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GENERATING ENERGY FROM URBAN AND RURAL WASTES IN A SELECTED COUNTRY OF THE ESCWA REGION: THE CASE OF EGYPT

UN ECONOMIC AND SOCIAL COMMISSION
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It should also be recognized that the Energy Programme of the ESCWA Natural Resources, Science and Technology Division, in the course of preparing the study for publication, made extensive use of the paper by Professor El-Halwagi and Mr. M. A. Hamad on "Rural Biogas Technology-Realistic Potential and Prospects in Egypt", which included, *inter alia*, pertinent remarks on the technical and economic viability of biogas projects in rural areas of Egypt.

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INTRODUCTION

The management of urban and rural waste is a multifaceted problem with widespread ramifications. It encompasses the collection, transfer, treatment, resources recovery and disposal of various wastes through the use of appropriate techniques.

Facing such a complex problem through the proper management of urban and rural waste and its utilization for various purposes, especially for generating energy, has become a major concern, particularly in countries where accumulated waste has serious environmental implications. This is primarily owing to the fact that in many countries, the authorities concerned are now fully aware that the utilization of waste, mainly as an alternative source of energy, also represents a viable means for conserving fossil fuel, preserving the quality of the environment and resolving a critical waste disposal problem.

In view of the importance of the issue and of the interest expressed by several countries of the region in the utilization of waste for energy generation, the ESCWA Natural Resources, Science and Technology Division has been undertaking activities that cover various aspects of the management of urban and rural waste, and suitable technologies for the utilization of this waste for energy generation. Among the main activities in that direction is programme element No. 3.2 on "Generating energy from urban and rural wastes in a selected country of the ESCWA region", which has been implemented in the form of a technical publication as part of the ESCWA programme of work and priorities for 1986-1987.

As a start, this publication is limited to the case of one ESCWA country, and Egypt was selected, because of the availability of expertise and information on the country, to be the subject of an assessment of the potential of urban and rural waste and its utilization for energy generation.

The publication first examines the different sources and types of urban and rural waste, the required technologies for generating energy from this waste, and the various economic, environmental, social, ecological and technical considerations related to the production of energy from it. It then goes on to elaborate on the specific case of Egypt and undertakes, to the fullest extent possible, a global assessment of the potential of waste in both urban and rural areas, the appropriate technologies to be used for generating energy and the prospects of their applications in the country.

In this publication, a number of projects are identified with the objective of promoting the utilization of urban and rural waste for the production of energy. The options presented are essentially based on the findings of the study and the accumulated experience of a number of countries in the field of waste management and treatment. They can, however, be of great interest to several other ESCWA countries which have similar conditions and to those willing to benefit from recent technology for generating energy from urban and rural waste.

I. WASTE MANAGEMENT AND TREATMENT

A. Municipal solid waste (MSW)

Solid wastes are all wastes generated by human and animal activities and that are discarded in a solid form. MSW refers to solid wastes in an urban setting, including residential, commercial and institutional sources, together with demolition and construction wastes, street sweepings, and garden waste.

Solid wastes are generally defined as those solid or semi-solid materials that are discarded at the source of generation because they are no longer of sufficient value to retain. However, they may be of significant value in another setting, whereby efforts can be made to make use of them. Indeed, economics can even change the situation to the extent that certain types of solid waste like newspapers and glass bottles may be of sufficient value at the point of generation to warrant their separation and retention for either reuse or sale to an outside agent.

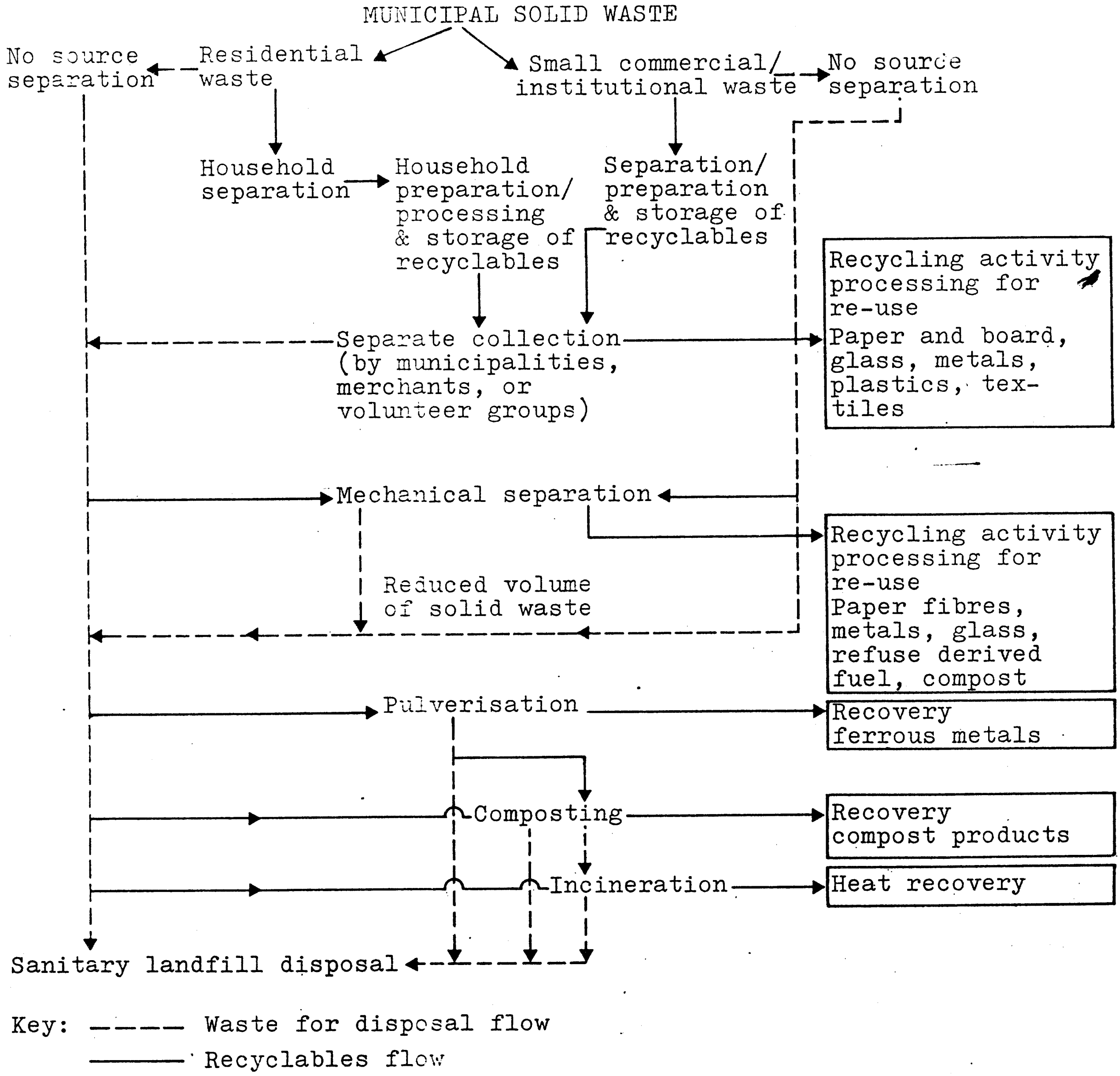
MSW management is an integrated system associated with the functional elements of waste generation, on-site storage, transfer and transport, processing and recovery and final disposal. It is a multidisciplinary activity that involves engineering principles, economics, urban and regional planning, public health and environmental aspects, as well as social considerations relating to public attitudes and concerns. It is also a highly dynamic field in which there is no ideal method for the solution of all the problems and issues that arise (1). In each situation, technical options and alternative management systems are worked out and then assessed and ranked in terms of cost-effectiveness, in order to provide the decision maker with a rational basis for selection. In effect, the scope of solid waste management embodies all the administrative, financial, legal, planning and engineering functions involved in the whole spectrum of solutions to the problems of solid wastes that are thrust upon the community by its inhabitants. Figure 1 shows a simplified municipal waste management system (2).

The quantity and quality of solid wastes generated in municipalities vary with the type of the society, the standard of living, habits of the people, climate and seasons. They also continue to change over time, and so the designer of solid waste facilities must be aware of these trends in order to make reliable projections that will allow the design of facilities that can remain functional and efficient over their estimated useful life. Table 1 gives the breakdown of municipal waste into its components, showing their relative percentage by weight (3), while table 2 gives the composition of solid wastes from urban sources.

B. Sewage solids

Municipal sewage is principally water, more than 99.8 per cent, with the remaining materials being in suspension or in a solution. It contains organic solids that must be filtered, treated or removed in order to abate

Figure 1. Simplified municipal waste management system



Source: OECD. Household Waste: Separate Collection and Recycling, Paris, 1983.

Table 1. Composition and analysis of composite municipal solid waste

Components	Percentage by weight
Corrugated paper boxes	23.38
Newspapers	9.40
Magazine paper	6.80
Brown paper	5.57
Mail	2.75
Paper food cartons	2.06
Tissue paper	1.98
Wax cartons	0.76
Plastic coated paper	0.76
Vegetable food wastes	2.29
Citric rinds and seeds	1.53
Meat scraps, cooked	2.29
Fried fats	2.29
Wood	2.29
Ripe tree leaves	2.29
Flowering garden plants	1.53
Lawn grass, green	1.53
Evergreens	1.53
Plastics	0.76
Rags	0.76
Leather goods	0.38
Rubber composition	0.38
Paint and oils	0.76
Vacuum cleaner catch	0.76
Dirt	1.53
Metals	6.85
Glass, ceramics, ash	7.73
Adjusted moisture	9.05
Total	100.00

Source: P. N. Cheremisinoff and A. C. Morresi, Energy from Solid Wastes, (New York, Marcel Dekker, Inc., 1976).

Table 2. Composition of solid wastes from urban sources

Urban sources	Waste	Composition
Domestic, household	Garbage	Waste from the preparation, cooking and serving of food; market waste from the handling, storage and sale of food.
	Rubbish, trash	Paper, cartons, boxes, barrels, wood, excelsior, tree branches, yard trimmings, metals, tin cans, dirt, glass, crockery, minerals.
	Ashes	Residue from fuel and combustion of solid wastes.
	Bulky wastes	Wood furniture, bedding, dunnage, metal furniture, refrigerators, ranges, rubber tyres
Commercial, institutional hospital, hotel, restaurant, stores, offices, markets	Garbage	Same as domestic
	Rubbish, trash	Same as domestic
	Ashes	Same as domestic
	Demolition waste, urban renewal, expressways	Lumber, pipes, brick masonry, asphaltic material and other construction materials from razed buildings and structures
	Construction waste, remodelling	Scrap lumber, pipe, concrete, other construction materials
	Special waste	Hazardous solids and semi-liquids, explosives, pathologic waste, radioactive waste.
Municipal, streets, pavements, alleys, vacant lots, incinerators, power plants, sewage treatment plants, lagoons, septic tanks	Street refuse	Sweepings, dirt, leaves, catch basin dirt, contents of litter receptacles, etc.
	Dead animals	Cats, dogs, horses, cows, marine animals, etc.
	Abandoned vehicles	Unwanted cars and trucks left on public property

Table 2. (Cont'd)

Urban sources	Waste	Composition
	Fly ash, incinerator residue, boiler slag	Boiler house cinders, metal scraps, shavings, minerals, organic materials, charcoal, plastic residues
	Sewage treatment residue	Solids from coarse screening and grit chambers, and sludge from settling tanks

Source: P. N. Cheremisinoff and A. C. Morresi, Energy from Solid Wastes, (New York, Marcel Dekker Inc., 1976).

environmental pollution and to recycle water. These solids can also constitute an important fuel or energy source. Energy recovery technologies are generally similar to those pertaining to MSW. In developed countries, energy recovery systems constitute a standard feature in sewage treatment plants. The most frequently found method is the anaerobic digestion of sewage sludge (biogas technology).

Sewage treatment involves a variety of processing combinations that depend on the composition and characteristics of raw sewage, the reuse and ultimate disposal of liquid effluent and solid sludge, together with financial constraints. Depending on conditions, the sewage treatment scheme can embody preliminary, primary, secondary and tertiary treatment. Normally, as a minimum, preliminary treatment is undertaken whereby the initial screening of floatage and the removal of grit is effected. This may be followed by primary treatment in which a large portion (50-60 per cent) of the suspended solids that will settle are removed in a form called a "primary sludge". The "primary effleunt" can then undergo a secondary treatment that is often biological in nature (as in the case of the activated sludge method, for instance). A " secondary sludge" is thereby produced. The secondary effluent may then undergo tertiary treatment, which can be something as simple as a disinfection process like chlorination, or it may take the form of more elaborate techniques that will produce a product of drinking-water quality. In this, or even in the previous stages, chemicals may be added to improve the removal of suspended solids or to precipitate some undesirable impurities. Under these circumstances a "chemical sludge" is formed.

Depending on the source of sewage, whether or not it is combined with industrial waste water and storm water, and the type of additives that are used during the treatment processes, almost any element can be found in sludge (4, 5 and 6). Primary sludge contains solids present in the raw waste water (except for those separated from it during preliminary treatment, including screened large-size solids and grit-heavy inorganic solids), while secondary sludge contains chemical or biological solids. The specific gravity of inorganic solids is about 2 to 2.5, while that of the organic portion is 1.2 to 1.3.

Primary sludge is a grey, slimy material with an offensive odour. In comparison with secondary biological waste, primary sludges thicken and de-water readily because of their fibrous and coarse nature.

The liquid waste sludge withdrawn from primary and secondary processing amounts to approximately 2 litres/person/day, and has a solid content of 5 per cent by weight. These figures are indicative, since the quantity and nature of the sludge generated relate to the character of the raw waste water and processing scheme employed.

The elemental composition of various sludges also differ widely. If sludges are to be reused, they need to be analyzed to establish the presence of a number of elements, particularly trace elements such as cadmium, chromium, copper, lead, nickel and zinc, as well as nitrogen, phosphorus and potash. Normally, reported sludge compositions also include a proportion of certain toxins such as pesticides and polychlorinated biphenyls (PCBs), and have a number of other common characteristics such as PH; total dry and volatile solids content, specific gravity, biochemical oxygen demand (BOD), chemical oxygen demand (COD), cellulose, hemicellulose and lignin properties and a heating value.

C. Industrial wastes

Aside from particulate matter-laden gaseous emissions, industrial wastes are composed of waste water and solid wastes. The treatment of industrial waste water also produces sludges that are classified as semi-solid materials. Waste effluent from modern complex industries can be classed as organic and inorganic or biological and non-biological. Sludges can either be organic, in a raw form or after being stabilized by digestion, or inorganic when they may contain numerous chemical pollutants.

Waste from living or previously live sources is called biological waste (7), in contrast to waste that emanates from non-living, non-biological sources. Biological waste can include discharges from tanneries, paper mills, food manufacturing plants, slaughterhouses and textile plants. Non-biological waste includes that from metal-plating industries, sheet metal industries, etc. Most of these plants discharge what are commonly referred to as "spent chemicals" into the plant effluent, and these can either be organic or inorganic.

1. Gaseous emissions (8)

The term "industrial gaseous emissions" covers gaseous pollutants including true gases such as sulphur dioxide, carbon monoxide and nitrogen oxides, vapours such as gasoline and solvents and particulate matter (finely divided liquids and solids) such as mists, fogs, and aerosols, dust, fumes and smoke.

Four methods are commonly used to control gaseous emissions: absorption, adsorption, combustion and condensation. Particulate emissions can be controlled by mechanical collectors, wet scrubbers, electrostatic precipitators and fabric filters.

2. Waste water and sludges (8)

Industrial waste water includes:

- Domestic waste water that is produced by plant workers, shower facilities and cafeterias;

- Process waste water resulting from spills, leaks and product washing;

- Cooling waste water that is associated with various cooling processes.

Domestic waste water is handled by the normal sanitation system. Cooling waste water poses few pollution concerns as it can be recycled or disposed of safely, unless it is contaminated by process waste water as a result of leaks in the cooling system. Process waste presents the most serious potential hazard to the environment.

Table 3. Sources and types of industrial wastes

ISIC code	Group classification	Waste-generating processes	Expected specific wastes
311	Food and kindred products	Processing, packaging, shipping	Meats, fats, oils, bones, offal, vegetables fruits, nuts and shells, cereals
321	Textile mill products	Weaving, processing, dyeing, shipping	Cloth and filter residues
322	Apparel and other finished products	Cutting, sewing, sizing, pressing	Cloth, fibres, metals, plastics, rubber
331	Lumber and wood products	Sawmills, millwork plants, wooden containers, miscellaneous wood products, manufacturing	Scrap wood, shavings, sawdust. In some instances, metals, plastics, fibres, flues, sealers, paints, solvents
332	Furniture, wood	Manufacture of household and office furniture, partitions, office and store fixtures, mattresses	Those listed under code 331. In addition, cloth and padding residues
3812	Furniture, metal	Manufacture of household and office furniture, lockers, springs, frames	Metals, plastics, resins, glass, wood, rubber, adhesives, cloth, paper
341	Paper and allied products	Paper manufacture: conversion of paper	Paper and fibre residues, chemicals, paper coatings and fillers, inks, glues, fasteners
342	Printing and publishing	Newspaper publishing, printing, lithography, engraving, bookbinding	Paper, newsprint, cardboard, metals, chemicals, cloth, inks, glues
351	Chemicals and related products	Manufacture and preparation of inorganic chemicals (ranging from drugs and soaps to paints, varnishes and explosives)	Organic and inorganic chemicals, metals, plastics, rubber, glass, oils, paints, solvents, pigments
353	Petroleum refining and related industries	Manufacture of paving and roofing materials	Asphalt and tars, felts, asbestos, cloth, fibre
355	Rubber and miscellaneous plastic products	Manufacture of fabricated rubber and plastic products	Scrap rubber and plastics, lamp back, curing compounds, dyes
323	Leather and leather products	Leather tanning and finishing, manufacture of leather belting and packing	Scrap leather, thread, dyes, oils, processing and curing compounds

Table 3. (Continued)

ISIC code	Group classification	Waste-generating processes	Expected specific wastes
361) 362) 3691)	Stone, clay and glass products	Manufacture of flat glass, fabrication or forming of glass; manufacture of concrete, gypsum, and plaster products, forming and processing of stone and stone products, abrasives, asbestos, and miscellaneous non-mineral products	Glass, cement, clay, ceramics, gypsum, asbestos, stone, paper, abrasives
37	Primary metal industries	Melting, casting, forging, drawing, rolling, forming, and extruding operations	Ferrous and non-ferrous metals, scrap, slag, sand, cores, patterns, bonding agents
381	Fabricated metal products	Manufacture of metal cans, hand tools, general hardware, non-electrical heating apparatus, plumbing fixtures, fabricated structural products, wire, farm machinery and equipment, coating and engraving of metal	Metals, ceramics, sand, slag, scale, coatings, solvents, lubricants, pickling liquors
384	Transportation equipment	Manufacture of motor vehicles, truck and bus bodies, motor vehicle parts and accessories, ship and boat building, repairing motorcycle and bicycle, and parts, etc.	Metal scrap, glass, fibre, wood, rubber, plastics, cloth, paints, solvents, petroleum products
385	Professional scientific controlling instruments	Manufacture of engineering, laboratory, and research instruments and associated equipment	Metals, plastics, resins, glass, wood, rubber, fibres, abrasives
390	Miscellaneous manufacturing	Manufacture of jewellery, silverware, plated ware, toys amusements, sporting and athletic goods, costume novelties, buttons, brooms, brushes, signs advertising displays	Metals, glass, plastics, resins, leather, rubber, composition, bone, cloth, straw, adhesives, paints, solvents

Source: Chemical Engineers' Handbook, 6th ed., R. H. Perry and C. H. Chilton, eds., (New York, McGraw-Hill Book Co., 1984), and United Nations Industrial Classification of All Economic Activities, (ST/STAT/SER.M/4/Rev.2), (New York, 1968).

Table 4. Typical density and moisture content data for industrial solid wastes

Item	Density, (kg/cu m)		Moisture content, percentage by mass	
	Range	Typical	Range	Typical
Chemical sludges (wet)	800-1 100	1,000	75-99	80
Fly ash	700- 900	800	2-10	4
Leather scraps	100- 250	160	6-15	10
Metal scrap (heavy)	1,500-2,000	1,780	0-5	-
Metal scrap (light)	500- 900	740	0-5	-
Metal scrap (mixed)	700-1,500	900	0-5	-
Oils, tars, asphalts	800-1,000	950	0-5	2
Sawdust	100- 350	290	10-40	15
Textile wastes	100-220	180	6-15	10
Wood (mixed)	400-675	500	10-40	20

Source: Chemical Engineers' Handbook, 6th ed., R. H. Perry and C. H. Chilton, eds., (New York, McGraw-Hill Book Co., 1984), chap. 26.

Table 5. Unit solid waste generation rates for selected industrial sources

Source	Unit	Range
Canned and frozen foods	Metric tons/metric tons of raw products	0.04-0.06
Printing and publishing	Metric tons/metric tons of raw paper	0.08-0.10
Automotive	Metric tons/vehicle produced	0.6 -0.8
Petroleum refining	Metric tons/employee/day	0.04-0.05
Rubber	Metric tons/metric tons of raw rubber	0.01-0.5

Source: Chemical Engineers' Handbook, 6th ed., R. H. Perry and C. H. Chilton, eds., (New York, McGraw-Hill Book Co., 1984, chap. 26.

Many industrial waste water streams need to be pre-treated on site prior to discharge into municipal sewerage systems, or even into a central industrial sewerage system. Pre-treatment of industrial waste water can be followed by primary treatment and then by secondary (biological) or physical-chemical treatment. The sludge that forms is subsequently processed, reused or disposed of.

3. Industrial solid wastes (8)

In the process of manufacturing products from raw materials, industries produce much waste material. Some of this can be recycled internally, but the rest has to be disposed of. Industrial solid wastes contain conventional waste that can be handled, treated and disposed of in ways similar to those described above under MSW. Such wastes embody food waste, paper, plastics, rubber, leather, textiles, wood and other energy-carrying residues, metals, glass, ceramics, ash, rocks and dirt. The sources and types of industrial solid wastes generated, as grouped by the International Standard Industrial Classification (ISIC), are reported in table 3. Typical density and moisture-content data are given in table 4, while the typical unit waste-generation rates for selected industrial sources are presented in table 5.

