effort.

Switzerland

There are several plants in Switzerland, mainly producing compost. Only one project is mentioned here -- the pilot plant of the ORFA Corporation in Zurich. This is a separation project directed to obtaining an organic fertilizer, a particle board product, and a pelletized fuel. The technology features an oxygenation process.

France

A number of agencies in France are concerned with waste management and resource recovery. These include the Agence Nationale pour la Recuperation et l'Elemenation des Déchêts; Ministère de l'Environnement, Direction de la Prévention des Pollutions; and Bureau de Recherches Géologiques et Minières (BRGM).

In addition to the BRGM Revalord project described earlier, there is a small-sized plant with the same recovery objectives being built in western France. There is also a pelletizing plant at Laval that has operated for a number of years. The Sobeia Company has a project for producing a refuse-derived fuel. In addition to a plant in the suburbs of Paris, this company has a plant under construction in Brittany. The name of this process, which produces a pelletized fuel, is Combusoc. It is also rumored that the Elf Aquitaine Company is entering the energy from the waste marketplace, but it was not possible to confirm this.

Netherlands

Approximately 25 percent of the waste generated in the Netherlands is handled by the VAM company, which operates a network of railway transit stations and reception facilities with an annual capacity of some 1 million tons of waste. The largest processing plant is at Wijster in northeast Holland. Some years ago the Flakt Company of Sweden, under contract to VAM, constructed at this location a plant similar to the one in Stockholm (described in Chapter 13). The Dutch facility was built before the Stockholm plant. Unfortunately, the quality of the paper and plastic products from the operation of the Wijster plant was not high enough to satisfy the requirements of the Dutch market. There was also some difficulty with the compost.

Through the course of three or four years, a series of modifications was undertaken but it did not solve the problems. As a result, VAM decided to reconstruct the project, changing the recovery targets somewhat as described in the next paragraph, and to upgrade its composting operation in order to reduce the metallic carryover into the compost and to generally produce a higher quality compost product.

VAM has also constructed a new plant at Mierlo near Eindhoven in the southern part of the country. The capacity of the Mierlo plant is 50,000 tons per year while that of Wijster is expected to be 150,000 tons. In the Wijster case, the reconstruction has amounted to a rather radical change in equipment from the original Flakt plant. In addition to paper, plastic, and compost, both plants are designed to produce a refuse-derived fuel. At Wijster, the zigzag air classifiers, typical of the Flakt equipment, have been replaced with air classifiers of a new VAM design, essentially of the vacuum cleaner type. They suck

the light plastic out of the waste stream at transition points such as the discharge of a conveyor. Rather than use a rotary valve as an exit mechanism for waste deentrained in a cyclone, the Mierlo plant is testing an air lock with two hydraulic doors.

At Wijster, the new equipment has cost the Flakt Company (who had a residual responsibility) and VAM approximately 5.5 million Netherlands guilders. The process begins with two stages of trommeling, with 150 mm holes in the first stage. The overs from the first stage are air classified to produce a light fraction consisting of paper and plastic. The unders from the first stage of trommeling are feedstock for the second stage. The second stage trommel has 40 mm holes. After air classification, the lights from the trommel overs are the RDF product. Heavies and 40 mm fines become either feedstock for the composting operation or rejects.

Because this plant is located at the site of one of the VAM landfills, methane gas from this landfill is captured and is used to generate electricity to power the plant. The outlet gas from this process is used to pyrolyze the cans, that is, to cook off the organic materials. An air knife is used to separate heavy and light ferrous material before the pyrolyzing drum. The final result is a high-quality ferrous fraction, consisting mainly of cans.

Paper is separated from the plastics by wet processing at the Wijster plant. The paper/plastics concentrate is the lights from the first air classifier. A large rotary drum is used to transport and to further mix the material. Water is added. Then a slow-speed trommel like a Sear drum makes the initial separation. The wet or damp paper is forced through the holes, while the plastic material stays within the drum. The latter is 99 percent plastic. The paper pulp is screened for sand and then again screened to recover the paper fibers. The paper material is about 90 percent water at this stage. It is pressed dry to a consistency of about 50 percent moisture. VAM has a short-term contract with a German paper mill for this material at a price of 110 Netherlands guilders per ton. The plastic fraction is delivered to a plastics clean-up operation and VAM currently receives 120 Netherlands guilders per ton for this concentrate.