In addition to conventional waste, hazardous wastes (8 and 9) are generated in limited amounts throughout most industrial activities. Such wastes can pose substantial danger to human, plant or animal life, immediately or over a period of time. They may exhibit one or more of the following characteristics: ignitability, corrosiveness, reactivity and toxicity. Hazardous wastes warrant special handling, treatment and disposal, and in addition, they should be clearly labelled.

D. Agricultural and agro-industry residues

Residues from agriculture and agro-industries can be considered to be the unused outputs from the growing and processing of raw agricultural products such as fruits, vegetables, meat, poultry, fish, milk, grain and trees. These residues may contain materials that can be of benefit to human beings but their economic value is less than the apparent cost of collection, transportation and processing for any beneficial use. Therefore, they are discharged as waste. If residues can be utilized for human benefit such as to enhance food production and energy, they would no longer be waste matter but could be considered as a new resource.

Only in a few situations has residue utilization been a component of waste management policy. The traditional focus has been on the treatment and disposal of waste, with the subsequent loss of material and energy resources. This one-time use and disposal of material is a result of policies that were developed earlier when materials and energy were abundant, when there was a lower demand for world food production and energy resources, and when there was less concern about the quality of the environment.

Most developing countries are agrarian, and the majority of the population lives in rural areas. In these areas, the source of livelihood is the production of food or fibre crops, or animal husbandry that is adapted to local soil and climatic conditions. Such countries are interested in ways of raising incomes and living standards. If these objectives are to be met, an increase in food production will be required, together with the optimum use of available resources, particularly residues that currently go unused. Residues can be used to increase local energy supplies, animal production, fertilizers and microbial protein for human or animal consumption, or they can be processed to produce different human or animal foods.

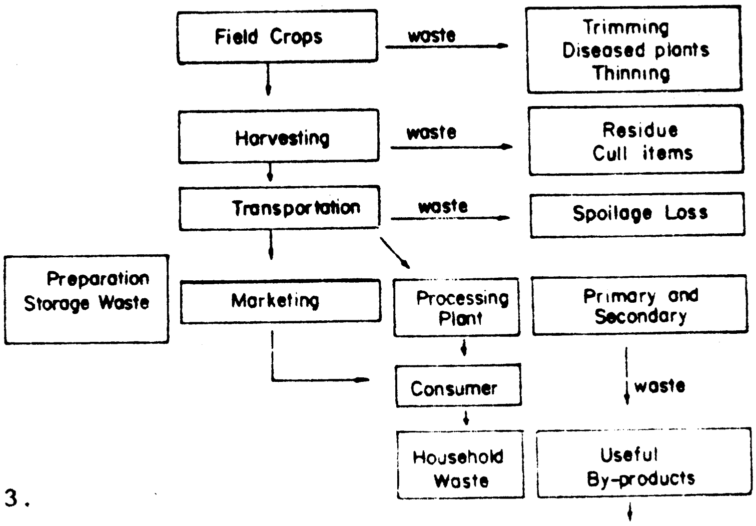
The potential for agricultural and agro-industrial residue utilization requires a knowledge of how and why residues are generated, the characteristics of residues available, and the technology that can be used to exploit them.

1. Residue generation

Man's basic needs include food, fibre, fuel, fertilizer and shelter. Small operations recycle available resources. The basic cycle is one of the land furnishing fuel, fibre, shelter and food in the form of crops and animals for the consumer. In a small agricultural operation, some of the residues resulting from harvesting and processing are used directly by the consumer, while the remainder are returned to the land to be used further for additional crops.

Inexpensive fossil fuel, inorganic fertilizers and greater mechanization have been used to increase agricultural productivity, the food supply and the standard of living in many countries. Therefore, agricultural and agro-industrial residues are no longer utilized as well as they were in small systems, a fact which has become more apparent and has given rise to concern for the environment. The trend towards large-scale agricultural and agro-industrial enterprises continues in all countries. As production increases, so, too, does the size of facilities and the quantity of residues at a specific site. The larger the production unit, the more likely it is that there will be residues that require treatment and disposal; hence, the larger the quantity of residues at the production site, the more necessary it is for the possibilities of residue utilization to be considered. Figure 2 shows the sources of typical agricultural and agro-industrial waste for which table 6 gives the component parts (3).

Figure 2. General agricultural and agro-industrial waste sources



Source: Reference 3.

Table 6. Composition of solid waste from agricultural sources

Agricultural source	Waste	Composition
Farms, ranches, greenhouses, livestock feeders and growers	Crop residue	Cornstalks, tree prunings, pea vines, sugar-cane talks (bagasse), green crop, culled fruit, culled vegetables, rice, barley, wheat and oats stubble, rice hulls, fertilizer residue
	Forest slash	Trees, stumps, limbs, debris
	Animal manure	Ligneous and fibrous organic matter, nitrogen, phosphorus, potassium, volatile acids, proteins, fats, carbohydrates
	Poultry manure	Same as for animal manure
	Animal carcasses, flesh, blood, fat particles, hair, bones, oil, grease	Ammonia, urea, a mines, nitrates, inorganic salts, various organic and nitrogen-containing compounds
	Pesticides, insecticides, herbicides, fungicides, vermicide and microbic residues and containers	Chlorinated hydrocarbons, organic-phosphorus compounds, other organic and inorganic substances, e.g. strychnine and lead arsenate

Source: P. N. Cheremisinoff and A. C. Morresi, Energy and Solid Wastes. (New York, Marcel Dekker Inc., 1976).

2. Residue characteristics

The feasibility of energy production from residues depends on the characteristics of the residues themselves, the quantity that is realistically available, the continuity of the supply, their energy content and the cost of collection and transport. Usually, the information available on the characteristics of agricultural and agro-industrial residues is inadequate.

However, the quantities produced from each particular residue appear to have a relationship with the main end-product that is statistically reported in each country's records (10). From the production ratios given in table 7 it is possible to estimate the quantities for each residue that could be of future economic and environmental importance. Aside from the issues of pollution and economic importance, table 7 also gives a reasonable guideline on the feasibility of setting up a particular process in order to utilize a residue for energy and other end-uses.

Another important aspect of the residues is their physical form, for this is related to their potential end-use. The various forms of residues are given in table 8.

With all these types of residue, there is the question of the dilution factor. In liquids, the dilution factor is usually water, though it could be oil. Similarly with solids the dilution factor could be in the form of inert material such as sand, clay or another inert mineral material, or it could be in the form of contamination such as bark and cork particles, lignum components, or other useful cellulosic residues. One of the most important factors that constrains the use of cellulosic residue is the presence of silica in the material.

The liquid sample is divided into those liquids that contain suspended solids, whether actual solids or immiscible droplets such as oil or colloidal solids, and those without suspended solids.

A slurry, that is solids in a pourable liquid mixture, is a very common form of residue, but it can be one of the most difficult to process. A typical slurry is cow dung, but others may be high mineral slurries in the form of sludges from industrial processing.

A difference in structured and unstructured solids is that the former may require commutation or separation on the basis of particle size. This may result in the separation of the physical and chemical characteristics of the components.

E. Energy content of urban and rural wastes

The per capita production of municipal waste varies from one country to another. In a developed country like the United States of America, per capita production has been estimated at approximately one per person. Table 9 shows the heating values and the moisture content of the components of combustible municipal refuse. Composite municipal waste generally has a heating value of between 2,500 and 3,611 kcal/kg. Heating values in general can be raised by some kind of drying process.

Table 7. Production ratios of by-products/residues

Oil palm (crude mill)

A. Crude oil	1.000
Fresh fruit bunch	5.000
Effluent (6 per cent solids)	2.750
Presscake fibre	0.605
Kernel	0.210
Kernel oil	0.085
Kernel cake	0.085
Kernel shell	0.235
Empty bunch	1.200
Sludge oil	0.050-0.150
Sludge solids (12 per cent H_2O)	0.138
Methane production	76.2m
B. Fresh fruit bunch	1.000
Crude oil	0.200
Effluent (6 per cent solids)	0.550
Presscake fibre	0.122
Kernel	0.042
Kernel oil	0.017
Kernel cake	0.017
Kernel shell	0.047
Empty bunch	0.240
Sludge oil	0.006-0.030
Sludge solids	0.078
Methane production	380.9m

Sugar-cane (raw mill)

A. Sugar-cane	1.000
Sugar	0.080-0.120
Bagasse	0.289
Tops	0.099
Molasses	0.280-0.370
Mud	0.020-0.050
Waste water	0.096
B. Molasses	1.000
Alcohol	0.270
Stillage	2.700
Cooling water	5.400
C. Sugar-cane	1.000
Alcohol	0.088
Bagasse	0.280
Stillage	0.880
Cooling water	1.760
D. Molasses	1.000
Sugar-cane	4.366
E. Alcohol	1.000 litre
Sugar-cane	15.900 kg
Molasses	3.642 kg
Cooling water	0.1140 m^3
Stillage	0.0570 m^3

Cassava

A. Chips	1.000
Tons chips	1.000
Fresh root	4.630
Recovery	21.6%
B. Starch	
Starch	1.000
Pulp	7.536
Peelings	0.480
Fresh root	5.000
Wash water	22.680
Fruit water	4.400
C. Alcohol	
Alcohol	1.000
Pulp	9.248
Wash water	12.335
Peelings	1.068
Cooling water	12.105
Stillage	8.203
Fresh root	7.519

Coconut

Copra	1.000
Nuts (1.2 kg)	2.898
Husk	0.944
Shell	0.438
Dessicated Coconut (360 gm/1.2 kg nut)	0.870
Coconut oil	0.630
Copra cake	0.260
Coir	0.197

Rubber

Any rubber	1.000
Liquid effluent	24.450
Rubber seed	0.080
seed meal	0.018
seed shells	0.028
seed oil	

Rice

Padi	1.000
Straw	2.600-3.960
Bran	0.050-0.080
Husk	0.200-0.250
White rice	0.690-0.740
Bran oil	0.010-0.130

Maize

Table 7. (Continued)

Coconut		Rubber	Rice	
Coconut water	0.533		Grain	1.000
			Stem	3.200-4.328
Dessicated coconut			Cobs	0.860
Waste water			Husk + skins	1.000
1 ton nuts - 3,850 litres				
1 ton dessicated powder = 12,850 litres				
Coir (1,000 husks = 400 kg produce 87.6 kg coir)				

Source: United Nations Economic and Social Commission for Asia and the Pacific (ESCAP), Technological Aspects of Agricultural and Agro-industrial Residue Utilization.

Workshop on Agricultural and Agro-industrial Residue Utilization in the ESCAP Region, Pattaya, Thailand, 10-14 December 1979.

Table 8. Physical forms of residues

Liquid) with suspended solids)
) without suspended solids) dilute, concentrated

Slurry

Solid) structured
) unstructured

With mineral/dirt contaminant
With toxic metal contamination
With organic toxin contamination
With biological/micro-organism contamination

Hot/ambient
) fermentable
High carbon) non-fermentable

High nitrogen (N)

High potassium (P)

High special nutrient components

High inert fraction (silica/silt/clay)

Source: United Nations Economic and Social Commission for Asia and the Pacific (ESCAP), Technological Aspects of Agricultural and Agro-industrial Residue Utilization, Workshop on Agricultural and Agro-industrial Residue Utilization in the ESCAP Region, Pattaya, Thailand, 10-14 December 1979 (AD/WAAIRU/7).

Numerous industrial wastes have appreciable heating values. Table 10 gives several types of valuable industrial wastes and their respective heating values. Composite industrial solid waste generally has a heating value of between 2,660 and 4,056 kcal/kg (3).

Industrial wastes are different from municipal wastes in that they can be composed of any type of material. Thus the characteristics of a particular waste must be carefully defined before an energy source application can be chosen. The following parameters should be determined:

1. Moisture content;
2. Volatile matter content;
3. Fixed carbon content;
4. Ash content;
5. Heating value;
6. Corrosiveness;
7. Toxicity;
8. Odour;
9. Explosiveness;
10. Flash point;
11. Density;
12. Ash-fusion temperature.

Table 9. Typical moisture content and heating values of municipal refuse components

	Moisture	Percentage kcal/kg
Paper, cardboard, cartons, bags	3	4,255
Wood crates, boxes, scrap	7	4,348
Brush, branches	17	3,967
Leaves	30	2,722
Grass	50	2,122
Garbage	75	1,011
Greenstuff	50	1,988
Greens	50	2,261
Rags, cotton, linen	10	3,578

Source: P. N. Cheremisinoff and A. C. Morresi, Energy from Solid Wastes (New York, Marcel Dekker Inc., 1976).

Table 10. Listing of common wastes with fuel value (average or average range)

	kcal/kg as fired
Gas	
Coke-oven gas	10,945
Blast-furnace gas	632
Carbon monoxide (CO) gas	319
Refinery gas	12,112
Liquid	
Industrial sludge	2,056-2,334
Black liquor	2,445
Sulphite liquor	2,334
Dirty solvents	5,556-8,890
Spent lubricants	5,556-7,778
Paints and resins	3,334-5,556
Oil waste, fuel oil residue	10,001
Solid	
Bagasse	2,000-3,611
Bark	2,500-2,889
General wood wastes	2,500-3,611
Sawdust and shavings	2,500-4,167
Coffee grounds	2,722-3,611
Nut hulls	4,278
Rice hulls	2,903-3,611
Corn cobs	4,445-4,611
Boot, shoe trim and scrap	4,723
Sponge waffle and scrap	4,723
Butyl soles scrap	6,389
Cement wet scrap	6,389
Rubber	6,901
Tyre cord scrap	6,889
Tyres, bus and auto	10,001
Gum scrap	10,945
Latex waste, coagulum waste	6,667
Leather scrap	5,556
Waxed paper	6,667
Cork scrap	6,889
Plastic and synthetic refuse	
Cellophane plastic	6,667
Polyethylene	11,023
Polyvinyl chloride	9,723
Vinyl scrap	9,723
Aldehyde sludge	10,084
Solvent naptha	10,279
Carbon disulphite	4,445
Benzine	5,556

Source: P. N. Cheremisinoff and A. C. Morresi, Energy from Solid Wastes (New York, Marcel Dekker Inc., 1976).

Table 11. Biogas generation potential of dung available from livestock and its energy value in some ESCWA countries

Country	Biogas generation potential (Millions of cu m)	Energy value of biogas (10^9 kcal)
Democratic Yemen	191	1,050
Iraq	1,583	8,706
Jordan	80	440
Lebanon	56	308
Oman	53	291
Saudi Arabia	374	2,057
Syrian Arab Republic	651	3,580
Yemen Arab Republic	946	5,203

Source: Food and Agriculture Organization of the United Nations, FAO Production Yearbook (Rome, 1984), vol.34.

Table 12. Energy values of selected fuels and agricultural residues

Fuel/residue	Moisture content (Percentage)	kcal/kg	kcal/cu.m
Sugar cane bagasse	12	3,860	-
Sugar cane bagasse	52	2,220	-
Rice husks	10	3,340	-
Rice husk charcoal	0	6,111	-
Palm oil fibre	30	1,512	-
Palm oil fibre	10	3,950	-
Palm kernel shell	6	1,960	-
Palm empty bunch	60	560	-
Coconut husks	-	-	-
Coconut husk charcoal	6		
Coconut shell	13	4,010	-
Coconut shell charcoal	6	7,860	-
Diesel No. 1	0	10,878	-
Gasoline	0	11,267	-
Fuel oil No. 2	0	11,183	-
Coal	0	7,215	-
Ethanol	5	9,269	-
Methane	0	13,243	846
Methanol	0	6,383	8,525
Biogas	0	-	5,517
Pyrolysis gas	0	-	4,450
Wood (soft)	10	4,500	-
Coconut stem charcoal (briquette)	0	9,600	-

Source: United Nations Economic and Social Commission for Asia and the Pacific (ESCAP). Technological aspects of agricultural industrial residue utilization, Workshop on Agricultural and Agro-industrial Residue Utilization in the ESCAP Region, Pattaya, Thailand, 10-14 December 1979 (AD/WAAIRU/7).

Agricultural and agro-industrial wastes and animal dung have been and are still used as energy sources. Table 11 shows the biogas that can be produced from dung and gives its energy value in some ESCWA countries (11). Table 12 gives the energy values of residues and traditional fossil fuels to facilitate the evaluation of the potential energy balance in any modification or new design for an industry using these crops as an energy source (10).

For both municipal and industrial waste the moisture content will have an important effect on the resultant energy recovery and downstream use of the reject heat. However, the effect of carbonization to produce charcoal not only leads to the production of a higher energy value, but also eliminates the problem of air pollution and contaminants that can result from combustion if the direct firing of the drying system is used to improve the efficiency of energy consumption.

Another source of energy that is normally neglected is the reject heat from a particular system. Most low calorific fuel boilers up until now have been designed to consume as much available fuel (bagasse or rice husks) as possible. Hence, these boilers have a very low efficiency rate with the result that about 50 to 60 per cent of the available energy is wasted. The wasted energy is in the form of flue gases that in an induction-fired boiler can reach 350-400 degrees Celsius possessing a moisture load that depends on the water content of the input material. Other sources of waste energy are in the form of unused heat from condenser cooling water or air, depending on the design of the power plant.

II. TECHNOLOGIES FOR ENERGY PRODUCTION FROM WASTE

Various processes are currently in use to produce energy from waste. Figure 2 shows the various steps in energy recovery technology (12) where two groups can be identified: material separation and chemical conversion. Material separation is the physical separation and/or classification of the various components of solid waste without changing their chemical make-up with the aim of preparing them for further physical change, chemical conversion or disposal. Some of the many techniques that could be included in the first group are shredding, magnetic separation, density separation, screening, non-ferrous separation and various wet processes that use water as a transport fluid.

There is a second group under the category of chemical conversion. This group uses techniques that change the chemical make-up of either processed or unprocessed waste for the purpose of recovering heat released in the chemical reaction, and/or changing the waste into a more accessible form. Pyrolysis and bioconversion are included in this group, together with direct combustion. Figure 3 shows the various methods of waste utilization for energy production.

A. Thermal processes (13)

When MSW is subjected to thermal processing, a mixture of solid, liquid and gaseous fractions are produced depending on the processing conditions. According to the amount of air, thermal processes can be divided into the following categories: combustion, gasification and pyrolysis.

1. Combustion

The combustion of MSW is a process of oxidation with oxygen in air that is commonly associated with the vigorous evolution of light and heat. Products that involve complete combustion are carbon dioxide, water, sulphur dioxide and nitrogen. The combustion of MSW can take place in open fires and by incineration.

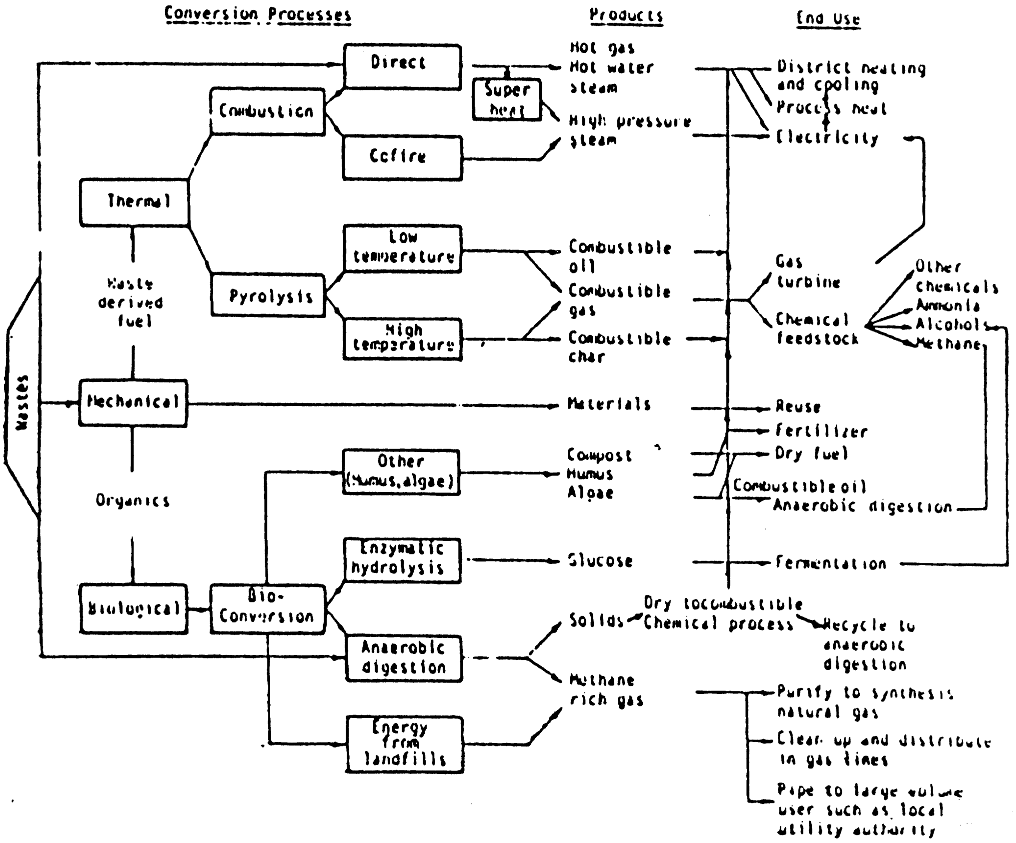
(a) Open fires

The disposal of solid waste in open fires has been practised since the creation of mankind. Although burning is one of the most hygienic ways of disposing of refuse, combustion gives rise to flue gases, particulate matter and odour that produce an unacceptable level of air pollution. Nevertheless, it is still used on a wide scale in both urban and rural areas.

(b) Incineration

Incineration is the controlled combustion of MSW. It is a well established technology that can claim over a century of operating experience. The principles of incineration are very simple: refuse burns at temperatures of between 900 and 1,000^{o} C. Odourless flue gases can only be guaranteed if the combustion gases pass through a zone of temperatures high enough to eliminate smell, i.e. about 800^{o} C. The hot gases must also be cooled to about 300^{o} C, and cleaned before they are discharged into the atmosphere. A

Figure 3. Various methods of waste utilization for energy production



Source: Reference 12.

process chart and a schematic flow of a waste incinerator are given in figures 4 and 5 respectively. The waste is transferred to a refractory furnace designed to ensure complete combustion. This is achieved through the proper control of temperature, excess air, gas turbulence, time spent in the hot zone, and burn-out time of the ash before discharge. After cleaning the gases and vapours are suitable for discharge into the atmosphere. The inorganic ash can be processes further in order to recover materials for use as hard core or landfill.

Heat may be recovered for use as steam or electricity.

(c) Types of incinerators

Various types of incinerators have been developed. They can be classified into continuous grate direct incinerators and the recently proposed simple batch-loaded modular incinerators. Grate incinerators include the following types:

(i) Multiple-chamber incinerator;
(ii) Multiple-hearth incinerator;
(iii) Rotary kiln;
(iv) Fluidized bed incinerator;
(v) High temperature slagging incinerator;
(vi) Suspension-fired incinerator.

The modular-controlled air incinerator has two combustion chambers in which the air to fuel ratio is closely regulated. In the primary chamber refuse is ignited and burned in an oxygen deficient atmosphere. Most of the organic material decomposes into small volatile molecules. Unburned organic material together with the exhaust pass under low turbulent flow conditions to a secondary chamber where combustion in an excess-air environment takes place. Auxiliary fuel (usually fuel oil or gas) can be used in the secondary chamber in order to promote complete combustion at temperatures of between 1,000 and 1,200° C. Particulate emissions from a controlled air incinerator usually fall within standard limits of air pollution. The combustion of organic material is fairly complete and the entrainment of inorganic material by low turbulence in the primary chamber is minimized. Conversely, the traditional uncontrolled single combustion chamber incinerator usually requires the addition of an expensive wet scrubber or electrostatic precipitator in order to meet air pollution codes. Modular incinerators which have a capacity of about one ton per hour (ton/h) for each module are available.

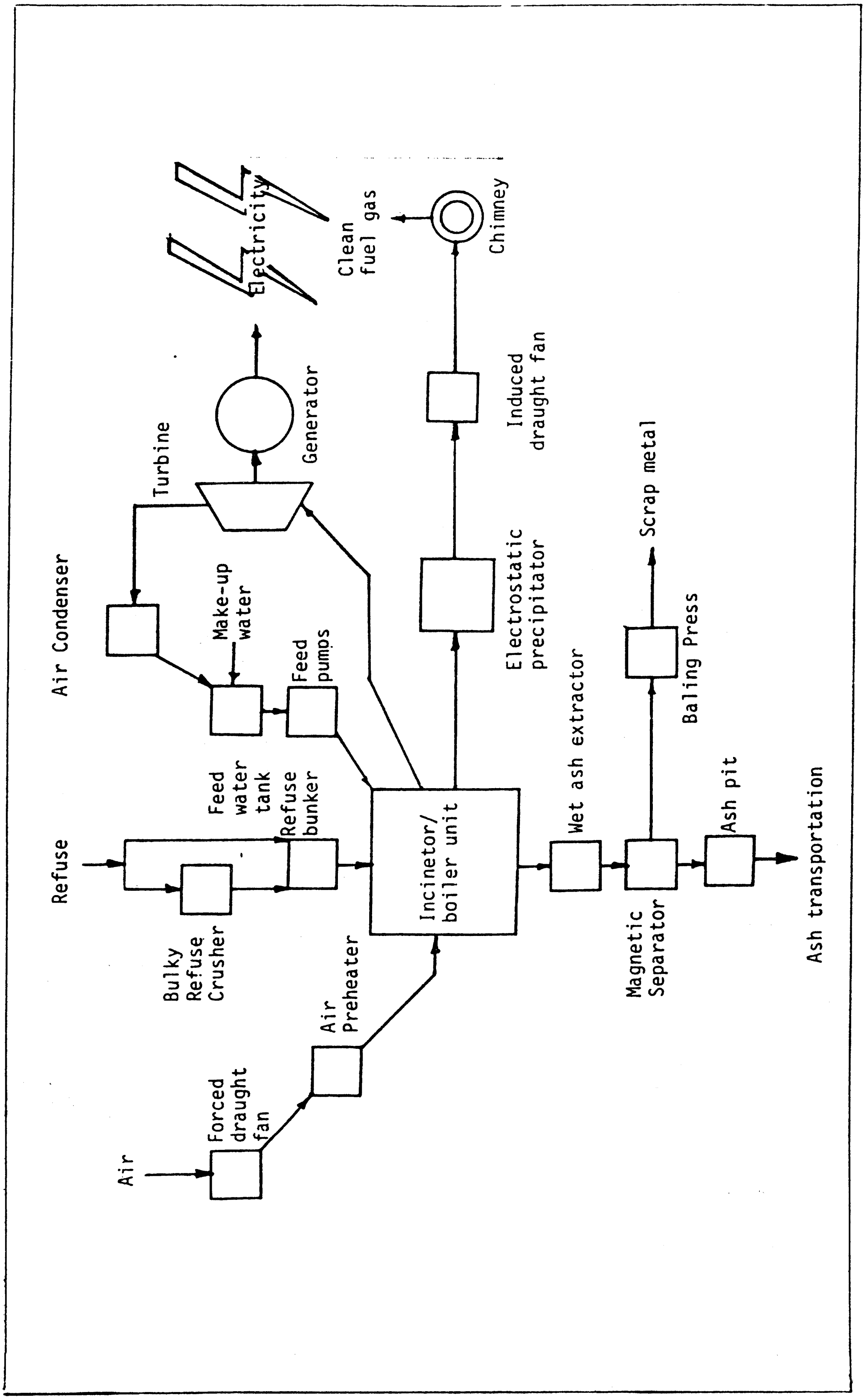
The approximate overall material balance for a modern direct incinerator can be represented as follows:

(i) Moisture and combustion products	68 per cent;
(ii) Fly ash	2 per cent;
(iii) Residue	30 per cent.

(d) Heat utilization

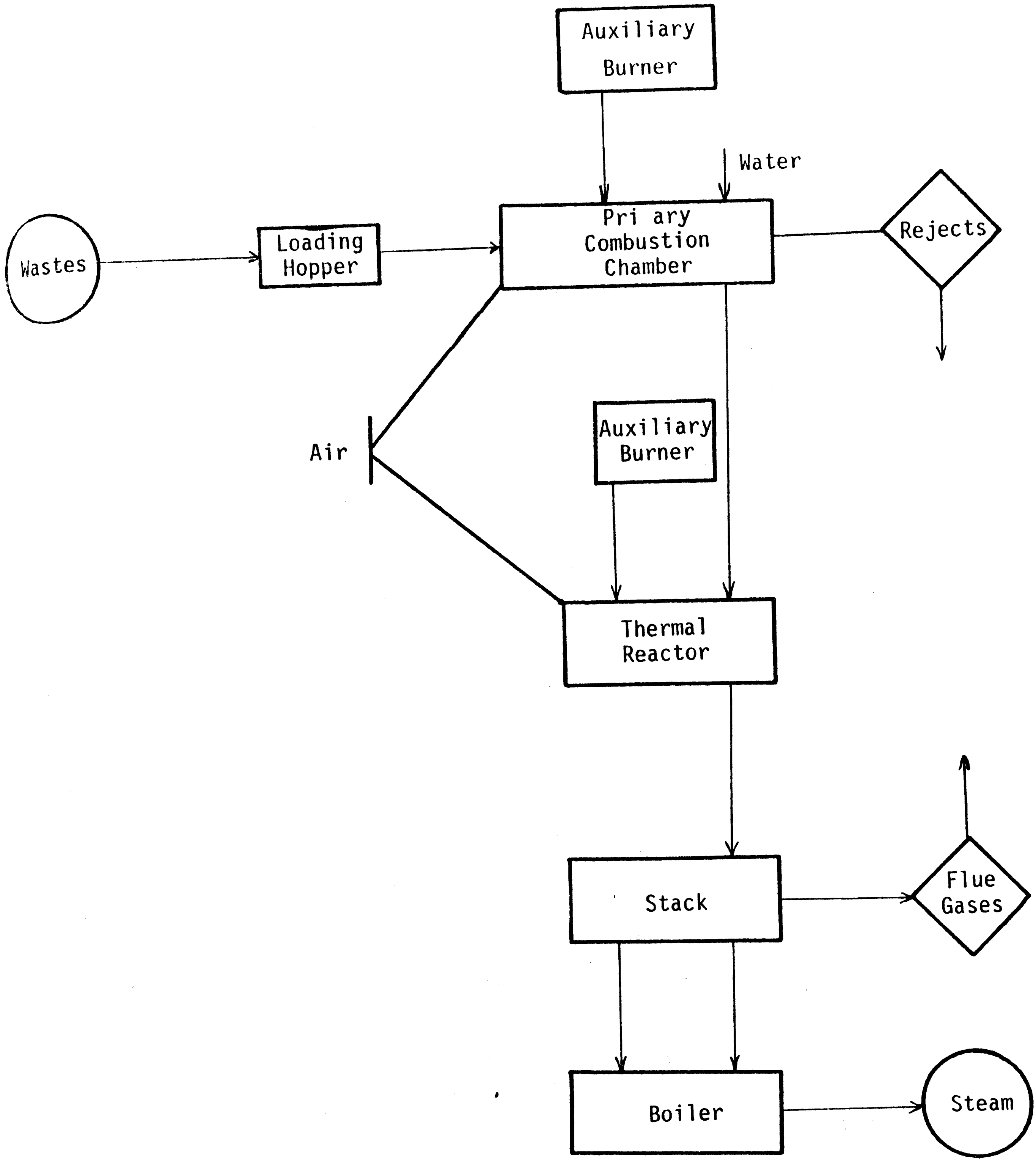
The calorific value of MSW in developed countries is about 2,200 kcal/kg. In developing countries where the paper and plastic content of waste is low, the calorific value may be as low as 1,400 kcal/kg.

Figure 4. <u>Process chart of a refuse incineration plant</u>



<u>Source:</u> Reference 12.

Figure 5. Simplified block diagram of modular incineration with energy recovery



The heat generated in incineration can be utilized to raise steam, and this can be used directly in order to drive process equipment or for heating, or indirectly to generate electricity. Heat may be recovered through water-cooled walls in the upper part of the furnace and/or by passing the hot gases through a heat exchanger. Heat recover efficiency ranges from 55-70 per cent. The net heat recovery from electricity generation is about 14-22 per cent.

The most serious problem hindering the spread of heat recovery is the difficulty in ensuring a steady market. Steam or electricity must be used directly, as it is produced, for there is no possibility of storing it.

Various developments for MSW incinerators have been proposed. The preparation of the waste into refuse-derived fuels (RDF) (as described below) before incineration allows the use of more sophisticated furnaces. However, increased sophistication does not necessarily produce increased energy efficiency.

2. Other thermal processes

These essentially include pyrolysis and gasification. Pyrolysis is the thermal degradation of organic materials in the absence of air to yield solid, liquid and gaseous fuels. Gasification describes the reaction of organic compounds with a smaller volume of oxygen or air than would be required to ensure the complete combustion involved in pyrolysis. Gasification generally yields a fuel gas diluted with combustion products and nitrogen.

A great variety of processes for the thermal treatment of MSW have been proposed. However, relatively few of these have reached the pilot plant stage, and none have been successfully proved on a large commercial scale.

Principles. When MSW or RDF are used as feedstock for thermal processing, a mixture of solid, liquid and gaseous fractions are produced, depending on process conditions. A large number of reactions may take place simultaneously. The relative yield of the various products can generally be regulated through the control of the environment within the reactor.

The main controlling parameter is temperature. Control is exercised through many process variables including the mode of heat transfer, the direction of evolved gas flow, the rate of heating, the particle size of feedstock, operating pressure or the use of catalysts.

Reactor designs can be classified into three categories: vertical flow, horizontal flow and dilute-phase reactors.

The major products and optimum conditions for their production are as follows:

(a) Solid char, mainly of carbon. This is a low-grade fuel, often burnt in order to provide heat for pyrolysis reactions. At high operating temperatures, and in the presence of some oxygen, the char is completely gasified in the reactor.

(b) Ash or slag produced as a residue, which can be used either as landfill or an aggregate.

(c) Liquid products that separate into two fractions: an aqueous solution that contains highly oxygenated compounds and a tarry oil, mainly consisting of oxygenated hydrocarbons. The production of oil can be maximized by the application of a low operating temperature (about 500° C), and a short retention time.

(d) Gaseous products vary greatly, depending on process conditions. Optimum yields of carbon monoxide, hydrogen and methane occur at about 1,000° C. Calorific values vary between 1,000 and 5,000 kcal/cu m, depending on product dilution.

Much work remains to be done to understand the complex chemistry and to optimize process conditions that will yield the desired products.

B. Mechanical processing

Several alternative or complementary technologies have been developed for the mechanical processing of MSW in order to recover salvageable materials and/or to facilitate further treatment or disposal. These include physical separation, baling, pulverization and the production of RDFS.

1. Physical separation

Physical methods of separation can be applied to solid waste by utilizing existing or induced differences in the physical properties of the materials to be separated.

The major differences in physical properties through which solid waste can be separated are variations in size, shape, bulk density, magnetic susceptibility, electrical conductivity, colour, brittleness, malleability and surface conditions.

Separation methods can be grouped into the following stages:

(i) Primary separation that will produce mainly organic and inorganic fractions;

(ii) Secondary separation of particular components from inorganic fractions;

(iii) Tertiary separation to upgrade the separated fractions.

The unit processes employed in each of these levels of separation can be summarized as follows:

(a) Primary separation

(i) Wet pulverization. The untreated waste is moistened and fed into a large, slowly rotating drum in which self-pulverization is achieved by the tumbling action of the hard components. The fine fraction is then passed through screens at the end of the drum. This contains about 60-80 per cent of the waste, which is mainly organic material and glass. The coarse material remaining mainly consists of inorganic material and large sheets of plastic. In developing countries where food waste constitutes a relatively large proportion of MSW, wet pulverization can substitute shredding prior to composting.

(ii) Wet pulping. Waste is introduced as an aqueous slurry (3-10 per cent solids) that is then reduced in size by a segmented blade rotating at high speed. The pulped waste, which is largely organic, passes out of the bottom of the pulper, while non-pulpable or non-friable materials are pushed to the outer sections of the pulper drum.

(iii) Dry separation. This method of primary separation is most commonly used for the recovery of salvageable materials. The major unit processes are size reduction, screening, air classification and magnetic separation.

(b) Secondary separation

Secondary separation into other types of organic material and a glass-rich or metal-rich fraction is included in the primary separation schemes. The methods that can be used combine one or more of the following processes: magnetic separation, screening, jigging, hydraulic classification and heavy media separation.

(c) Tertiary separation

The tertiary separation of inorganic components aims at the recovery of non-ferrous metals or glass fractions that can be recycled. These include: heavy media and electrostatic separation, together with flotation.

Most of the above mentioned techniques for mechanical waste separation have not yet been successfully proven on a commercial scale.

(d) Baling

Although the high-density baling of solid waste is a comparatively recent development, several large-scale plants are already in operation. The basic principle is that the waste is compressed into bales weighing approximately 1 ton with about 1 cu m in volume by three hydraulic rams. These bales can then be stacked at the landfill site. The landfill operation is thereby simplified, and much of the inconvenience is eliminated. There is still no scientific understanding of the effects of baling on waste degradation. Furthermore, its technical feasibility as a reliable option for solid waste management has yet to be demonstrated.

(e) Pulverization

The mechanical processing of waste by pulverization before landfilling has the following advantages:

(i) The waste does not smell;
(ii) It minimizes the attraction to and support of vermin;
(iii) Fly nuisance is diminished;
(iv) Daily covering may not be necessary;
(v) The space required for landfilling can be reduced;
(vi) The settlement and maturing of the landfill site is quicker and more even.

Many types of size-reduction machines are available. The most common are hammer mills and impact crushers.

(f) RDFs

A wide range of technologies have been developed to produce refuse-derived fuels. These technologies differ markedly in the production methods used, their state of development, quality and the form the RDF takes. There are three basic approaches for the production of RDF through the separation of organic and inorganic fractions, as summarized below.

(i) Dry separation. This is the most widely-applied approach that is based on several combinations of unit operations. Typical procedures include the following:

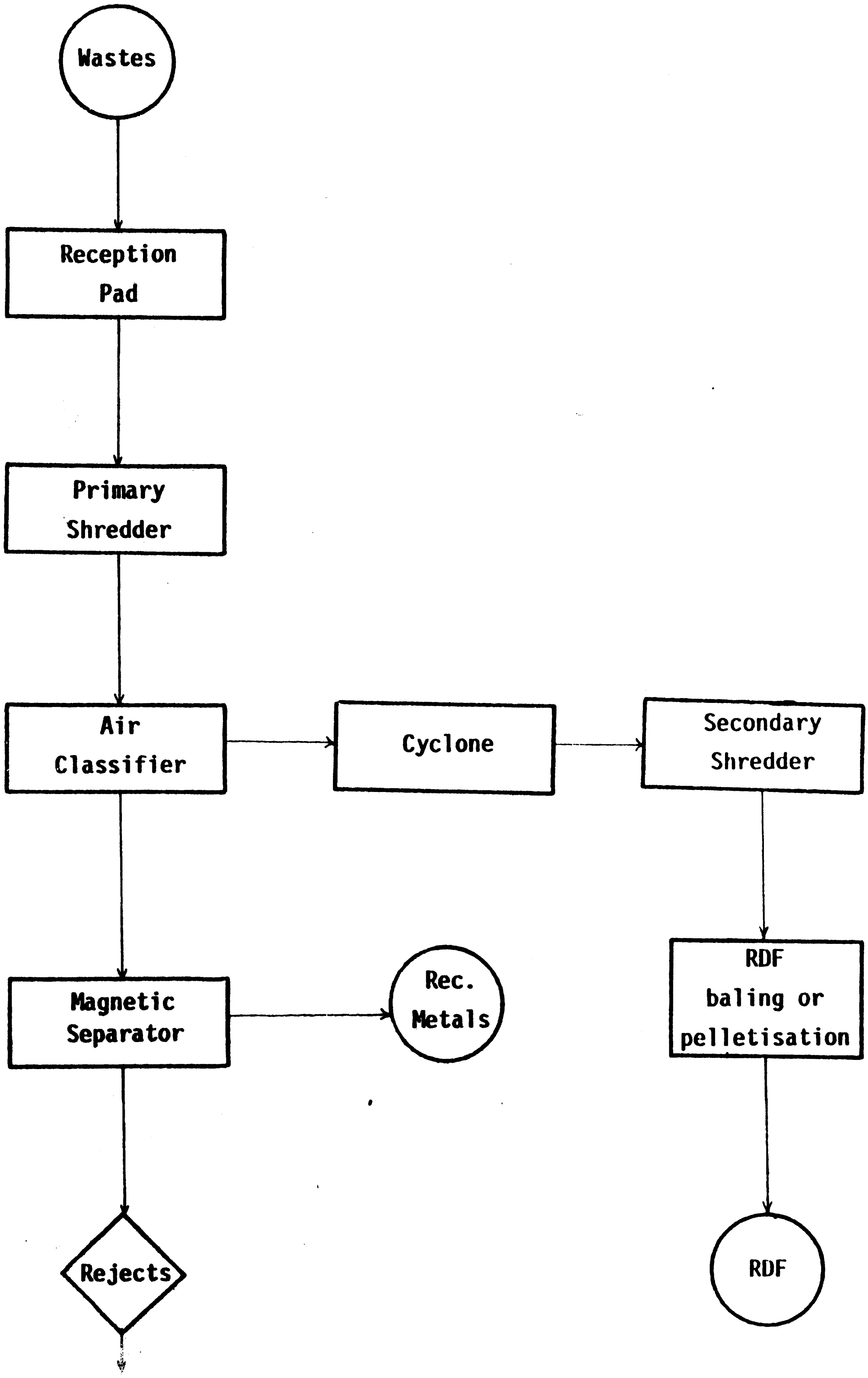
a. The production of a single organic fraction containing most of the putrescible matter, in addition to paper and plastics. Up-grading before use may involve further size reduction or pelletization. A schematic block diagram is shown in figure 6.

b. The upgrading of the prepared RDF in order to produce a powdered fuel suitable for co-firing with fuel. This is considered to be a suitable substitute for pulverized coal in suspension-fired boilers.

c. The production of two organic fractions, where the paper and plastics are utilized as RDF and the putrescible materials are used as landfill or composted.

d. The simplest and cheapest procedure to produce RDF for direct use is pulverization and magnetic separation. This fuel is limited in its application to older boilers that have chin-grates and extensive ash-handling facilities, or to cement kilns. The quality of feedstock required in the latter case is rather high and it needs double pulverization. The high ash content is usually incorporated with a cement product. Net energy efficiency is in the region of 50-60 per cent.

Figure 6. A simplified block diagram of the refuse-derived fuel process



(ii) Wet pulverization. The second method of producing RDF is based on wet pulverization. A further development of this theme is to replace water by an oily waste that gives rise to an enriched pulverized fuel.

(iii) Wet pulping. The third method is based on wet pulping, where the organic fraction is produced in the form of a wet slurry. Several variations for further processing include the following:

a. Processing for fibre recovery, where residual materials are de-watered and incinerated;

b. Recovering the fibre and marketing the de-watered residue as wet RDF;

c. Upgrading the RDF to 20 per cent moisture.

The net energy efficiency of RDF ranges between 30 to 60 per cent. The drawbacks to the production and use of RDF are as follows:

a. The technology has to be proven over an extended period of routine operating;

b. Markets for the fuel products have to be explored.

2. The recovery of energy from conversion products

Most of the conversion technologies described in the previous sections result in the recovery of materials and/or energy from MSW, as is summarized below:

Technology	Type of ultimate resource recovery
Sanitary landfilling with gas recovery	Energy (fuel) and reclaimed land
Composting with the sorting of salvageable materials	Recycled materials and fertilizer (compost)
Anaerobic digestion	Energy (fuel) and fertilizer
Hydrolysis	Product materials
Incineration with energy recovery	Energy (heat)
Gasification and pyrolysis	Energy (fuel)
Production of refuse-derived fuel	Energy (fuel) and recycled materials

Thus direct energy recovery options include: sanitary landfilling with gas recovery, anaerobic digestion, incineration, gasification and pyrolysis and the production of RDF. All can be considered to be systems that produce fuels or energy while they dispose of solid waste.