The Wijster plant does not have a shredder. It has an input of 30 tons/hr.

Denmark

Waste recycling in Denmark has been almost totally confined to household separation. This effort is quite well organized and has included a good deal of work on waste composition. However, the government recently appropriated funds for the development of a number of pilot/demonstration plants to mechanically separate both household and industrial waste. Tenders are out for the construction of a plant on the Jutland Peninsula capable of handling 18,000 tons per year, of which one half will be household

waste and one half industrial/commercial waste. Many of the firms involved with the plants described elsewhere in this report have offered to participate in this undertaking. As yet there has been no definitive move to construct a plant in the Copenhagen area. However, there are a number of planning activities, and if all were to come to fruition, there would not be sufficient waste to accommodate their combined capacities.

Commission of the European Communities

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Contacts

Dr. Gian L. Ferrero
 Directorate General for Science, Research and
 Development (DG-XII)
 Commission of the European Communities
 EEC Sq. de Meeus
 Brussels, Belgium
 or 200, Rue de la Loi
 B-1049 Brussels,
 Belgium
 Ph. 23 57972/51686
 Telex. 21877 COMEU B

Prof. Alfons Buekens
 Chemische Ingenieurtechniek
 en Industriële Scheikunde
 Vrije Universiteit Brussel
 Pleinloan 2
 B-1050 Brussels
 Belgium
 Ph. (00322) 641 21 11
 Telex. 61 051 VUBCO B

D.V. Jackson
Head, Materials Recovery Division
Warren Spring Laboratory
P.O. Box 20
GB-Stevenage 3388
Herts SG1 2BX,
England
Ph. Stevenage 3388
Telex. 82250

Colin Parker
Environmental Resource Ltd.
79 Baker Street
London W1M 1AJ,
England
Ph. 01-486 8277
Telex. 25247 (Attn: ERL)

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Contact

Pierre Lieben
Administrateur Principal
Direction de l'Environnement
OCDE
2, rue Andre Pascal
75775 Paris Cedex 16,
France
Ph. 502 12 20 ext. 32.73
Telex. 620 10

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Contacts

B.W. Gulley
Department of Environment
Marshamstreet 43
GB-London,
England
Ph. 01-212 3434

D.B. Charnock
County Engineer
East Sussex County Council
Phoenix Causeway, Lewes
East Sussex BN7 1UE,
England
Ph. Lewes 5400

V. Lawson
WMC Resource Recovery Ltd.
2 Eaton Crescent
Clifton, Bristol BS8 2 Ej
England
Ph. 0272-738742
Telex. 449752 - CHACOM G-VLA

ItalyContacts

Dott. Ing. Emilio Tirabschi
db Impianti S.p.A.
De Bartolomeis
Gruppo S.A.F.I.L
Via Settembrini 7
20124 Milan,
Italy
Ph. (02) 2774
Telex. 311267 DB MI 1

Prof. Gincarlo Chiesa
Ufficio Studi e Sviluppo
CNR
Piazza R. Morandi 2
20121
Milan,
Italy
Ph. 02 780190

Prof. Giacomo Elias
CNR Energeitca
Via Nizza 128
00198
Rome,
Italy
Ph. 06 8448000

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Contacts

Dipl. Ing. Dr. Heinz Schreiber
 BMWF, Sektion Forschung
 Minoritenplatz 5
 A-1010 Vienna,
 Austria

Dr. Gerhard Vogel
 Institut fuer Technologie
 und Warenwirtschaftslehre
 der Wirtschaftsuniversitaet
 Wien
 Augasse 2-6
 A-1090 Vienna,
 Austria
 Ph. (0222) 75 72 18 (home)
 (0222) 34 05 25 801 (office)

Dir. Dipl. Ing. Peter Liebl
 Gmundner Zementwerke Hans
 Hatschek A.G.
 A 4810 Gmunden,
 Austria
 Ph. 07612/2881

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Contacts

O. Prof. Dr. -Ing. Heinz Hoberg
 Wuelnerstrasse 2
 5100 Aachen
 Federal Republic of Germany
 Ph. 0241-805700

Peter Knauer
 Federal Environmental Agency
 Umweltbundesamt
 Bismarckplatz 1
 1000 Berlin 33,
 Federal Republic of Germany
 Ph. 030/89 03 - 242

Dr. Klaus Komoroski
 Federal Ministry of
 Research & Technology
 Heinemannstrasse 2
 D-5300 Bonn-Bad Godesberg
 Federal Republic of Germany
 Ph. (0228) 59-1

Prof. Dr. -Ing. Oktay Tabasaran
 Technische Universität Stuttgart
 Institut für Siedlungswasserbau,
 Wassergüte- und Abfallwirtschaft
 Abteilung Abfalltechnik
 BAndtale 1
 D-700 Stuttgart 80,
 Federal Republic of Germany
 Ph. (0711) 6855500
 Telex. 07 255 445

Carl J. Thome-Kozmiensky
 Institut für Technische Umweltschutz
 Sekr. KF5
 Technische Universität Berlin
 Straße des 17. Juni 135
 D-1000 Berlin 12,
 Federal Republic of Germany
 Ph. (303) 314 2619
 801 30 53

France

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Contacts

Mrs. Jacqueline Aloisi de Larderel
 Ministère de L'Environnement
 et du Cadre de Vie
 Direction de la Prévention
 des Pollutions
 Service des Problemes de Déchêts
 14 Boulevard de Général Leclerc
 92521 Neuilly sur Seine,
 France
 Ph. 758.12.12

Agence Nationale pour la Récupération et l'Elimination
 des Déchêts. 2, Square La Layette, 49004 Angers
 Ph. 41 88 98 25

NetherlandsContact

Ir. P. Visser
 Directeur Bedrijven
 N.V. Vuilafvoer Maatschappij (VAM)
 Stadhouderskade 401071 ZD
 Amsterdam,
 Netherlands
 Postbus 5380 1007 AJ Amsterdam,
 Netherlands
 Ph. 020-730307
 Telex. 18357 VAM NL

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Contact

Tage Mikkelsen
 Gendan - NYT
 Holbergsgade 26
 DK-1057 Copenhagen K,
 Denmark
 Ph. +45 1 12 50 00

15. OVERVIEW AND SUMMARY

There are several differences between the circumstances underlying the decisions to construct and operate the waste-processing facilities described in this report and the circumstances that might lead to such decisions in developing countries. First, and probably foremost, is the cost of alternative waste disposal opportunities. The high cost of conventional waste disposal drives major European municipalities to consider recovery based waste disposal options. Even if this circumstance is matched -- even in a relative sense -- by population centers in developing countries, one still needs to look to the second difference. This concerns the quantity and composition of the waste. Tables 50 and 51 show the quantity and composition of urban refuse for industrialized countries, middle-income countries and low-income countries.

It is clear from Table 50 that the quantity of waste available for processing is considerably less per capita for low-income and middle-income countries than it is for industrialized countries. The availability of waste obviously affects the decision as to whether or not to invest in a mechanized processing facility. Table 51 displays waste composition. Clearly, the recovery potential differs as well. The information in this report on the amount and the composition of waste, either for proposed plants or those in operation, illustrates together with the data in Table 51 the rather large differences in this regard between the low-income and the industrialized countries and their cities.

The not surprising conclusion is that there is less waste per capita and very little to recover from the waste of the low-income cities. The waste of the middle-income cities obviously shows more promise. Paper, plastics, and metal contents are fairly high. They are almost on a par, and in some instances exceed, the percentage composition for these ingredients in the waste of industrialized cities. Therefore it is highly unlikely that any of the processes, both in terms of their equipment and recovery objectives, would find application in the low-income cities, let alone the countries as a whole. There is some promise of direct applicability in the middle-income countries, but this would very much depend upon the individual cities and their particular waste composition. This, then, is the first and principal lesson to be learned from this report. In other words, it is unlikely that the overall technology can be transferred from the European facilities to waste processing in developing countries. As was pointed out in the introduction, this may not be true for certain unit processes. Even there, however, possible utilization should not be taken on faith, but must be carefully investigated and evaluated.