Additional system components are required for the recovery of energy (1) from heat: various gaseous, liquid (oils) and solid fuels. These include boilers for the production of steam, steam and gas turbines for motive power, together with electric generators for the conversion of motive power into electricity. Typical flow sheets for alternative energy recovery systems are given in figure 7.

C. Bioconversion process

1. Anaerobic digestion

The bioconversion process generally includes enzymatic hydrolysis, anaerobic decomposition and sanitary landfilling. Of these methods, the anaerobic digestion method has been proved to be effective and economically advantageous in the production of energy (alcohols, methane, gas, etc.) from wastes rich in organic materials. This method can effectively be applied to process solid, semi-solid and liquid waste rich in organic material and nutrients. Figure 8 shows the anaerobic decomposition process of waste utilization for energy.

Figures 9 and 10 respectively show the sources of methane in the anaerobic decomposition of waste, and the process of production of ethanol from sugar-cane. Anaerobic digestion essentially proceeds through three basic steps:

(i) The conversion of glucose and other carbohydrates, proteins and fats by acidogenic bacteria into short-chain fatty acids;

(ii) The conversion of these acids by acetogens into acetate and bicarbonate;

(iii) Conversion by methanogens into methane and carbon dioxide.

The digester operation requires the control of the following parameters:

(i) Temperature, which can be held in the mesophilic (40^o C) or thermophilic (60^o C) ranges, where the latter gives higher methane yields and has a shorter retention time;

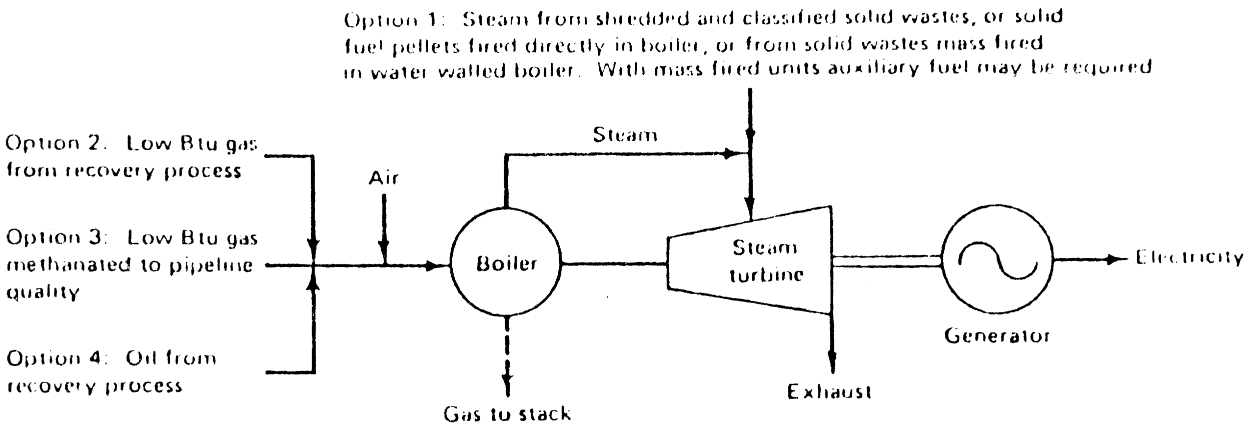
(ii) Maintenance of anaerobic conditions;

(iii) pH in the optimum range of 6.7 to 7;

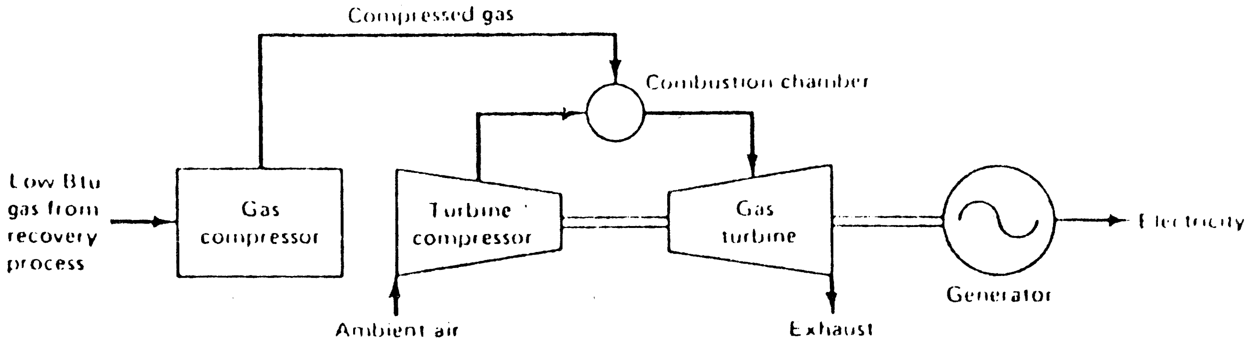
(iv) Nutrients necessary for bacterial growth that can be supplied by sewage sludge;

(v) Reduction of the toxicity of the input waste through the separation of inorganic materials and by dilution.

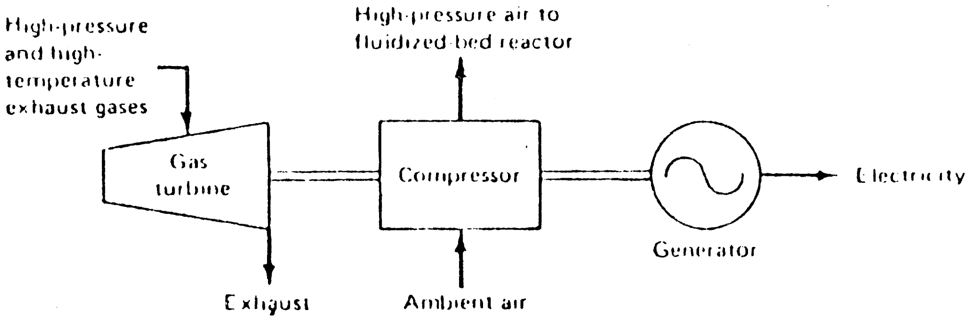
Figure 7. <u>Alternative energy recovery systems</u>



(a) Options with steam turbine - generator combination



(b) Options with gas compressor-gas turbine - generator combination



(c) Option with gas turbine - compressor generator

Figure 8. Anaerobic decomposition process of waste utilization for energy

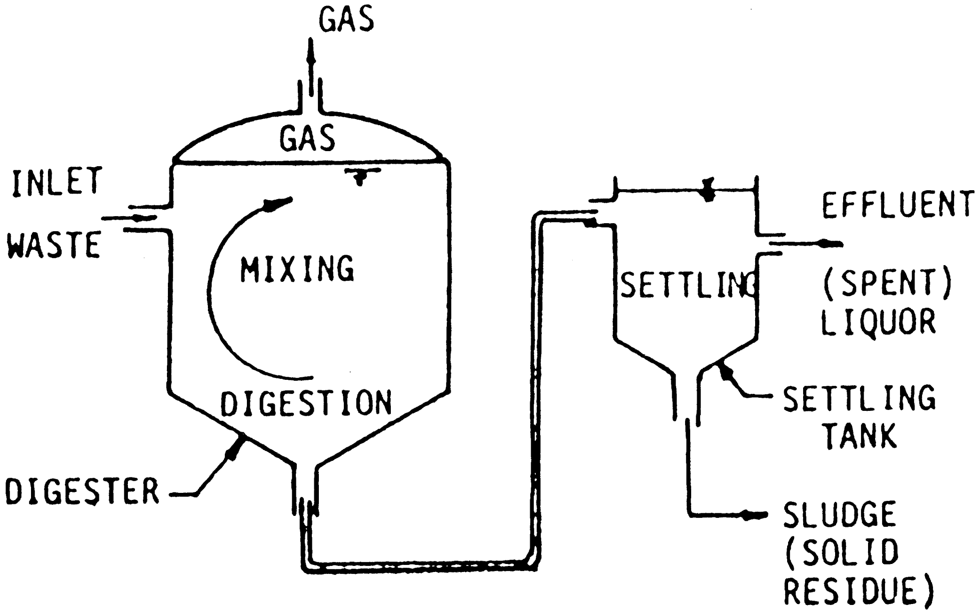
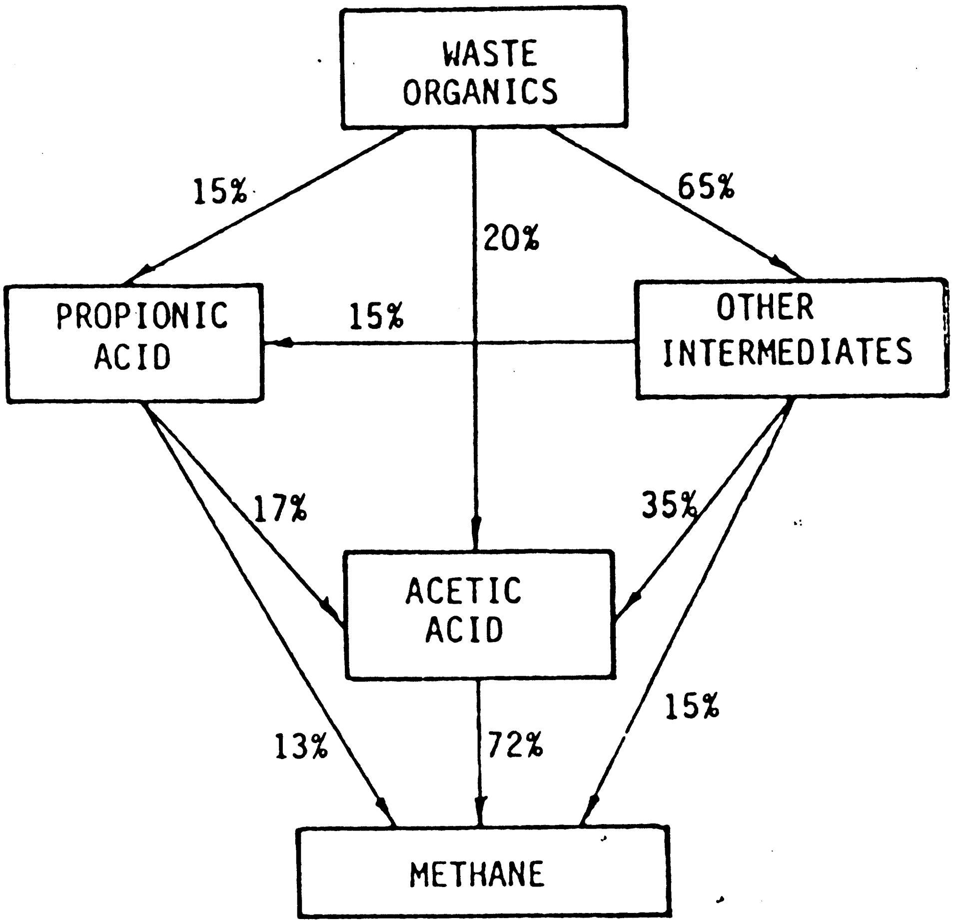
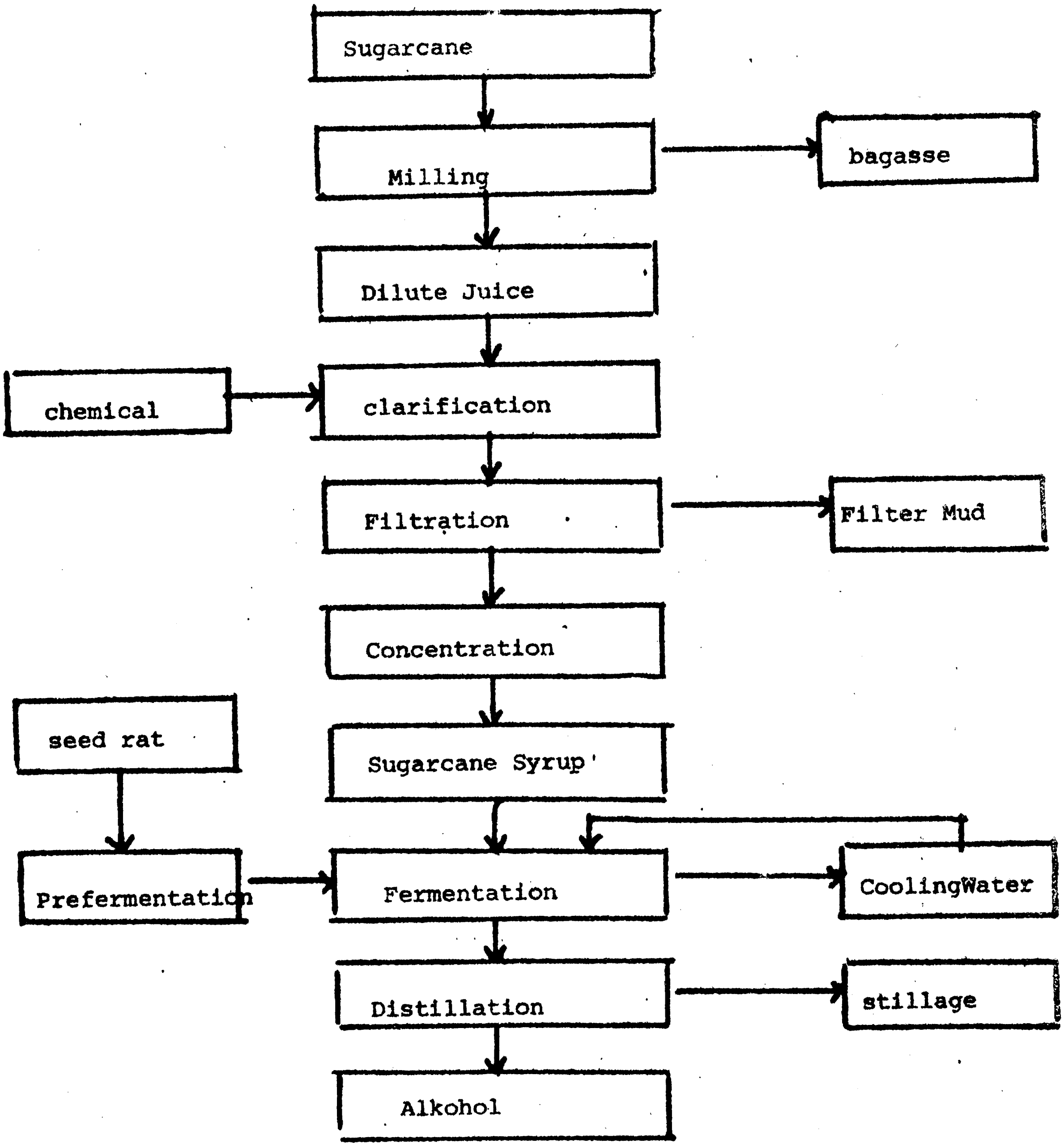


Figure 9. Sources of methane in anaerobic decomposition of wastes



Source: Reference 12.

Figure 10. Ethanol from sugar-cane process flow chart



Source: Reference 10.

Most of the cases studied use a single digester, but recent work suggests the use of multi-stage digestion. The gas from the digester contains about 60 per cent methane the remainder being mostly carbon dioxide (CO_2). The remaining slurry must be de-watered if it is to be used as a fertilizer. The viability of the anaerobic digestion of MSW has yet to be proven.

2. Sanitary landfilling

Though landfilling can be classified under biological treatment, it forms a separate class in its own right. Actually, it is the ultimate sanitary disposal process where land becomes the waste sink. The word 'sanitary' differentiates this technology from the bad practice of open dumping. It should be noted that whatever treatment and processing the MSW may undergo, a residual matter that has to be disposed of, presumably by landfilling always remains.

In this method of disposal, waste is charged, spread and compacted in layers. The exposed surfaces are regularly covered with an inert material excavated on the same site or hauled from outside. Figure 11 depicts a sectional view of a sanitary landfill (1). Compaction and covering help to eliminate vermin within the landfill, reduce the nuisance value of waste scattering, and improve the visual impact of the landfill operation.

The sanitary landfilling of MSW produces a methane-rich gas. At one time this was collected and flared to reduce the hazard of explosion, but since the early 1970s the gas has often been recovered. Recovered sanitary landfill gas is used to produce heat and/or electricity, or is cleaned and transported by pipeline to consumers.

(a) Gas collection and utilization

Ideally, the landfill site should be constructed in such a way as to deal with the total containment of all wastes and liquids, as well as to maximize the collection of the gas generated. Significant advances have been made in the last two decades in the recovery of processed methane-rich gas from landfill sites. Several beneficial utilization options are available through the direct firing of the raw gas and electricity generation, which are the only means immediately available on site.

In many cases, the gas is not utilized but merely collected by suitable means such as permeable gravel trenches that are built into the landfill (see figure 11), and then vented to the atmosphere or even flared off. With the growing energy shortage, landfill gas is viewed as a potential asset and energy source. The focus in some places has been on optimizing gas production and using it directly as a fuel. The gas can be used in a nearby industrial furnace such as brick and cement kilns.

(b) Hazards associated with landfilling

Hazardous situations can arise from two main sources:

(i) If water is allowed to come into contact with the waste, then an obnoxious mineralized leachate is produced that causes water pollution;

Figure 11. Sectional view of a sanitary landfill

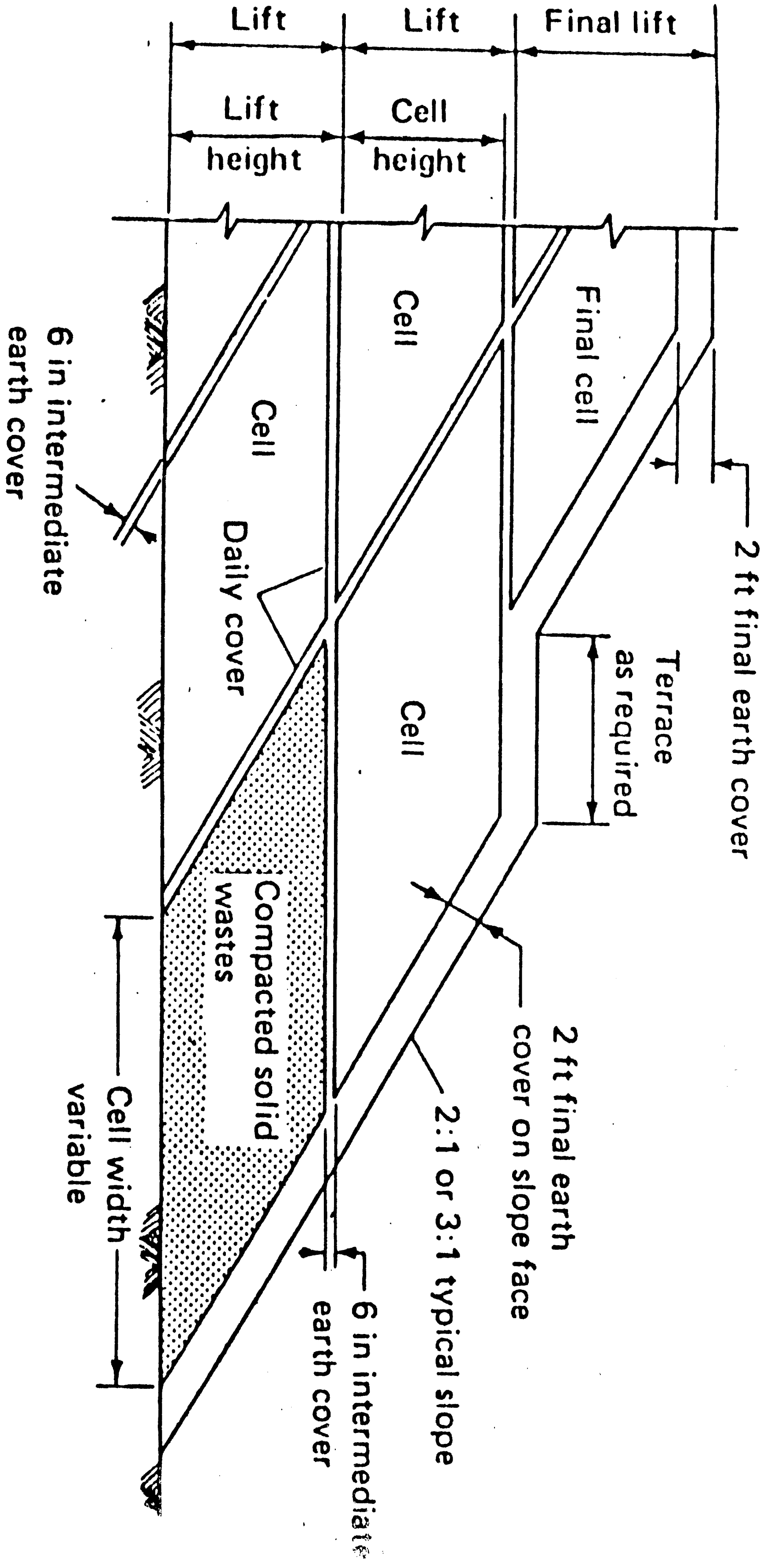
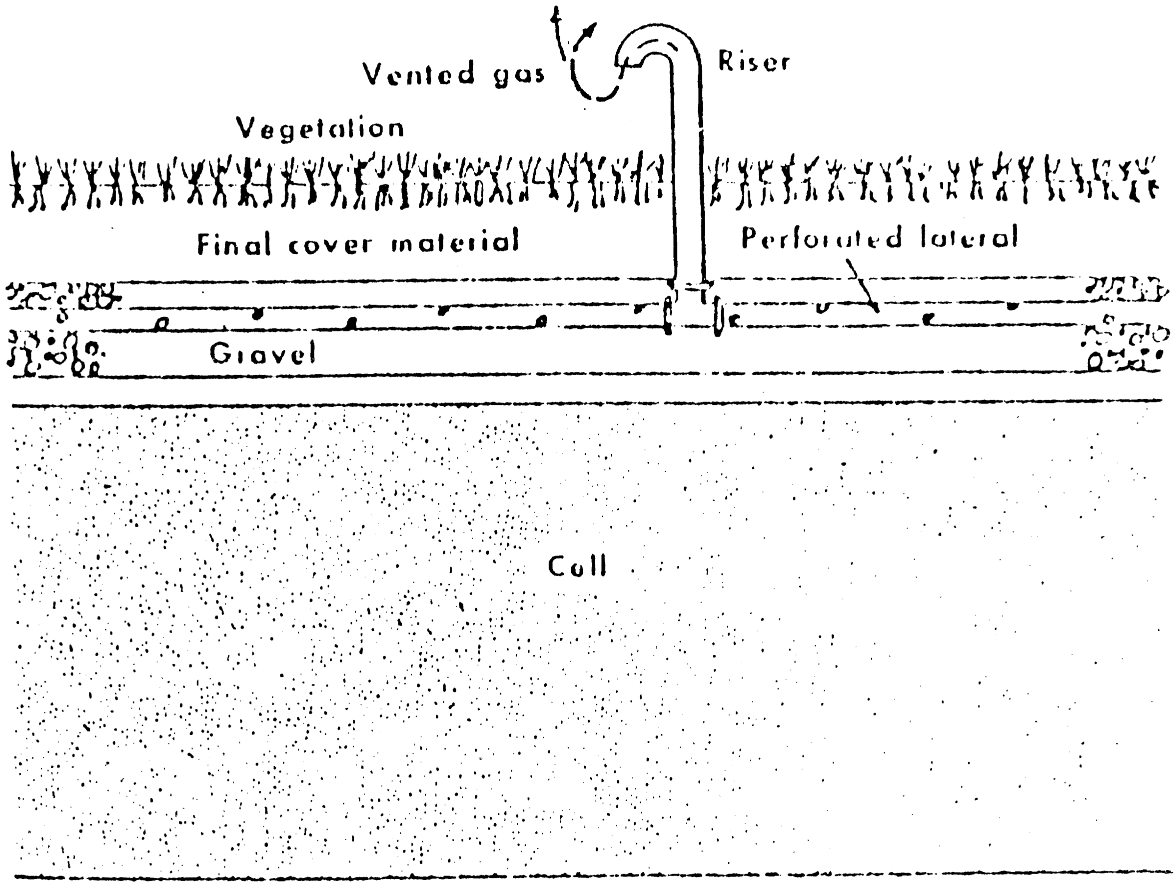


Figure 12. <u>Method of gas venting</u>



(ii) As the temperature within the landfill increases, there is a danger of fire hazard. In addition, the gases generated from biodegradation of the waste can escape into the atmosphere and create both a fire and explosion hazard.