Table 50. Generalized Quantities and Characteristic of Urban Refuse

	Quantity kg/cap/day	Density kg/m ³	Percent Moisture
Industrialized countries	0.7 to 1.8	100 to 150	20 to 40
Middle income countries	0.5 to 0.9	200 to 400	40 to 60
Low income countries	0.3 to 0.6	250 to 500	40 to 80

Source: Cointreau, Sandra J. Environmental Management of Urban Solid Wastes in Developing Countries--A Source Project Guide. The World Bank, Urban Development Department. Urban Development Technical Paper Number 5. Washington, D.C. (June 1982). Also in Gunnerson, C.G., and Jones, D.C., "Costing and Cost Recovery for Waste Disposal and Recycling." Paper presented at UNEP/BMPT International Symposium on Solid Waste Management, Karlsruhe, Germany (October 5, 1983). p. 11.

Table 51. Composition of Urban Refuse (in percentage by weight)

Type of Materials	Industrialized			Middle Income						Low Income				
	Brooklyn, N.Y. (62)	London, England (63)	Rome, Italy (64)	Singapore (65)	Hong Kong (66)	Medellin, Colombia (67)	Lagos, Nigeria (68)	Kano, Nigeria (69)	Manila, Philippines (70)	Jakarta, Indonesia (71)	Lahore, Pakistan (72)	Karachi, Pakistan (73)	Lucknow, India (74)	Calcutta, India (75)
Paper	35	37	18	43	32	22	14	17	17	2	4	<1	2	3
Glass, ceramics	9	8	4	1	10	2	3	2	5	<1	3	<1	6	8
Metals	13	8	3	3	2	1	4	5	2	4	4	<1	3	1
Plastics	10	2	4	6	6	5	-	4	4	3	2	-	4	1
Leather, rubber	-	-	-	-	-	-	-	-	2	-	7	<1	-	-
Textiles	4	2	-	9	10	4	-	7	4	1	5	1	3	4
Wood, bones, straw	4	-	-	-	-	-	-	-	6	4	2	1	<1	5
Non-food total	74	57	29	63	60	34	21	35	40	15	27	4	18	22
Vegetable, putrescible	22	28	50	5	9	56	60	43	43	82	49	56	80	36
Miscellaneous inerts	4	15	21	32	31	10	19	22	17	3	24	40	2	42
Compostable total	26	38	71	37	40	66	79	65	60	85	73	96	82	78
Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Note: The above values have been rounded to the nearest whole number, unless the amount was less than 1.0.

Source: Cointreau, Environmental Management..., p. 11.

Materials Recovery

The most likely targets for materials recovery from the waste of the developing countries appear to be in the area of ferrous metals, plastics, and perhaps a low grade paper fiber. Caution must be exercised in looking at any figures that describe the overall plastic content of the waste since a mixed plastics fraction is of little value. Plastics, to be of any use, must be concentrated into similar types of plastic material, such as PVC or polyethylene. In particular circumstances, this may be achieved using some of the screening approaches described earlier in this report.

Use in Cement Kilns

An exception to the generalization that complete facility transfer between Europe and the developing countries is probably not feasible is in terms of the burning of process waste in cement kilns. This idea has already been developed in Chapter 4, which deals with the Westbury Blue Circle Cement facility in the United Kingdom. The conclusion portion of that section contains a brief discussion of the need and prospects for drying a portion of the organic combustible waste. Ideally, it would be useful to separate the lighter dryer combustible material from the wetter materials. Unfortunately, it is probably still necessary to dry even the less moist fraction. To accomplish this economically, one needs a source of what is otherwise virtually valueless energy. This may be present in the exhaust gases of the cement kilns themselves and in the stack emissions of electric-power generating facilities. Whether the utilization of this heat is economically feasible or not depends on the local circumstances.