Thus, landfills should be properly designed, constructed and operated in order to ensure minimization of pollution and fire hazard.

(c) Principles of waste decompositon and gas generation in landfills

Landfilled solid waste undergoes a number of simultaneous biological, physical and chemical changes. Among the more important of these changes (1) are:

(i) The biological decay of organic putrescible materials;

(ii) The chemical oxidation of materials;

(iii) The escape of gases and their lateral diffusion through the landfill;

(iv) The movement of liquids caused by differential pressure;

(v) The dissolving and leaching of organic and inorganic materials through the movement of water and leachate in the fill;

(vi) The movement of dissolved material by concentration gradient and osmosis;

(vii) Uneven settlement caused by the consolidation of material into voids.

Decomposition and stabilization in a landfill depend on many factors such as the composition of the waste, the degree of compaction, moisture, rate of water movement, temperature, together with the amounts of inoculum, nutrients and inhibiting materials that are present.

Scientifically, a landfill site is considered to be a sort of biological reactor in which waste decomposes over time. On being deposited, MSW contains entrapped air. With a moisture content of around 25 per cent, aerobic bacteria multiply rapidly and the resultant decomposition raises the temperature in the landfill. As the oxygen is used up quickly, the aerobic bacteria are replaced by anaerobes.1/ Anaerobic degradation of organic matter proceeds more slowly, and the temperature gradually declines. If the landfill is well compacted, the peak temperature reaches about 35 °C. If compaction is less efficient, the temperature can rise to 60-80 °C. Anaerobic degradation is more efficient when the moisture content is higher. The final products of the anaerobic degradation of organic materials are carbon

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1/ Micro-organisms that cannot grow or survive in the absence of oxygen are called obligate aerobes. Obligate anaerobes cannot survive or are inhibited in the presence of oxygen. Facultative organisms are capable of growth either in the presence or absence of oxygen.

dioxide and methane. Many other intermediate chemicals are produced, particularly under aerobic conditions. These include many short chain aliphatic organic acids. The composition of the landfill leachate that is produced depends on many factors, including waste composition, moisture content and the age of the landfill. If moisture is not added, it is not uncommon to find materials in their original form years after first being buried.

Under normal conditions, gas production reaches a peak within the first two years and then slowly tapers off, continuing, in many cases, for periods of up to 25 years or more.

3. Composting (13)

Composting is a process by which micro-organisms break down organic matter into a humus-like material and carbon dioxide. Though the term composting is sometimes used to describe anaerobic or aerobic digestion, it is usually taken to signify the more widely used aerobic process. Compost is a low-grade fertilizer mainly valued as a soil conditioner. Composting would seem to have a good potential in cities of the developing countries which have a high population where MSW is rich in organic matter and has a high moisture content.

(a) Principles of composting

In the early stages of composting, mesophilic organisms1/ (mainly bacteria) multiply, and the temperature in the active mass rises rapidly. Above 40° C the mesophiles die and thermophilic organisms (mainly actinomycetes and fungi) take over. By the time the temperature reaches 60° C, the thermophilic fungi have died off and the reaction is maintained by spore-forming species of bacteria and actinomycetes. The attainment of temperatures around 60° C is necessary in order to ensure the destruction of pathogenic organisms. At this stage the rapidly degrading vegetable putrescible matter is consumed, and the reaction slows down. The rate of generation falls lower than the rate of heat loss from the surface, and the mass begins to cool down. As the temperature decreases, the various types of organisms in turn slowly start to attack the cellulose and lignin components of the waste. After an ambient temperature has once again been achieved, a further period of curing or maturing is required. This additional maturation is necessary to allow the degradation of the remaining cellulose and lignin. The use of immature compost actually takes nutrients from the soil, and may damage plants.

The composting of organic waste is a very complex process. The rate of degradation to reach the final stable product is controlled by a number of factors. These factors and their optimum value are summarized below:

1/ Micro-organisms that grow best in temperature ranges of 20-40° C are called mesophiles; those that grow best at a temperature of about 45° C are called thermophiles.

(i) Particle size and structural strength. Particle size should be small enough to provide an adequate surface for microbial attack, but be large enough to allow interstitial spaces;

(ii) Carbon/nitrogen ratio. Carbon supplies the bacteria with energy while nitrogen is required for cell building. The degradation process involves the reduction of the carbon/nitrogen (C/N) ratio from 20:1-70:1 to a final level of 15:1-2:1. The optimum C/N ratio is about 30:1;

(iii) Moisture content. Water with a minimum level of about 30 per cent is required by micro-organisms. If the moisture level exceeds 55 per cent, water begins to fill the voids and produces the onset of anaerobic conditions. Egyptian waste falls within the optimum range;

(iv) pH control. During composting, the pH changes from acidic to alkaline. However, the deliberate control of pH has little or no effect on the process;

(v) Aeration and agitation. Adequate aeration is necessary for the composting process. Regular agitation aids aeration and exposes fresh material, but over-agitation leads to excessive heat loss and to the compression of the heap.

(b) Composting process

A simplified block diagram is presented in figure 13. The process is comprised of four basic steps, namely:

(1) Preparation. This principally involves the separation of inorganic and organic materials. Manual separation and magnetic extraction is the most common, though air classification can also be used. Preparation may require the addition of nutrients (nitrogen), and sewage sludge is often used;

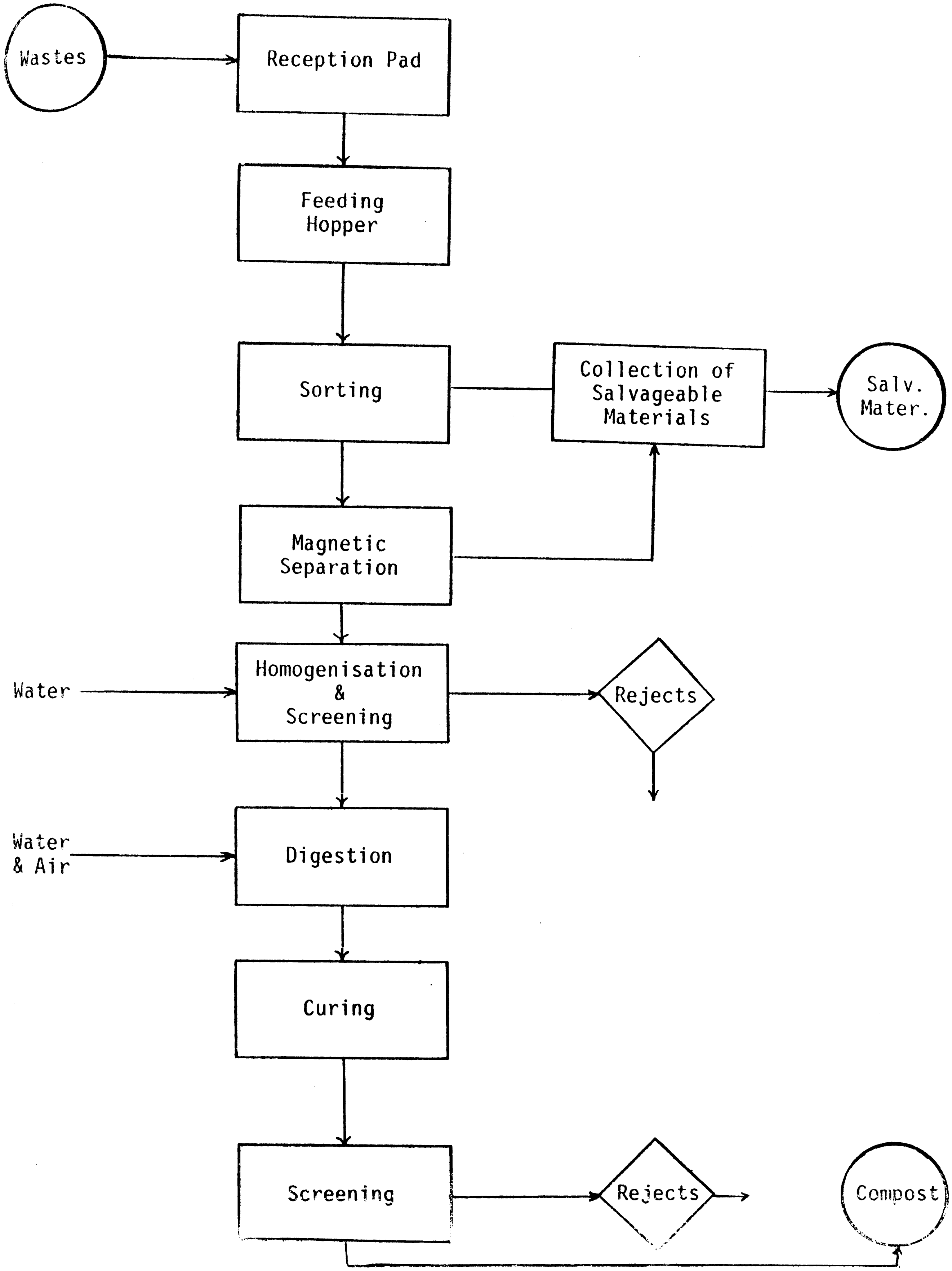
(2) Digestion. This is the critical step during which time the microbiological action takes place. There are two main systems for digestion:

(i) The wind-row system, in which waste is piled in wind-rows 1.5-2 m high and about 2-2.5 m wide. The wind-rows must be regularly turned in order to ensure adequate aeration. This is best achieved using wind-row turning machines. A well-managed mechanized wind-rowing operation can achieve digestion in as little as two weeks;

(ii) Mechanical digesters in which decomposition is speeded up by agitation and forced aeration. Typical retention times are about 3-6 days. There are a number of systems that can be classified into three categories:

a. The rotary drum (e.g. Dano);
b. Tank digesters (e.g. Fairfield-Hardy);
c. Silo digesters.

Figure 13. A simplified block diagram of a composting process



Practice appears to favour the mechanized wind-row method, rather than the more capital-intensive high-rate mechanical digesters.

(iii) Curing. After initial degradation, curing is necessary in order to allow the decomposition of the remaining cellulose and lignin to take place. The time needed is about 2-3 months.

(iv) Finishing. Finishing depends on the pre-processing stages. Screening to remove inorganic material, drying, grinding and pelletization are commonly used. The product is marketed in bags or in bulk.

The approximate material balance of the composting process is as follows:

10 per cent recoverable matter;
45 per cent compost;
20 per cent gases and volatile matter;
25 per cent reject material.

Reject material mainly of an inorganic nature, is usually disposed of in landfills.

(c) Compost properties

Compost is a brown, peaty material whose main constituent is humus. When applied to the soil it has the following physical properties:

(i) It lightens heavy soil;
(ii) It improves the texture of light sandy soil;
(iii) It increases water retention;
(iv) It enlarges the root system of plants;
(v) It makes the additional plant nutrients available in three ways:

a. It contains about 1.2 per cent N, 0.7 per cent P, and 1.2 per cent potassium (K);

b. In conjunction with artificial fertilizer it makes the phosphorus more readily available;

c. It contains all trace elements.

As was indicated earlier, waste and residues can be converted to fuel or energy by a number of thermochemical or biochemical conversion technologies. It is also of particular interest to stress that some of the waste can be transformed into useful products such as compost produced from MSW, which can be used as a soil conditioner and fertilizer.

III. ECONOMIC, ENVIRONMENTAL AND SOCIAL CONSIDERATIONS

A. Economic considerations

The economic feasibility of generating energy from urban and rural waste may vary widely. It is a very complex problem that requires a broad and detailed study in which the availability of domestic sources of energy, the cost of imported fuel, the uses and actual benefits from energy generation, the public and private costs associated with waste collection, and the technology used to generate energy must be included. Since these factors vary with each application, the evaluation of a potential solid waste recovery unit using urban or rural waste must be considered in its entirety. Aside from rising costs, the evaluation should include a complete analysis of the reliability of the quantity of the urban and rural waste.

Although municipal and industrial solid waste has a high energy value, it cannot be utilized as easily and economically as conventional fuels that have a concentrated energy content such as natural gas, oil or coal. By burning solid waste, an energy source is made available, while at the same time the problem of waste disposal can be solved. Some of the costs of collection, transportation and processing could be viewed as the fuel price, and the whole cost must support the price of solid waste disposal. Figure 14 gives a summary of the general characteristics that are thought to influence the relative value of secondary materials found in municipal waste. These together with government policy and other factors, influence the relative costs and financial profitability of a separate collection and recycling scheme (13).

As was mentioned earlier, the actual value of urban and rural solid waste burning is dependent on the cost of conventional fuels, the actual energy content of the solid waste and the cost of conventional disposal methods. These costs should be considered along with the fact that many solid waste items have an actual and/or potential market for recycling.

The economics of a solid waste power plant should be based on several parameters, as follows:

(a) Governmental regulations covering solid waste landfill sites;

(b) The air and water pollution affected by the process;

(c) Transportation, handling and processing costs;

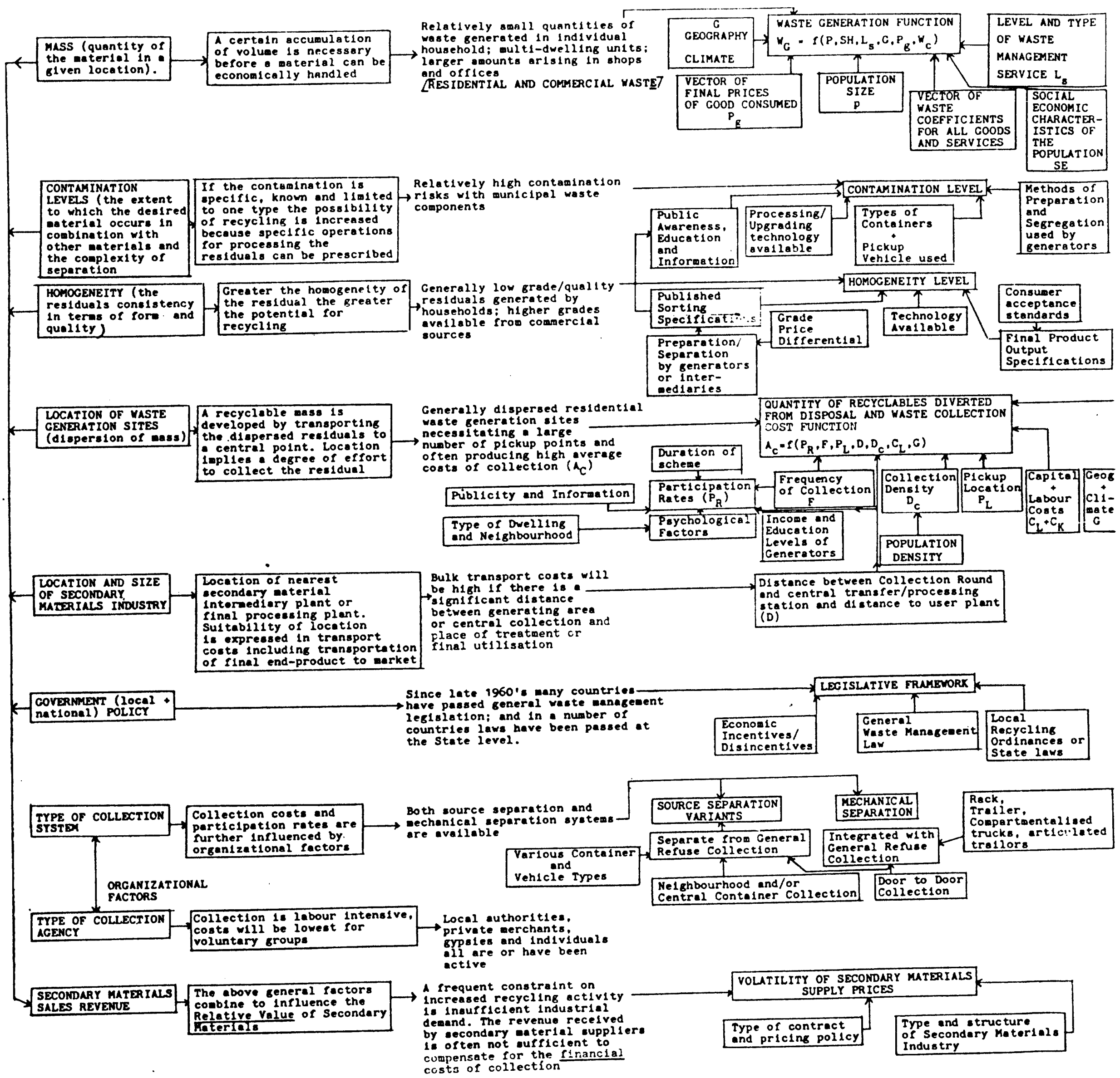
(d) The cost effectiveness of alternative methods of solid waste disposal and/or utilization;

(e) Sanitary landfill costs;

(f) The recovery of valuable resources and by-products;

(g) Conventional fuel costs.

Figure 14. General factors in the financial viability (private profitability) of municipal waste recycling schemes



Source: OECD. Household Waste: Separate Collection and Recycling, Paris, 1983.

The economic feasibility of biogas production from agricultural and agro-industrial waste using simple systems suitable for rural areas, has been examined in many countries around the world, namely China, India, the Philippines, Sri Lanka, Thailand, and Egypt. The economic cost of construction, maintenance, extension and organic materials has to be assessed on the input side. The value of labour appears to be a crucial parameter in this respect, that influences not only the general economic feasibility of biogas, but also the choice between large- and small-scale digesters. Therefore, the economic benefits of biogas depend to a large extent on the alternative energy source it is supposed to replace. Since biogas has no market price, its value has to be derived from the market price of the particular energy equivalent it will replace. Depending on its end use, relevant alternative sources would be firewood, kerosene, butane gas, electricity, diesel and solar and wind energy.

B. Environmental considerations

The control of the environmental impact of urban and rural solid waste burning is one of the major stumbling blocks that inhibits the wide-scale development of solid waste as an energy source in many developed and developing countries. A possible alternative would be to accept environmental trade offs. Obviously, such a situation would only be possible under the auspices of governmental regulatory agencies.

Environmental control for bioenergy conversion and bioconversion processes are readily available for many of the modern combustion and thermochemical options; technology from the petroleum industry is often readily available for all these processes. For example, in the case of biogas, methane is clean and smokeless-burning. It does not constitute a health hazard on skin contact. The effects of accidental methane release upon terrestrial or aquatic organisms are nil, and air emissions of gas are relatively benign as far as environmental and health effects are concerned.

C. Social considerations

Waste generation imposes social costs on society, depending on the type of disposal method used in a particular area in the country. These social costs may be covered by government intervention, in conjunction with an economic incentive approach in order to accelerate the rate of recycling or to reduce the volume of waste generated.

As soon as benefits of a more social nature enter the picture, such as health, convenience and leisure, biogas increases its attractiveness for rural areas. Cooking with biogas is healthier and easier than traditional cooking, and it appears to be highly appreciated by female users. Therefore, biogas technology can go far to improve the quality of life of the rural population.

IV. ECOLOGICAL AND TECHNICAL CONSIDERATIONS

Urban and rural waste is disposed of because of its zero market value. However, its environmental implication for municipalities calls for collection and recycling. In this report the focus is on generating energy from such disposable and recyclable waste. It is recognized that whenever waste can be utilized for human benefit, its subsequent increase in economic value changes its output status from that of a non-product to a product, as in the case of generating energy.