Foreign Exchange Considerations

One factor that is difficult to quantify in an economic calculation is a trade-off involving the use of domestic resources to dry the waste so that it can be made into fuel instead of using imported petroleum energy to fuel a power plant or an electric generating station. This brings up the issue of the relative scarcity of foreign exchange and the demands placed upon this resource for other current needs and for long term economic development. It may be that, in terms of the conversion of scarce foreign exchange, the drying of portions of the waste stream to make it into a usable fuel indeed makes economic sense, even if, as a straightforward domestic investment calculation, the numbers say otherwise.

Some of the same considerations arise with respect to pelletization of the waste. Here the question is mainly one of transportability and storability, and in developing countries the issue of storability may be a primary concern. The pelletization of waste during the dry season could allow for significant

carryover into the wet season, when the use of the raw waste as a fuel may be completely impracticable.

Pelletization

Of the facilities described earlier, a fairly large number are engaged in pelletizing. At the time of writing, the PLM BRINI System seems to have the greatest number of operating hours and is perhaps the most efficient in terms of input and output. Its pellets, actually cubets, appear to have sufficient pellet integrity to allow for storage and transport. The other pellet-making facilities -- Byker, Doncaster, and Herten -- produce a smaller, denser pellet. At these facilities experience is being gained on two basic types of pellet mills, but they do not seem to be as far along as PLM. The first two of these three facilities have pellet mills with a circular die within which rollers press the material into die holes. The third has a die that is a horizontal plate; the rollers revolve on the top, pressing the combustible material down into and through the die. The operating experiences of these plants should produce evidence of the relative efficiency of these two approaches to pellet making.

The Sorain Cecchini refuse-derived fuel process is yet another example of the development of a means to produce a usable, high-quality processed energy product from municipal waste. The characteristics of this fuel and the process are described in some detail in Chapter 4. Because of its low utilization of electric energy, the Sorain Cecchini process may have particular merit.

Paper and Plastics

As mentioned earlier, the recovery of low-grade paper fiber and plastics from the waste may have merit. Six of the facilities covered in this report attempt the recovery of paper and plastics. The methods vary. For example, the Esmil plant in the Netherlands and the Stockholm Flakt recovery facility effect separation by means of differential shredding, various steps of air classification, and differential screening. After initial trommeling, the Nancy plant relies on handpicking to recover the paper fraction, and then an eddy current and infrared sensing operation to recover PVC water bottles. The Vienna plant, as well as the facility in Madrid, add moisture to the mixture of paper and plastics and utilize the difference in adhesive quality and the fact that the wet paper can more easily be forced through holes in a screen than plastics to assist in separating the two products.

The Rome facility employs a differential shredding step that tends to cut the paper into smaller pieces than the plastic. This difference in size, and to some extent density, is used in air classification and in trommel screening to separate waste material into plastic-rich and paper-rich fractions. The

paper-rich fraction is pulped on site to remove plastic contaminants. As mentioned, the Madrid plant, the Vienna plant, and also the Esmil facility in the Netherlands use a form of pulping whereby moisture is added and then a special device separates the plastic and the paper by pushing the paper fibers through holes in a drum sieve. The plastic material remains inside the sieve, exiting at the end of the device. These machines are proprietary products of their designers. With the passage of time, more data on the effectiveness and efficiency of these separating units should be available.

Materials Markets

As was pointed out earlier, while these facilities are indeed able to separate plastic and paper, their operators are having only a modest success in marketing the products. In Rome the plastic product is used by the Sorain Cecchini Company to make plastic garbage bags and plastic pipe. The plastic products, both the plastic bottles and the film plastic recovered at the Madrid facility, find a market. The PVC recovered at the Nancy, France, facility also is marketed. The Neuss facility recovers plastics but mainly from its industrial waste feedstock. There has been little interest in the plastic recovered by the Flakt facility in Stockholm. Although the Flakt paper product is quite pure, it, too, had difficulty finding a ready market and much was burned as a refuse-derived fuel. To some extent, this is also the case with the Neuss facility. The paper recovered at Nancy is marketed, but a good deal of the more contaminated material is left on the belt by the handpickers to be utilized as a fuel. The Rome facility markets its paper pulp to a nearby paper-making facility. Interestingly, some of the refuse-derived fuel, that is, the pellets, produced in Doncaster and Byker have been used on an experimental basis by local paper-making facilities.

Fuel Markets

A caution is also in order with respect to the production and sale of refuse-derived fuel. It is not yet safe to assume it can be marketed. Because it is a new, untested fuel, many owners of what might appear to be suitable heat exchangers are reluctant to make a long-term commitment to use the refuse-derived fuel, whether pellets or fluff. The real marketing test will come when the Herten operation in Germany comes into production. The developers and the management of this project have assumed that they will be able to obtain markets for the pellets at prices that will make the operation viable. Obtaining these markets will be the real test of the acceptability of this fuel.

A principal benefit of recent activity in the refuse-derived fuel area, as described in this report, is the test and evaluation work on its combustion by a variety of heat exchangers. Although the text here gives some detail on these tests, a valuable service could be rendered if a more comprehensive study were

undertaken to catalog these combustion tests and to compare the results. It is safe to say that the expansion of the potential for cofiring refuse-derived fuel along with coal in existing boilers awaits such a cataloging of the tests as have been run, or are now being run, throughout the world.

Until boiler owners and operators have positive answers to questions about the feasibility of such cofiring, they will be reluctant to participate even in test efforts. More important, if the financing of a recovery facility depends on a relatively firm commitment for the purchase of the refuse-derived fuel product, this reluctance takes on an added meaning. That is to say, if an owner is reluctant to try the material, even if the fuel is available, he will be even less amenable to signing a contract to burn it before the facility is put in place to produce the fuel. Yet, this is the time such a contract is necessary to support-financing. In most countries the funding of municipal endeavors cannot take place in such a situation. The fact that such operations exist in Europe is due mainly to three factors: national government support; private entrepreneurs, as in the PLM BRINI system; and possible miscalculation. Several facilities have been built and are coming on line believing -- it is hoped with reason -- that there will be no difficulty in marketing the product.

Four Candidate Facilities (Waste Fuel)

A great deal of experience has yet to be gained that will, it is hoped, be transferred through reports such as this one to a broader audience so that more countries will be able to evaluate the feasibility of waste processing in their own environments. The experience in Europe has already provided important information. Of the facilities described here, four seem to warrant the greatest consideration as approaches to the utilization of the energy value inherent in the waste stream. Three of these are currently operated at full scale, while the fourth -- the Herten resource recovery center Ruhr project -- is just coming on line. It is included because it illustrates how some of the offheat from another source can be used to dry the refuse before it is pelletized into a refuse-derived fuel. As mentioned earlier, drying may be one of the keys to utilizing the high moisture content waste of many developing countries as a source of energy. The Flakt plant in Stockholm also uses waste heat to dry.

The other three are full-sized operational plants that have accumulated a significant number of operating hours, the first and foremost of which is the Sorain Cecchini plant in Rome. This company, with its multiple facilities, has perhaps the most extensive operating experience in Europe, or worldwide for that matter. The second is the Westbury Blue Circle Cement facility in the United Kingdom. Its approach could have broad applicability since many countries have cement kilns located relatively close to major population centers. It should be possible to

construct and maintain this relatively simple process in a developing country. Additional screening could also improve the quality of the fuel.

The third is the PLM BRINI process. As far as the production of a densified refuse-derived fuel is concerned, BRINI appears to use one of the simpler types of equipment available. This is not to imply a rudimentary processing facility; that is not the case. It is a relatively sophisticated operation, even though it does not involve air classification; in fact, it avoids some of the complexities of facilities that do. The PLM ballistics separator will, it is believed, find wide applicability. The unit process is available and can be purchased from the PLM company. Overall, the PLM plant in Stockholm appears to be one of the best engineered plants of those discussed in this report. The company appears to have solved a number of problems that have also arisen in many other recovery facilities. Because waste processing generally involves a number of unit processes, there are a large number of transition points in the materials flow. In most plants these can be identified by the spillage that occurs, which has been by and large avoided or contained in the PLM-engineered plant. Other plants are also making progress in this regard. Obviously, spillage is an important consideration if one is investing in an operation with a number of connected unit processes.