Within the ESCWA region, it seems difficult to visualize a common approach for the recycling of waste to energy. This is because of the population size of most Gulf countries where agricultural or animal waste either does not exist in quantities worth collecting for recycling, or it exists in scattered and remote areas. However, the municipal waste of such metropolises as Kuwait City, Doha, and Abu Dhabi has an energy content that is easily accessible for collection and has a potential for generating energy. In countries like Egypt, Iraq and the Syrian Arab Republic, in view of the size of their populations and the diversity of agricultural activities, significant quantities of waste could be considered for both energy generation and environmental improvement. The recycling and utilization of such wastes are of serious concern in view of the following:

(a) Environmental hazards that result from their non-collection or non-disposal;

(b) Energy as a by-product from recycling waste deserves consideration, particularly where the calorific content of such waste is high. This is necessary in the light of expanding urbanization and rapid industrialization in the largest cities in the region.

However, the effective mechanisms to generate energy from urban and rural waste are impeded by several socio-economic and institutional factors.

However, sound ecology is good economics. In this context, every measure should be taken to protect the environment, such as:

(a) The creation of a unit in the municipality of ESCWA countries that could be entrusted with the task of generating energy from recycled waste;

(b) A country-by-country assessment of types and quantity, including the characteristics of urban and rural waste;

(c) The design of a subregional programme for recycling urban and rural waste including the possibility of energy generation;

(d) Participation in a regional programme to conserve the environment, and the expansion of budgetary allocations to municipalities in order to secure technologies for recycling waste, including the generation of energy;

(e) Exploration of the possibilities of regional co-operative efforts by ESCWA countries in a long-term campaign to protect the environment;

(f) Institutionalization of an approach to waste disposal as resource management that puts a premium on energy and environmental protection.

V. THE CASE OF EGYPT: STATUS AND TRENDS

A. Overview of the Egyptian context

Egypt is located in the extreme north-east part of Africa and occupies a total land area of about 1 million sq km. It is respectively bounded by the Mediterranean and Red Seas, the Libyan Arab Jamahiriya and Sudan on the north, east, west and south. Only about 4 per cent of the country is inhabited, with the great majority of population living in the Nile Valley and Delta.

The present population of Egypt is over 50 million. By the year 2000, it is expected to approach 70 million.

In Egypt about 50 per cent of the population lives in rural areas and 50 per cent in urban areas. However, if rapid population growth, in conjunction with massive rural migration towards cities remains unchecked, it will result in a gradual tremendous urban growth and serious overcrowding in the cities.

Greater Cairo, with a total population approaching 9 million, constitutes the largest urban conglomerate in Egypt. It includes the Governorate of Cairo (about 6.4 million), the urban section of the Governorate of Giza (about 1.9 million), and Shubra el Kheima in the Governorate of Kaliubiya. It is estimated that the population of Greater Cairo will increase to about 16 million by the year 2000.

Alexandria, with a population of about 3 million that is expected to increase to about 4.7 million by the year 2000, is the second largest city. Other urban centres include the Suez Canal region and several small cities in the various governorates with populations in the order of 100,000 to 400,000.

The last Five-year National Development Plan (1982/1983-1986/1987) emphasized the following relevant factors:

(1) Protection of the environment from pollution emanating from industry, agriculture and consumption;

(2) Acquisition of modern and appropriate technology for the utilization of alternative energy sources in order to reduce the burden on non-renewable ones;

(3) Enhancement of the local manufacture of equipment and appliances relating to renewable energy systems.

B. Urban waste

In Egypt, the problems related to MSW have been growing at an alarming rate. Their manifestation in large cities like Cairo and Alexandria reached such serious proportions that they called for considerable government intervention and a series of judicious actions in the short-, medium- and long-term (13). An important action in this regard was the establish ment of two specialized cleaning and enhancing agencies for Cairo and Giza to undertake the various responsibilities associated with MSW management.

Until recently, proper solid waste management techniques were not practised in Egypt on any notable scale, particularly from the standpoint of waste treatment and disposal. Attempts at resource recovery and reuse are neither organized nor hygienic. Final waste disposal was mainly achieved through non-sanitary, non-aesthetic open dumping. The situation, however, is being rectified through the adoption of appropriate treatment and disposal schemes.

C. Municipal waste characteristics

The term urban or municipal waste covers domestic and commercial waste, with industrial wastes constituting an independent category. However, solid effluent from small-scale industries scattered within the residential communities are usually included in the MSW category.

A number of studies of a few of the larger Egyptian cities have been conducted. Table 13 gives an analysis of the Egyptian waste identified in these studies. It should be noted that there is a wide variation in composition. Although this variation is partly owing to differences in the sampling of sites or in dates, it can largely be attributed to variations in the types of waste included, and the methods used to estimate them.

From this data, as shown in table 14, the average composition of Egyptian MSW has been estimated and compared with world-wide urban waste. It is apparent that the Egyptian figures are more or less the same as the corresponding figures for other oriental developing countries, where vegetable waste constitutes a high percentage of the total. In this respect, the waste is quite different from that of industrialized countries where the paper content is relatively high.

In a recent investigation (14), it has been shown that seasonal variation has no marked effect on waste composition. The waste is characterized as having a density of 0.25-0.30 tons per cubic metre, and a calorific value of 1,500-1,800 kcal/kg. Additional characteristics and indicators are depicted in figures 15 and 16.

1. Waste quantity

With reference to table 13, estimated generation rates of MSW vary according to the standard of living and range between 200 and 720 g per person per day. According to the 1976 census, the waste generated by the urban population of 16 million amounted to about 8,000 tons per day, or three million tons annually.

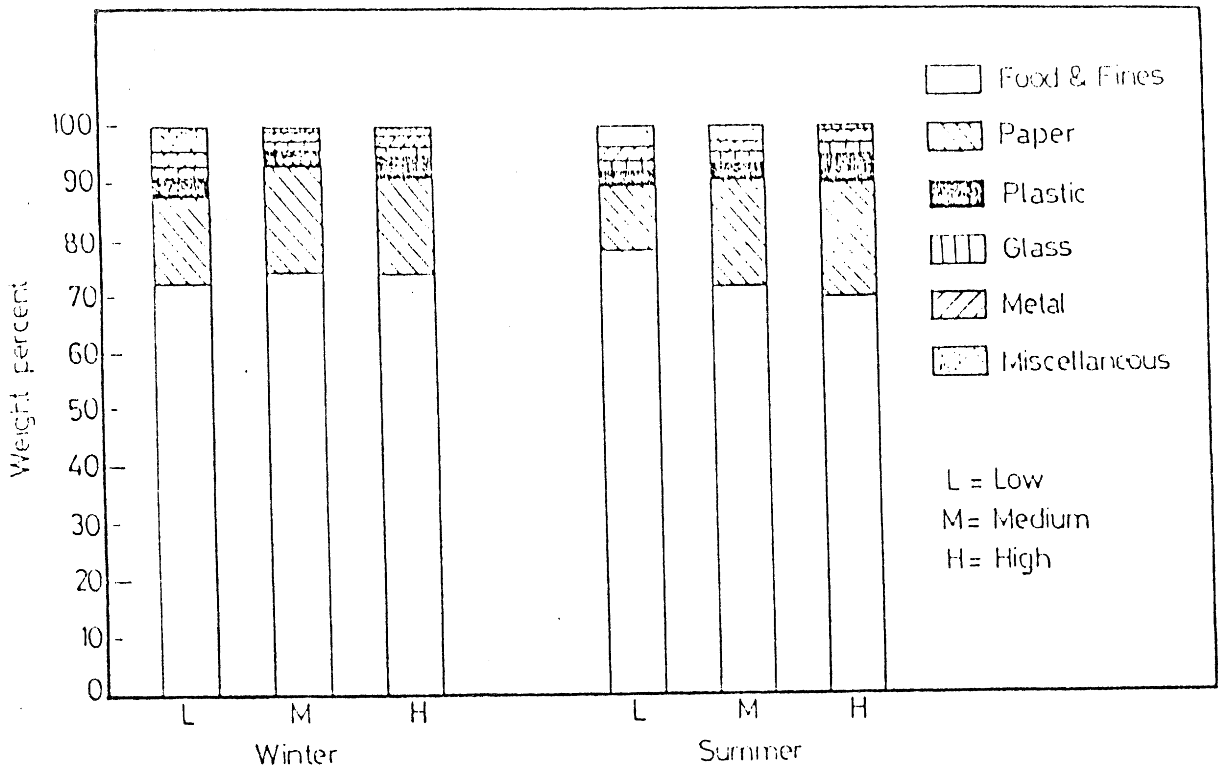
MSW is expected to reach about 15,000 tons per day by the year 2000. This somewhat optimistic estimate is based on an average annual population increase of 2.7 per cent (without taking into account growing urbanization and the increase in the rate of generation that can be expected from the anticipated rise in living standards). While this cumulative figure is indicative of the magnitude of the problem, it is of little value in estimating requirements for treatment/disposal facilities. These depend solely on the quantities that are generated by a specific large city, district or adjacent cities separated by just a few kilometres. It would, in fact, be impractical to establish centralized plants owing to the inadequacy of the network of routes, high transportation costs and administrative divisions.

Table 13. Reported Egyptian MSW composition and generation rates, as estimated for various cities

City	Year	Source reference	Vegetables	Percentage composition							Rubber	Miscible combustables	Miscellaneous	Moisture content percentage	Generation rate per capita (kg/day)	Method of estimation
				Paper	Metals	Class	Textiles	Plastics	Bones							
Cairo	1964	(18)	83.00	6.00	0.40	1.00	1.00	0.20	1.00	-	1.40	6.00	-	-	Not known
Cairo	1966	(18)	64.50	16.00	4.00	5.00	7.00	-	-3.50	-	-	-	-	-	Not known
Cairo	1977	(18)	70.00	10.00	4.00	2.00	2.00	1.00	1.00	-	4.00	6.00	-	0.60	Visual inspection
Cairo	1981	(19)	43.77	9.21	2.99	1.86	3.04	1.95	1.34	-	-	28.13	-	-	Sampling and weighing at Shoubra plan
Cairo and Giza	1981	(20)	60.00	20.00	2.00	4.00	3.00	2.00	-	-	-	9.00	40-60	-	200 kg of wastes and visual inspection
Giza	1981	(21)	43.80	0.20	3.00	1.90	3.00	2.00	1.30	-	10.30	25.50	40	0.20	Sampling from containers in Giza
Giza	1984	(16)	44.30	20.40	2.80	1.40	2.30	3.40	0.20	-	-	25.20	40-60	0.79	Sampling
Alexandria	1977	(18)	70.00	10.00	4.00	3.00	3.00	1.00	-	-	3.00	6.00	-	-	Rational estimation
Suez Canal region	1982	(22)	37.10	22.60	3.10	1.30	2.20	3.00	0.30	0.30	9.30	20.80	32	0.47	Extensive sampling
Port Said	1986	(17)	46.20	25.00	2.30	5.50	2.10	4.50	0.40	-	-	17.50	-	0.73	Sampling
Damietta	1983	(15)	63.00	14.26	2.48	1.09	-	2.00	-	4.04	9.95	3.18	45	0.72	Sampling

Source: Data compiled from various references, as referred to in the keyed bibliography.

Figure 15. Seasonal variation of household waste composition (Giza city)



Additional Characteristics and Indicator
Relevant to Egyptian Municipal Solid Wastes

Figure 16. Sectorial generation pattern

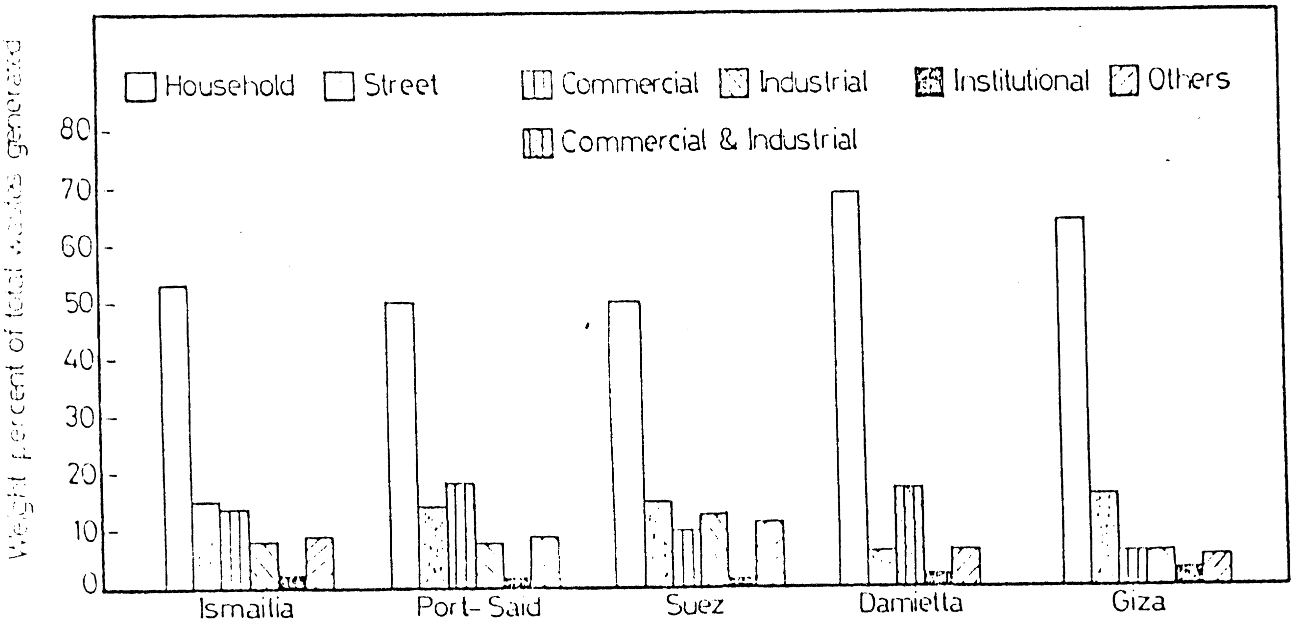


Table 14. Composition of Egyptian and other world-wide MSW

	Putrescible Vegetables	Paper	Metals	Glass	Textiles	Plastics	Bones	Rubber	Miscible combustables	Miscellaneous	Moisture content percentage	Per capita generation rate (kg/day)
Egypt	60.0	13.0	3.0	2.5	2.5	1.5	1	0.5	3.5	12.5	40.0	0.60
Austria	18.6	38.3	8.1	9.2	7.6	6.1	–	–	2.2	9.9	–	–
Bulgaria	54.0	10.0	1.7	1.6	1.7	7.0	–	–	7.0	24.0	–	–
Denmark	44.0	32.9	4.1	6.1	1.5	6.8	–	–	1.6	3.2	–	–
Gabon	77.0	6.0	5.0	2.1	4.1	3.8	–	–	–	–	–	–
Iran	69.8	17.2	1.8	2.1	4.1	3.8	–	–	–	1.1	52.0	0.57
Italy	50.0	18.0	3.0	4.0	–	4.0	–	–	–	21.0	–	1.20
Kenya	42.6	12.2	2.7	1.3	1.4	1.0	–	–	–	38.7	–	–
Republic of Korea	76.0	10.0	3.0	7.0	–	4.0	–	–	–	–	–	–
Spain	50.0	18.0	4.0	3.0	2.0	4.0	–	–	–	19.0	–	–
United Kingdom	15.5	29.5	8.0	8.1	2.1	1.1	–	–	–	35.7	25.0	1.00
United States	27.4	39.6	9.9	–	1.6	4.1	–	–	6.3	11.8	25.2	2.20

Table 15. Estimated population and generated MSW of principal Egyptian cities (1986)

City	Approximate population (In thousands)	Municipal solid waste (Tons/day)
Shibin el Kom	140	84
Sohag	140	84
Beni Suez	165	99
Aswan	200	120
El Menia	205	123
Kafr el Dauwar	205	123
El Faiyum	225	135
Damanhur	230	138
Ismailiya	240	144
Suez	270	162
Zagzig	280	168
Asyut	290	174
Port Said	330	198
El Mansura	360	216
Tanta	380	228
Mahalla el Kubra	390	234
Shubra el Kheima	540	324
El Giza	1,900	1,140
Alexandria	2,900	1,740
Cairo	6,400	3,840

Table 15 gives in ascending order the current population of the principal cities of Egypt, and the corresponding estimated quantities of MSW they generate. It would appear that the quantities range from a minimum of 84 tons per day for Shibin Elkom to a maximum of about 4,000 tons per day for Cairo.

2. Possible uses of MSW

(a) Agriculture and land reclamation

Egypt has approximately 6 million feddans (4,200 sq m^2) of arable land concentrated in the immediate vicinity of the Nile Valley. With the increasing concern about food supplies, efforts are directed towards maximizing the productivity of this arable land, in addition to the reclamation of the extended area of desert.

Ever since the construction of the High Aswan Dam which prevented the supply of silt with the annual flood, the soil has undergone continuous deterioration. There is thus an ever increasing demand for both organic and mineral fertilizers, in addition to soil conditioners. There are claims that the deficit in organic fertilizers for farmyard manure amounts to about 120 million tons annually (13). MSW has a substantial role to play in providing fertilizers/soil conditioners through composting.

(b) Energy (23, 24)

In 1980, Egypt consumed about 24.2 million tons of oil equivalent (TOE). Of these, about 18.5 million TOE came from conventional commercial sources, i.e., oil, hydropower, gas and coal. The balance represented non-commercial sources comprising crop residues, animal waste, wood, animate power, etc.

By the year 2000 it is anticipated that primary energy requirements will be about 65 million TOE, which is equivalent to a per capita consumption rate of 1 TOE per year (compared to 0.6 TOE per year in 1980), at an aver age growth rate of about 6.6 per cent.

The bulk of the energy will be supplied from traditional commercial sources. However, it is expected that new and renewable energy sources will contribute about 5 per cent to total national energy needs.

MSW represents a potential energy source that can make a contribution to national requirements. The calorific value of Egyptian MSW has a minimum of about 1,500 kcal/kg. This energy can be utilized by three main treatment alternatives:

(1) Sanitary landfilling with gas recovery;

(2) Incineration and the recovery of energy in the form of steam or electricity for direct immediate utilization. In this case 1 ton of MSW would be equivalent to about 0.15 tons of fossil fuel with a calorific value about 10,000 kcal/kg;

(3) Production of RDF that can be stored and used as a solid fuel when needed. One ton of refuse provides about 0.5 tons of RDF, while 1 ton of RDF is equivalent to about 0.17 tons of fossil fuel (taking into account both the calorific value and efficiency).

Although theoretically MSWs annual tonnage is fairly substantial, its actual contribution is purely a matter of economics. In view of the current subsidization of fuel prices, expectations as to the marketability and utilization of this potential energy source appear to be rather limited.

(c) Economic indicators

Although the cost of MSW collection and transport, treatment and disposal is variable and site specific, some of the general cost indicators, as estimated in other works, are summarized in table 16.

It would appear that, in view of economic considerations, sanitary landfilling is an appropriate option as long as land is available.

D. Sewage solids

Mainly because of financial constraints, most Egyptian cities have no sewage projects. Where cities do possess some sewage treatment and sanitary disposal facilities they do not provide either a proper or complete service to the community.

Table 16. Economic indicators for the collection and transport, treatment and disposal of MSW under Egyptian conditions

Phase	Description	Net cost (LE/ton of waste) a/	Remarks
Collection and transport	For communal collection and transport to a distance of 25-30 km	12-15	As estimated for Giza city
Treatment			
Composting	(a) Pilot plant (10 tons/hour) (Soft loan fund in 1982)	10	As estimated when operating at full capacity
	(b) Conceptual 30 tons/hour plant	15	As estimated for Port Said city
Incineration	For a continuous incinerator plant (15 tons/hour)	34	As estimated for Port Said city
Disposal			
Sanitary landfilling	A 2 million cubic metres site (500 tons/day)	2.5	As estimated for the Cairo site

a/ $US 1 = 1.36 Egyptian pounds (LE)

Though Egypt's first experience of biogas technology dates back to 1938, when a 750 cubic metre sewage-sludge digester and a separate 1,500 cubic metre gasholder were installed at Al Gabal Al As far in in Cairo, virtually no sludge processing or energy recovery currently takes place in the country. Even this pioneering anaerobic digestion endeavour was abandoned long ago, presumably because of technical difficulties.

In effect, sewage receives very little, if any, treatment; it is mostly confined to the preliminary screening of floatables and to grit removal, since the capacity of existing treatment plants is much less than the actual flow. However, future plans call for more pollution control practices. Therefore, advanced treatment that encompasses primary and secondary treatment, to be followed by disinfection before disposal or reuse, is gradually being implemented. Sludge processing will subsequently become mandatory, and will thus improve resource recovery in terms of materials and energy. Nevertheless, the success of such plans will, to a large extent, depend on the ability to effect proper on-site treatment of industrial waste water before it is mixed with domestic sewage in the combined sewerage system.

E. Industrial waste

The current status of industrial waste-management in Egypt is unsatisfactory. Industrial waste water perhaps poses the most serious problem. Alarming levels of pollution have to be anticipated unless appropriate measures and action are taken. Most industrial effluent is discharged into water bodies without adequate treatment. The rest is discharged into public sewers, causing severe problems for municipal waste water treatment plants. The consequences of such highly negative environmental effects led to the enactment of Law 48 of 1982 to protect water bodies. It is mainly concerned with protecting the River Nile from pollution. The discharge of all waste is prohibited unless it is properly treated and conforms to specific conditions, regulations and standards.

Though the proper treatment of industrial waste is at present generally absent, the trend seems to be towards great improvement in the not too distant future. A great deal of consideration is also being given to material recycling and energy recovery. The few instances of existing industrial energy recovery, such as the use of rice husks and bagasse as a fuel, will definitely be extended and improved in order to comply with the increasing necessity of conserving the limited energy resources. Anaerobic digestion of agro-industrial solid waste is an option that seems to have good prospects, and it is currently being examined at several industrial sites. The co-production of fuel gas and stabilized organic effluent would be an encouraging asset in this regard.