Conclusions

Waste processing in Europe has advanced significantly since the late 1970s. Because the traditional mass-burning approach is becoming more and more expensive, it is not surprising that the waste management authorities at both the central government and local government levels, as well as private entrepreneurs, are seeking less expensive alternatives involving the realization of some of the materials and the off-site utilization of energy values inherent in municipal household discards. Mass burning permits energy recovery, but not materials recovery (except ferrous). Off-site burning is, moreover, seen as a means of avoiding the cost of constructing a new heat exchange.

This report is for readers interested in the applicability of the European waste-processing experience to waste management problems in developing countries. Although the prospects for general transferability are considered to be relatively low, a number of the general approaches described here could have merit, depending on the composition of a particular city's waste and the economics of alternative methods of disposal.

More importantly, however, the prospect of utilizing individual unit processes to accomplish certain types of separations would significantly improve the prospects for more labor-intensive separation approaches. Skimming off the better fuel material through selective screening is a case in point.

What remains would then be more amenable to hand separation. However, when all is said and done, the picture that emerges is that of a series of waste-processing facilities, each of which -- for one reason or another -- is seeking to establish its economic viability within the environment of an industrialized country.

In this environment, the prospects for economic viability are generally better than they are in the developing countries. Alternative means of disposal cost more. And, greater economic benefit can be derived from substituting capital investment for labor. Working against the facilities attempting to prove their economic viability is a consumer market with an established taste for high-quality goods. This translates into a reluctance among manufacturers to use lower grade material inputs. The opposite may be the case in developing countries. However, since the economic equation has not yet been balanced in the case of the waste-processing facilities in Europe, it is unlikely that most of the European technology can be transferred to less economically feasible situations such as in the developing countries. Despite some offsetting factors, only in very special circumstances are they likely to be of sufficient magnitude to rebalance the economic viability equation.

APPENDIX. MOBILE RDF-RECOVERY SYSTEM (MVU)
(FEDERAL REPUBLIC OF GERMANY)

The equipment described in this appendix does not, strictly speaking, constitute a plant in its own right. It is designed for operation on a landfill, but it could also be operated at a site closer to the center of waste generation or at a site adjacent to the fuel user. This equipment is minimal; it is mobile and the investment demands as well as the specific operating costs should be low in comparison to a permanent installation.

The benefit of the Mobile RDF-Recovery System is that it can resolve the problem of not being able to obtain a commitment to burn a waste-derived fuel until trials have been made at the candidate boiler, and of not being able to make substantial tests because there is no nearby source of fuel.