1. Industrial waste water (15)

According to the Water Master Plan (1981) (25), the estimated volume of industrial raw water in 1980 was 2.700×10^9 cubic metres per year. The projected demand for industrial raw water in the year 2000 is 9.730×10^9 cubic metres per year, while corresponding waste water production is expected to amount to 9.292×10^9. Thus, water consumption in industry is expected

Table 17. Annual industrial waste water generation in 1985

Industry	Quantity of waste water (10^6 cu m/year)
Agro-industry	200.423
Chemicals	176.330
Pulp and paper	47.453
Textiles	93.661
Iron and steel	190,347

Table 18. Waste water characteristics in certain Egyptian Industries

Industrial sector	BOD mg/l	COD mg/l	TSS * mg/l
Oil and soap	520	700	770
Tanneries	1,300	2,250	1,175
Dairy products	1,330	2,400	2,100
Pulp and paper	1,270	2,300	1,360
Iron and steel	95	170	80

Source: A. Al-Sawy, "The role of the General Organization for Industrialization (GOFI) in industrial pollution abatement", Proceedings of the Third International Symposium on Management and Industrial and Hazardous Wastes, Alexandria, Egypt, 1985.

* Total suspended solids (TSS).

Table 19. Average analysis of trace metals in industrial effluent

(Milligrams/litre)

Source	Zn	Cu	Ni	Cr	Cd	Fe	Mn	Pb
Copper works	594	450	388	...	...	1,392	144	209
Electronics	6,250	70	...	50	8	1,525	373	255
Oil and soap	5,550	95	60	30	0.5	3,625	445	285
Tanneries	2,133	603	545	127*	715	14*	979	1,238
Foundry	8,400	290	30	460	3	21,800	630	260

Source: A. Hamza, Management of Industrial Hazardous Wastes in Egypt, United Nations Environment Programme, Industry and Environment Special Issue, 1983.

to reach 0.437 x 10^9 cubic metres per year. The net impact will actually be greater, for it is estimated to be 1.370 x 10^9 cubic metres in the year 2000. Total industrial water demand in Cairo was 43.200 x 10^6 cubic metres per year in 1981. Industrial waste water generation in some industrial categories is shown in table 17.

The characteristics of industrial waste water vary according to the nature of the industry and the pattern of fresh water consumption or internal water management schemes. Tables 18 and 19 depict some of the characteristics of waste water in certain Egyptian industries:

2. Indicative industrial case of relevance to energy recovery

The enforcement of Law 48 of 1982 with its very severe effluent requirements, gave strong encouragement to concerned organizations and industrial firms to adopt rapid plans for controlling pollution. Because of the associated burden of high costs, much attention has been given to the economic resource recover of materials and energy. The following case of a large industrial firm near Cairo is illustrative in this respect.

The firm operates a distillery and organic chemical plant that produces alcohol, yeast for bakers and fodder, vinegar, glacial lactic acid and acetone/butanol using cane molasses as the raw material. The waste water effluent of this industrial complex includes cooling water that can be returned to the Nile without treatment, medium-contaminated flow with a BOD of over 50 mg/l, whose hourly volumetric flow rates are in the order of 200 cu m, and highly contaminated effluent ranging in BOD from 10,000 to 36,000 mg/l with a rate of flow in the order of 1,000 cu m/hr. The latter two types of effluent warrant special treatment before they can be discharged into the Nile in order to achieve quality standards that conform to Law 48.

A number of alternatives were examined and assessed technically and economically. These included: aerobic and anaerobic treatment, as well as concentration to 65 per cent solids in multiple-effect evaporators for use either as a fodder or incinerator fuel for energy and potash (from ash) recovery.

The results indicated that the preferred system for the medium-contaminated effluent was aerobic biological treatment, whereas anaerobic digestion was recommended in the case of heavily contaminated streams. Presumably the treatment schemes would encompass pre-treatment (screening, equalization and neutralization), together with sludge processing with the necessary clarifiers, thickeners and de-watering.

In the case of both aerobic and anaerobic biological treatment, the sludge produced would probably be used as a fertilizer. In addition, anaerobic digestion generates biogas that could be used to produce steam in existing boilers once the required devices for gas firing have been installed. It is estimated that about 55 tons of biogas could be produced daily. On the basis of a 65 per cent methane content, the calorific value of the gas would be in the region of 5,200 kcal/kg, so that the total amount of gas produced per day would be equivalent to about 27 tons of fuel oil.

3. Industrial solid waste (26-29)

In industry, two categories of solid waste are generated: processor manufacturing waste and plant trash. The characteristics of the former waste depends on the type of industry, the kinds of raw materials employed, the product and, above all, the specific process being used. Plant trash originates in offices, cafeterias, warehouses and in maintenance, and is similar in nature to residential and commercial trash. The amount of waste produced tends to be a function of the number of employees, rather than the output of the establishment (29).

Generally, in Egypt, industrial solid waste is handled and disposed of in a manner similar to MSW. Though many industrial establishments, particularly the larger ones, undertake the collection and transfer of the solid waste they generate themselves, in most cases ultimately it goes undifferentiated to municipal disposal sites. Recently, however, the trend has been towards more in-plant and off-plant recycling, as well as differentiation between normal plant trash and the more hazardous manufacturing waste. In effect then, under current practices, the management of industrial solid waste - or at least its treatment and disposal - follows almost the same course as MSW, described above. Nothing more, therefore, will be added in this respect.

Two recent studies (31 and 32), together with the results of several estimates for Giza and Suez Canal cities, have calculated the overall average industrial solid waste generation rate to be in the range of 0.6 to 1.1 kg/labourer/day. The latter figure, which was reported in a solid waste management study for Giza City and Greater Cairo (30), consisted of about 42 per cent plant trash, with the remainder classified as true industrial waste (process waste). Five types of industry were considered: food, engineering, textiles, plastics and wood industries. A summary of typical results is given in table 20.

In the context of assessing the prospects of utilizing energy derived from refuse generated by Egyptian industry (28), 40 industrial establishments were surveyed. These included establishments in the mechanical, chemical, textile, food products, wood and electrical industries. On the basis of the results of this survey and other available information, it was estimated that the annual industrial generation of energy-carrying industrial solid waste was over 600,000 tons, equivalent to at least 200,000 tons of oil. Agricultural 200,000 tons of oil. Agricultural residues used as fuel in residue used as fuel in agro-industries were not included.

F. Agricultural and agro-industrial waste

Agricultural and agro-industrial wastes are derived mainly from the biomass available in Egypt. Crop residues and dung cakes provide the of the energy used by inhabitants in rural areas. The current methods of handling, storing and burning these residues not only waste energy, but they also pose a serious threat to the ecological balance.

Bagasse from sugar-cane and rice husks offer two important sources of energy for their processing industries. About 70 per cent of the estimated

Table 20. Typical generation rates and composition of industrial solid waste in Giza city

Industry	Generation rate (Kg/labourer/day)			Composition (Percentage)						
	Total	Plant trash	Pro-cessing waste	Paper	Wood	Plastics	Metals	Glass	Food	Miscel-laneous
Food	0.928	0.466	0.462	52.4	7.7	0.9	8.2	4.9	16.7	9.2
Engineering	2.601	1.098	1.503	42.2	11.4	2.5	23.7	-	8.2	12.0
Wood	5.785	0.185	5.600	10.0	80.0	-	-	-	-	10.0

annual production of 3 million tons of bagasse is used as fuel on the sugar production sites. Of the 40,000 tons of rice husks produced annually, about 15,000 tons are used in the rice mills as fuel. Large amounts are used off-site as fuel in redbrick-making. This trend declined considerably after the enforcement of laws forbidding the use of silt in brick-making.

In 1978 the National Research Centre (NRC) started a national research, development and demonstration programme to assess the viability of biogas technology (BGT) in the rural areas of Egypt (32). Biogas technology attracted much attention in the domain of rural applications. Though early interest was associated with the pressing energy problem, the impetus grew as further system attributes and multiple outputs were demonstrated. These include the appropriateness of the technology, its decentralized nature, as well as the system benefits related to the sanitation and recycling of nutrients when effluent is used as a fertilizer or animal feed supplement. The scale of applications vary from small, household units, to large community plants and industrial schemes that are used as an adjunct to agricultural processing enterprises, such as relatively large-scale animal/animal product operations.

Because of their much more pronounced potential impact on society, NRC has given a great deal of attention to rural biogas systems over the past seven years. Recently, the biomass utilization programme was extended to cover other potential applications, particularly those related to industrial waste treatment. This section, however, will be confined to rural applications and prospects.

1. Potential designs and systems[1/]

NRC development efforts were directed towards the design, construction, testing and operation of different prototype digesters. The performance characteristics of these digesters were determined in terms of gas production rates, gas composition and their relation to the effect of pressure and temperature inside the digester, as well as the effects of ambient temperature. The rate of destruction of parasites and pathogens was also determined. Intensive work was done on the evaluation of digested products as fertilizers and soil conditioners, as well as their ease of handling, storage and actual application. Internal mixing patterns were assessed by measuring retention time distribution. As a consequence, designs that were suitable for local village conditions were proposed.

Biogas technology was demonstrated in three villages: Manawat village in Giza, Omar Makram village in El Tahrir province and Shubra Kas village in Garibiyah. Digesters with a capacity of 6-50 cu m were constructed. Large, mechanized digesters with a capacity of 320 cu m were designed (for the Misr Aluminium Company). More than 10 different designs were installed and evaluated. Some have been operating since 1980. Family-sized, community and large-scale mechanized units were tested as a source of energy and for waste recycling and management techniques. The gas produced was used for cooking, heating, refrigeration and the production of electrical power.

1/ This part of the study draws heavily on "Rural biogas technology realistic potential and prospects in Egypt", an unpublished paper prepared by M. M. El-Halwagi and M. A. Hamad of the National Research Centre, Cairo, Egypt.

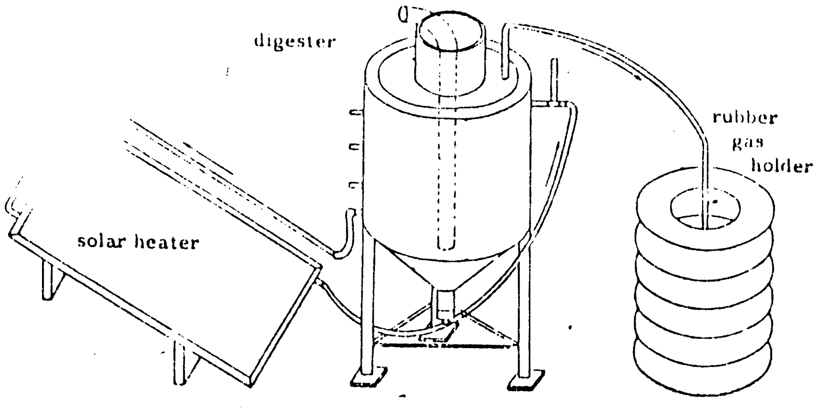
It should also be noted that the success and failure of biogas systems depends very much on whether the different design parameters are adequately taken into consideration or not. These parameters are: gas production, consumption patterns and storage capacity; the fermentation temperature; internal digester flow patterns; gas pressure and its stabilization; scum formation and mixing. Local situations need to be given due attention in setting these design parameters. Satisfaction of the needs of the end user should also constitute a major concern. Adequate coverage of other relevant factors and socio-economic aspects should serve and enhance the main objective of the diffusion of technology.

Based on these experiences, several candidate designs that satisfy the requirements of a multitude of situations and locations are proposed here. All these designs have potential with regard to their economic viability, as was demonstrated previously in a number of NRC studies. These designs are basically grouped according to size.

(a) Ready-made mini-digesters

These are small-sized digesters whose capacity is in the order of 1-2 cu m. They can be made of prefabricated steel or plastic materials. Figure 17 depicts one of the models provided with a solar heater for operation at higher temperatures, and therefore with increased gas productivity, that was developed by NRC.

Figure 17. Mini-digester



The advantages of this type of digester are as follows:

(i) It can be erected easily because of its ready-made nature;

(ii) As a result of its relatively high productivity, it will meet the energy requirements of a rural family that only have access to the waste from two large animals;

(iii) It requires only a small land space for installation;

(iv) It is suitable for high water-table locations since it is erected above ground.

Its disadvantages include the following:

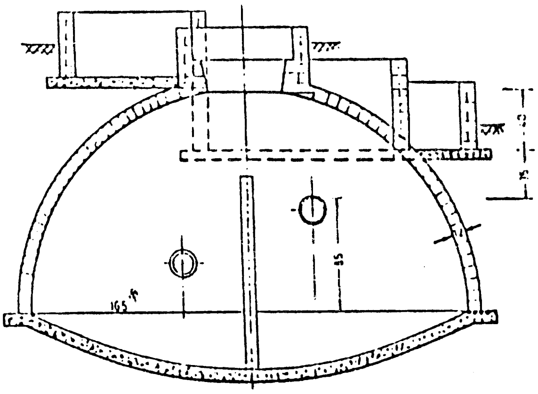
(i) It warrants erection on a sunny site in order to maintain high gas production rates;

(ii) It requires manual feeding of the animal dung and urine.

(b) Egyptian-Chinese water pressure digester

The digester is spherically shaped with adjacent inlet and outlet chambers. Figure 18 gives the digester's main features. Passive solar heating is used to warm the slurry in both chambers. The capacity of the digester ranges from 5 to 30 cu m, so that it can be used in family-sized as well as small-scale community systems. The digester is made of concrete and brickwork.

Figure 18. Egyptian-Chinese digester



The main advantages of this type of digester are that:

(i) It requires less depth underground, which makes it more suitable for prevailing high water-table conditions;

(ii) The system is easier, faster and less costly to build, therefore it is adequate for local village situations and skills;

(iii) The gas production rate is higher than for conventional Chinese designs;

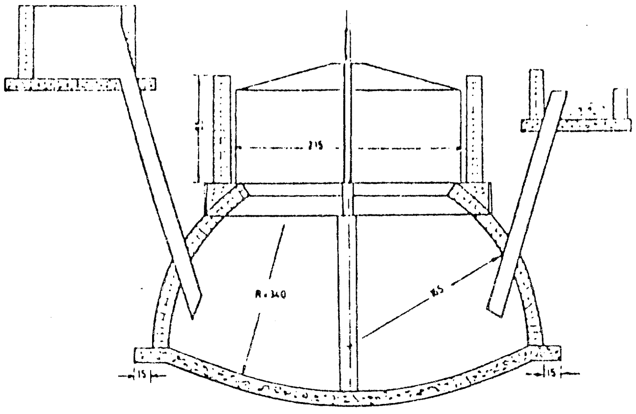
(iv) The gas storage capacity is high while gas losses are reduced considerably;

(v) The effluent flows outside automatically under the influence of gas pressure, thus reducing operating costs.

(c) Modified BORDA-type digester

Figure 19 illustrates the BORDA-type digester that was constructed and tested in Manawat village. The lower part of the digester is spherical, while the upper part in which the floating gasholder is installed, is cylindrical. The base is concrete, the lower and upper parts are made of masonry, while the gasholder is metallic. The digester capacity ranges between 6 and 50 cu m.

Figure 19. Modified BORDA-type digester



The main advantages of this type of digester are that:

(i) It can be easily constructed and operated;

(ii) It is appropriate for medium water-table levels;

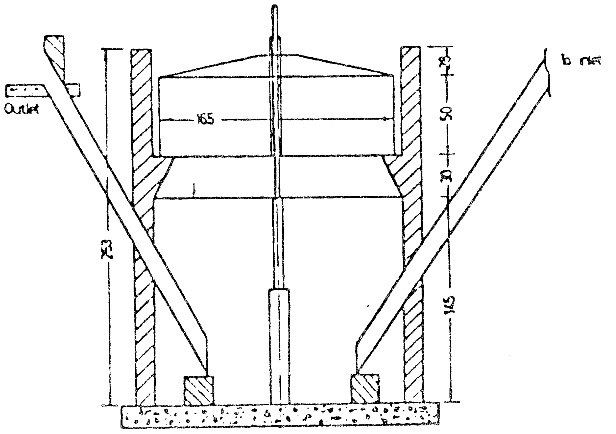
(iii) It is suitable for small- and medium-sized systems.

(d) Modified Indian type digester

Figure 20 depicts one of the modified Indian-type digesters. It is composed of a cylindrical masonry building with a floating metallic gasholder.

The main advantage of this type of digester is that it is easy to construct and operate. Its principal disadvantage, however, is that it requires a deep underground space, especially in the case of a large digester. It is very difficult to meet this condition in most of the Delta region owing to the high water-table.

Figure 20. Modified Indian-type digester

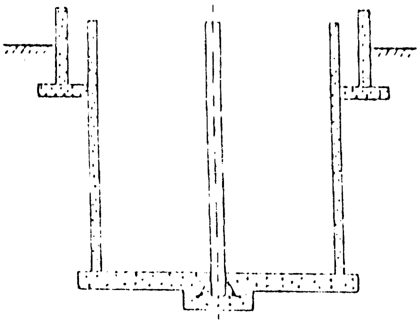


(e) Batch "dry" fermenters

Where there is a deficiency of animal waste, which is quite common in the rural areas of Egypt, the dry fermentation of agricultural residue would be a logical solution. The process is carried out in a batch system with high solid concentrations of about 25 per cent. For the continuous supply of gas, at least two digesters should be constructed and operated in unison, so that while one is operating, the second can be discharged and refed, and so on.

The dry fermenter consists of a digester and gasholder. The digester can be cylindrical or rectangular in shape and made of brick or concrete. The gasholder can be metallic, rubber or plastic. Figure 21 depicts one of the designs for the digestion of agricultural residue.

Figure 21. Dry fermenter



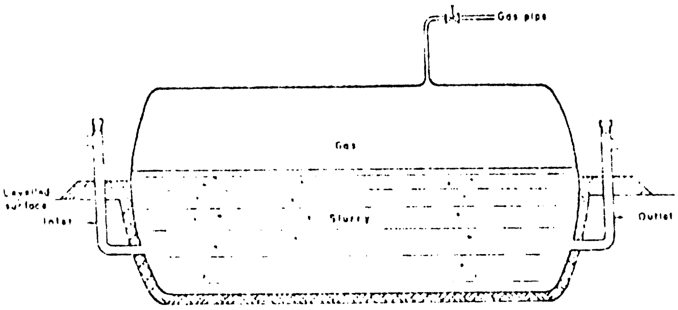
The main advantages of the system are that:

(1) It enables the production of gas where animal waste is defficient;
(ii) It augments the amount of organic fertilizer produced;
(iii) The digester can be located outside the village when there is no space near to the house.

(f) Flexible bag digester

The digester is made from rubber or a plastic material, and is already mass-produced in some countries. A typical design is depicted in figure 22. Taiwan produces durable digesters made from red mud plastic at a reasonable cost. This type of digester could have a wide application in Egypt. A number of digesters of this type were imported for testing purposes, while at the same time work is going on to produce similar types. They are normally produced in sizes ranging from 5-50 cu m.

Figure 22. Flexible bag digester



The main advantages of this type of digester are that:

(i) It is ready-made and portable;
(ii) It is relatively quick to erect;
(iii) It is horizontal, and is thus suitable for a high water-table;
(iv) It has a high gas production rate;
(v) It has a comparatively low capital cost.

The main disadvantage is its low durability under adverse conditions, as it can be easily cut and damaged. However, this can be avoided by taking proper care of the digester and protecting it.

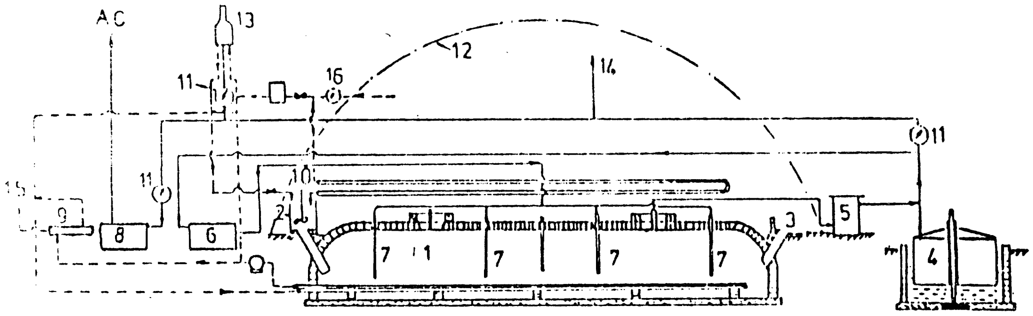
Another digester of this type is under construction at NRC. It is merely composed of a horizontal polyethylene sheet. The cost of this digester is very low. However, its durability under various weather conditions needs to be tested before a complete evaluation can be made.

(g) <u>Fixed-roof tunnel-type digesters (plug flow)</u>

Tunnels are more suitable for large digesters. Therefore, digesters of various designs with a capacity greater than 50 cu m can be constructed in different shapes. Figures 23 and 24 depict a one-channel-type digester that was constructed a Shubra Kas, Garibiyah to serve a poultry-rearing house.

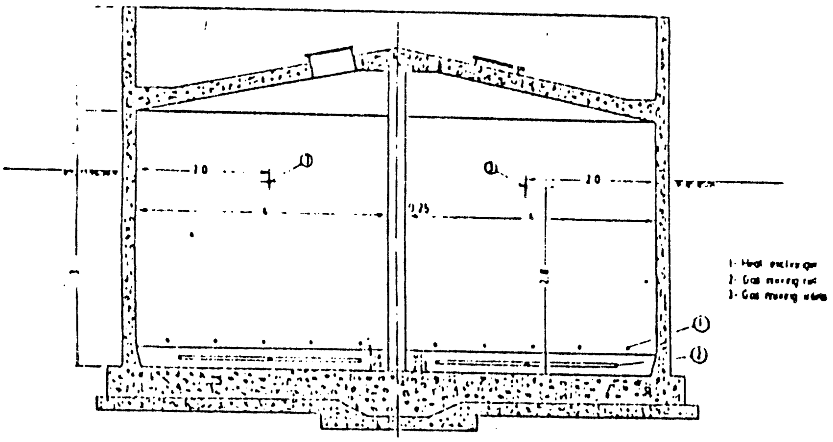
The design is based on a two-channel system. The digesters are built in bricks and concrete. The gas produced can be stored either in a built-in or separate gasholder.