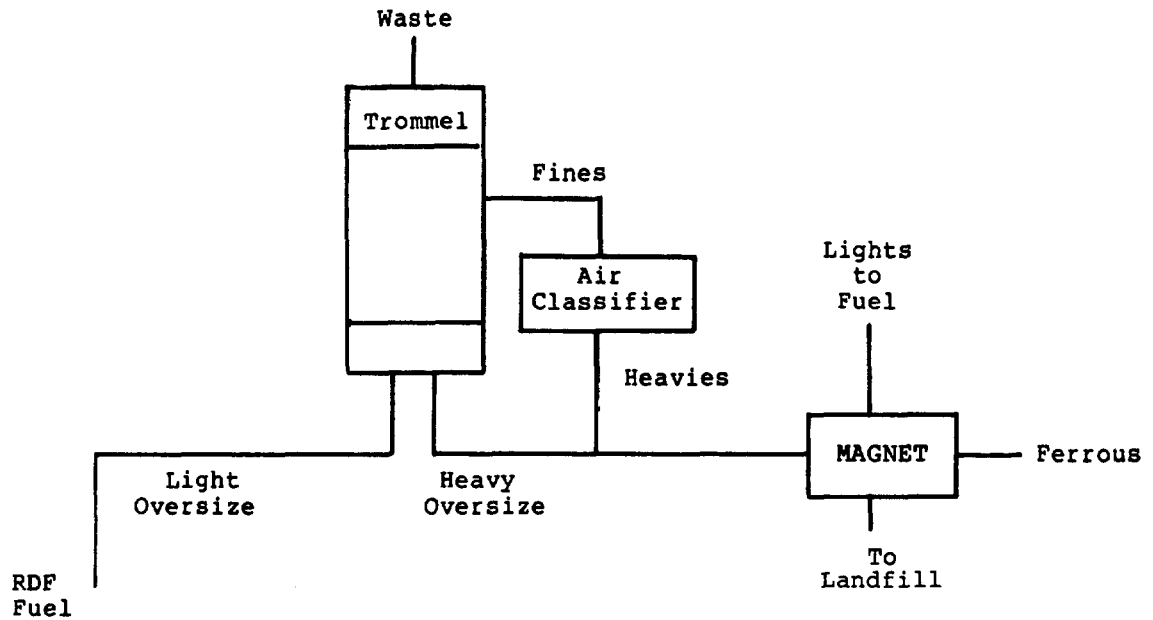
The mobile equipment would also allow for various tests to confirm, or allow for, the modification of initial engineering judgments as to appropriate hole size, belt widths, air velocities and so on, without having incurred the cost of constructing a permanent installation. The permanent plant could come later and the mobile equipment moved to another prospective recovery location.

Technological Description

Figure A-1 depicts the materials flow of the mobile sorting plant. The input is between 10 and 15 tph. The product outputs are a light fraction for RDF, a fine material suitable for composting and ferrous. The light fraction could be charged directly as a boiler fuel if the heat exchanger is on site. Otherwise the "fluff" could be baled and transported to the user facility. The fuel could also be densified, either on site or at a central location.

The first unit process is a horizontal rotating drum consisting of three processing stages. The first is an opening and breaking stage in which bags are opened and the contents are liberated, and in which glass and dense plastics are partly broken or crushed. At this point the drum is solid. This changes to a screen with 25 mm holes, the purpose of which is to screen out fine material, much of which is noncombustible. The third section of the trommel is also solid. Here the light plastics and paper are drawn out of the waste stream and deentrained in a cyclone.

The screened oversize consists mainly of metals, glass, larger sized inert material, and hard plastics. A magnet removes the ferrous, both from this stream and from the fines that were extracted in the second stage of the trommel. This fine fraction can also be air classified to blow off the light, mostly combustible fines. These can be added to the fuel fraction.

Figure A-1. Mobile RDF Recovery System (MVU) GermanyTable A-1. Characteristics of Materials: Mobile RDF Recovery System

Characteristics	Screen Undersize*	Screen Oversize	Ferrous Scrap	Untreated Fuel
Percentage by weight	20-55%	5-25%	2-5%	30-45%
Percentage by volume	[15% to 25%]		2-5%	75-85%
Uncompressed pile density	[0.3 t/m ³ to 0.6 t/m ³]		0.3-1.2 t/m ³	0.03-0.06 t/m ³
Particle size	<25 mm	>25 mm		>25 mm

*Depending on the hole size.

Source: Schmidt, P. Eco-BRIQ Processp. 15.

Characteristics of the products are shown in Table A-1. The calorific value of the waste fuel (LHV) is 13-17 GJ/t. Six workers are required to operate and maintain the equipment. The investment cost is estimated to be 2.8 million DM while the operating costs should be approximately 31 DM/t. Twenty-five Kwh/t are required to do the processing.

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Contact

Peter Schmidt
Diplom-Ingenieur
Marketing Und Verkauf
Mannesmann Veba Umwelttechnik GMBH
Sudstr, 41, D 4690 Herne 2,
Federal Republic of Germany
Ph. 023 25/4 30 01
Telex: 820377

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