Figure 23. Tunnel-type digester



1- Tunnel digester
2 Feed chamber
3- Effluent outlet
4- Gasholder
5- Gas Scrubber
6- Gas Compressor
7 Gas mixing distributors
8- Electrical power generator
9- Engine waste-heat recycle
10- Solar water heater
11- Gas meters
12 Greenhouse
13- Gas heater
14 Main biogas line
15 Flue gases
16- Water meter

Figure 24. Tunnel-type digester with pyramidical roof



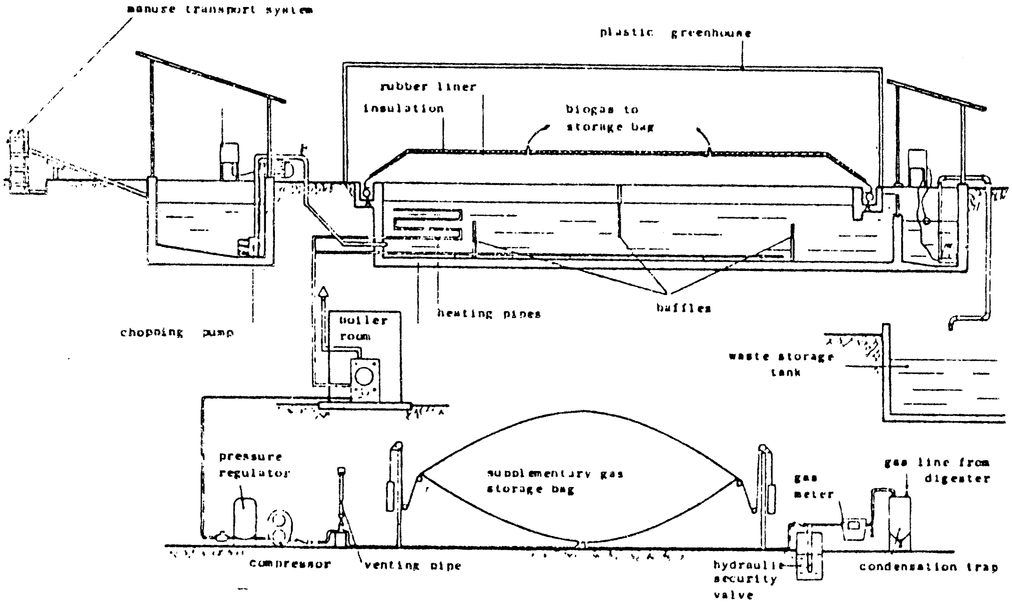
The advantages of this system are that:

(i) It is suitable for large systems such as cattle-raising and poultry-rearing operations;
(ii) High gas production rates are possible, as the design allows for the economic control of the digestion temperature through relatively sophisticated heating systems;
(iii) The depth of the digester can be matched to that of the prevailing water-table at any given locality;
(iv) The cost of the unit is reasonable;
(v) Its plug-flow conditions are conducive to better digestion and, therefore, to higher gas production rates.

(h) Tunnel-type digester with flexible roof

This digester would appear to have one of the most promising designs owing to its relatively low cost compared to the fixed-roof type. The digester is made of masonary or concrete rectangular slabs, while the roof is of rubber or a plastic material. Figure 25 depicts one of the suggested designs.

Figure 25. Tunnel-type digester with flexible roof



2. Potential of biogas technology in the rural areas of Egypt

Despite its numerous outputs and benefits, BGT has not spread as quickly as was expected in many developing countries. The main reason for this is thought to be the inability of the agencies concerned to integrate BGT into target social systems in order to meet actual perceptible needs at an affordable cost, as well as to provide an effective organizational infrastructure that can plan, implement, maintain and follow-up, paying due attention to the available resources and constraints.

In earlier NRC studies, it was shown that on the basis of the distribution of cultivated land and the availability of raw materials, over a million digestion units could be constructed in rural areas. However, taking the constraining cluster structure of Egyptian village housing into consideration, only 400,000 units could reasonably be installed. It was estimated that these units would produce about 0.4 million TOE annually. These estimates, however, were based on the assumption of being able to adapt conventual Indian- and Chinese-type technologies. The development of some of the newer potential designs described earlier in this section, is anticipated to stretch BGT potential beyond previous estimates by mitigating the principal constraining factors in the Egyptian rural context. These include the following:

(a) The lack of land space sufficient for installing units of a house-scale owing to the clustered nature of most village housing areas;

(b) The insufficiency of animal waste in many households owing to limited animal ownership;

(c) The Low productivity of gas under non-heated conditions.

Moreover, a model system for newly-planned villages has been developed in order to encourage the utilization of BGT to the full in areas recently reclaimed from the desert. The application of this model system allows for a 100 per cent utilization of BGT in these areas, as well as for the complete recycling of water and organic matter.

Based on these new developments and modifications, the potential of BGT in rural areas could almost be doubled. As is shown in table 21, the number of biogas units could realistically be extended to more than 1 million. These units could produce about 0.9 million tons of kerosene equivalent per year. Most (around 80 per cent) is expected to be used as residential fuel, while about 20 per cent can be used in agricultural processing. A comparison of these amounts with the projected annual demand of petroleum products by the year 2000 (see table 22) shows that biogas could provide about 28 per cent of energy for residential uses, and about 14 per cent of the demand for agricultural processing.

The biogas that is produced could serve about 9 million people in rural areas if the proposed programme was implemented to its fullest extent. Thus, the role and impact of BGT could be extremely significant.

Table 21. Rough estimation of potential number of digesters for the rural areas of Egypt, classified according to type and characteristics

Type of digester	Capacity of digester (cu m)	Possible number 10^3	Operating conditions		Expected gas rate (cu m/cu m d)	Total digester capacity 10^6cu m	Expected amount of gas 10^6cu m/yr	Percentage share
			temperature (^{o} C)	retention time (days)				
Ready-made	1-2	150.0	30-40	30	0.70	225	55.5	3.91
Mini	1-2	200.0	22-31	40	0.35	300	36.7	2.59
Egyptian-Chinese	6-12	200.0	20-30	40	0.30	1,600	168.0	11.84
	20	4.0	20-30	40	0.30	80	8.4	0.59
	30	2.0	20-30	40	0.30	60	6.3	0.44
BORDA and Indian	6-12	150.0	20-30	40	0.30	1,200	126.0	8.88
	20	8.0	20-30	40	0.30	160	16.8	1.18
	30	6.0	20-30	40	0.30	180	18.9	1.33
	40	6.0	20-30	40	0.30	240	25.2	1.78
	50	4.0	20-30	40	0.30	200	21.0	1.48
Dry fermenter	6-12	400.0	20-35	100	0.20	3,000	210.0	14.80
	16-200	40.0	20-35	100	0.20	1,600	112.0	7.90
Flexible bag	6-12	50.0	23-33	40	0.50	400	70.0	4.93
	20-50	1.0	23-33	40	0.50	30	5.2	0.37
Tunnel type	50	4.0	20-30	40	0.30	200	21.0	1.48
	100	6.0	35	30	0.80	600	168.0	11.84
	200	3.0	35	30	0.80	600	168.0	11.84
	300	1.5	35	30	0.80	450	126.0	8.88
	400-600	0.4	35	30	0.80	200	56.0	3.94
Total		1,235.9					1,419.0	100.00

Table 22. Estimate of possible biogas share in rural energy supply for the year 2000

	Total rural demand 10^6tons	Potential supply from biogas 10^6tons	Biogas possible share (Percentage)
Residential	2.6	0.72	27.7
Agriculture	1.3	0.18	13.8
Total	3.9	0.90	41.5

About 1.23 million digesters could be installed by the year 2000. It is possible to group this large number of digesters as follows:

(i) 350,000 mini digesters with capacities of 1-2 cu m for families who own small number of animals;

(ii) 400,000 family-size digesters with capacities of 6-12 cu m, where there is sufficient animal and poultry waste, and space available for unit erection. The types recommended for this group, in order, are: the Egyptian-Chinese, BORDA, Indian and flexible bag digesters, as shown in table 21;

(iii) 35,000 community-size units (20-50 cu m) that use animal and poultry waste. It is assumed that the waste would be found in one location. The gas produced could serve other nearby families, or be used for other purposes;

(iv) 400,000 family-size dry fermenters with capacities of 6-12 cu m, depending on the digestion of agricultural residues;

(v) 40,000 dry fermenters with capacities of 16-200 cu m. For some of these, the surplus gas would either be shared by other families, or used in agricultural processing;

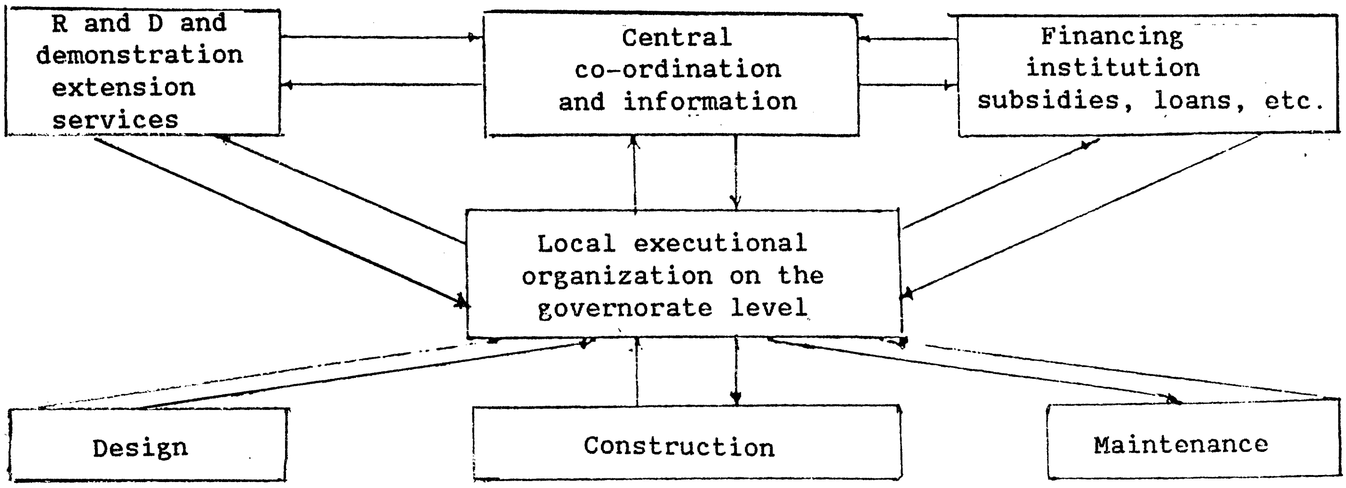
(vi) 10,900 large mechanized units with capacities ranging between 100 and 600 cu m. It is estimated that these units would operate on the waste from large animal sheds and poultry-rearing houses, and that the gas produced would meet the requirements of farm production units, agricultural processing and residential uses. These units would be mainly of the plug flow-tunnel type, with either flexible or rigid roofs.

3. Proposed guidelines for viable infrastructure promotion

The previous rather generous estimates are based solely on the technical potential. In order to meet such challenging expectations, implementation should behandled with an optimum organizational infrastructure that could provide the appropriate vehicle for achieving such highly demanding targets.

The promotion of BGT requires interaction between a number of centralized organizations in order to form an integrated network of agencies capable of planning, financing and implementing this technology. Research and development and demonstration should be the responsibility of the core agencies, which would develop and solve the problems of implementation, and the operation and utilization of products. Figure 26 illustrates the general features of the proposed organizational system for BGT diffusion.

Figure 26. Schematic of the proposed organizational system for the diffusion of BGT



VI. MAIN FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

It can be concluded from the findings of previous chapters that it is technically feasible, economically viable and socially beneficial to convert a large proportion of urban and rural waste into energy. Resource and energy recovery systems are therefore viable alternatives for the resolution of the critical waste disposal problem in some countries of the ESCWA region, the improvement of environmental conditions and, to a certain degree, the production of energy for decentralized use. The economic recovery of this potential energy source is highly dependent on the energy content of the waste and on the level of technical capability in the area of waste collection, handling and and preparation, thermal and bioconversion and plant management.

A properly planned waste management programme that would utilize the various kinds of waste in the country for the production of energy could improve the situation in rural areas, reduce the cost of fuel-oil to generate power plants in cities, in addition to enabling the recovery of valuable by-products in order to make urban and rural waste disposal safe, efficient, environmentally sound and economically attractive.

As the purpose of this study is to identify some of the energy recovery options associated with urban and rural waste management schemes that are of relevance to ESCWA countries, and that could form the basis of potential projects that make use of the results of this study and the experience to be gained from the case study of Egypt, a number of recommended options are presented for consideration.

As has already been mentioned, energy from waste can either be recovered directly or indirectly (i.e. saving energy by recycling material). The options are limited to the first category, since the latter - though very important - belongs rather to the options for material recovery. However, the systems that will be described will also include material recovery components, but emphasis will be on the part related to direct energy recovery.

In the case of direct energy recovery methods, the organic fraction of the waste is processed with the intention of reclaiming energy by combustion or other thermal processes, or by biochemical conversion. Here the generic product is termed a waste-derived fuel (WDF), while the term refuse-derived fuel (RDF) is reserved for processed solid fuel concentrates, normally in a pelletized form that can be stored, transferred and used again in another place as fuel.

Though the options proposed here involve technologies that can be applied to the various types of urban waste that have a rich organic fraction, individually or in combination, the suggested schemes will each emphasize one type of waste. Thus, the first scheme is based on the recovery of methane-rich gas largely from MSW landfills (though equally valid for the combined landfilling of MSW and sewage sludge); the second scheme involves the anaerobic digestion of sewage sludge; the third system, on the other hand centres on the gasification of solid agro-industrial residue. Basically, these options involve feasible and proven technologies deemed to be appropriate to the nature of waste and to the condition of developing countries that are similar in nature to Egypt.

1. Option 1(a). Sanitary landfilling with gas recovery

(a) Rationale

(1) The landfilling of solid waste is a long-practiced technique.

(2) It will continue to be used because it is the ultimate land disposal method (unlike other methods such as incineration or composting which yield a residue that then requires disposal).

(3) As a general rule, it is still one of the most economical waste disposal systems currently in use.

(4) Many cities in the ESCWA region like those in Egypt, have adequate land areas (particularly desert) that could be used as landfill sites.

(5) The recovery, processing and utilization of the combustible gases generated in sanitary landfills can be a cost-effective method of developing an available energy source and should not be viewed as a nuisance and potential hazard. Thus, with the increasing need for energy, it is logical to consider landfill gas as a potential asset and energy source.

(b) Background and basic principles

An overview of sanitary landfilling was presented in a previous section of this report. Complementary information particularly on gas generation and its handling aspects and relevant international practices, is presented here.

The gas generated in a landfill varies widely in composition depending on the age of the fill, the nature of the waste and the landfill site and operating conditions. In the recovery stage, the gas basically contains methane (45-60 per cent), the remainder being composed mostly of carbon dioxide. Minor concentrations of hydrogen sulphide and other trace gases are also present.

In general, a mature landfill that has reached its maximum gas generation rate (34), will produce gas at a high rate for at least six to 10 years, and may continue to produce gas for up to 100 years. The period of commercial operation for a landfill methane recovery field is currently thought to be 10 to 20 years (34).

The theoretical generation of methane from typical American MSW, assuming the complete transformation of all available organic carbon, ranges from 0.43 to 0.51 standard (std) cu m/kg, if received as wet waste. Actual gas production under practical recovery conditions ranges from 0.006 to 0.038 std cu m/kg of wet waste per year, with a common average of about 0.01 std cu m/kg per year (33).

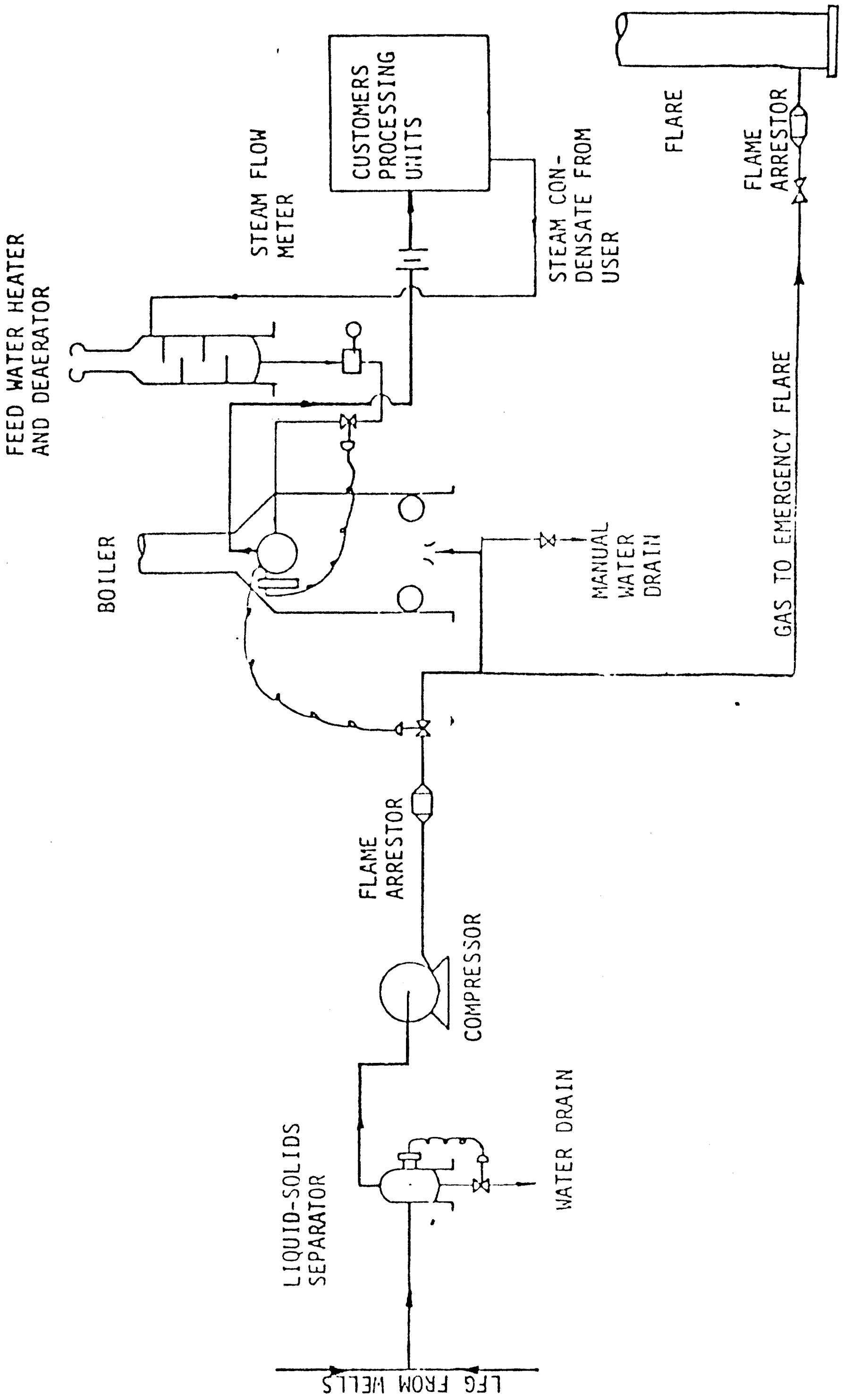
The primary variables that can affect the quantity and quality of landfill gas are: moisture content, pH, temperature, age, nutrient availability, micro-organism distribution, landfill composition, oxygen content, rainfall and the depth of the wells. Optimum moisture content of landfilled waste for maximum gas generation is reported (33) to occur at between 30 and 50 per cent wet weight, although landfills in dry climates with a measured moisture content at or below 20 per cent wet weight have been found to generate gas. It has been noted (35) that landfills in dry climates can have active lives of up to three times the length of those in moist areas (though the latter will produce gas more quickly).

The method of extracting gas usually involves sinking perforated plastic pipes into the landfill and sucking the gas out under vacuum. A major concern of the gas recovery process is how to control the corrosive water that condenses as the saturated gas cools, in order to prevent the blockage of the gas flow through the pipes and to alleviate the corrosion of equipment further downstream. Several discharge systems that use water traps have been developed to allow the condensate to flow from the collection line, but, prohibit air from entering the system (34). Raw gas is either burned "as it is" locally or purified to varying degrees to reach natural gas pipeline quality by removing carbon dioxide, hydrogen sulphide, water and other trace impurities before it is compressed and pumped into gas mains for external distribution. The designers of processers now seem to favour using the gas for on the spot electric power generation, feeding the electricity directly into the grid of the local utility (35), or as a fuel for nearby facilities like a boiler or kiln. The advantage of on-site (or adjacent to the landfill site) utilization is that little or no processing is required. The gas can be used as a medium heating value fuel directly after it has passed through a condensate and particulate separator (33). Figures 27, 28 and 29 offer a schematic presentation of on-site steam generation. In 1979 it was demonstrated (33) that by using raw landfill gas (LFG) as a fuel in such schemes to generate steam or electricity and sold to users at retail prices ($ 2.00/1 million BTU [1/] for gas product and $2.56 for steam, and $0.05/kWh for electricity it was technically and economically feasible, even for operations charging modest landfill gas recovery rates (in the order of 20 std cu m/min).

Methane recovery from landfills is becoming common practice in the United States of America, Canada, the Federal Republic of Germany, the United Kingdom of Great Britain and Northern Ireland, Switzerland and Japan. A large number of landfill gas recovery facilities have come into operation in the United States of America since the practice was first introduced in 1977. The pioneering plants worth noting are: the landfill site at Staten Island, New York (the largest in the world, where about 5 million cu ft/day of upgraded gas is fed into the network of a local utility); the Pacific Gas and Electric Company's landfill gas wells at Mountain View, California; the three operations of Getty Synthetic Fuels at Palos Verdes or Rolling Hills Estates, Monterey Park and Orange County, California, together with two other facilities in Chicago and Calumet City, Illinois; the City of Los Angeles Sheldon-Arleta project at Sun Valley, California; the Azusa Land Reclamation Company's plant at Azusa, California and the Public Service Electric and Gas Company's installation at Cinnaminson, New Jersey. It is expected that the gas that can be recovered economically from American landfills will eventually amount to some 0.4 x 10 15 BTUs per year (of an estimated total of 2 x 10^{15} BTUs the currently escape) (34).

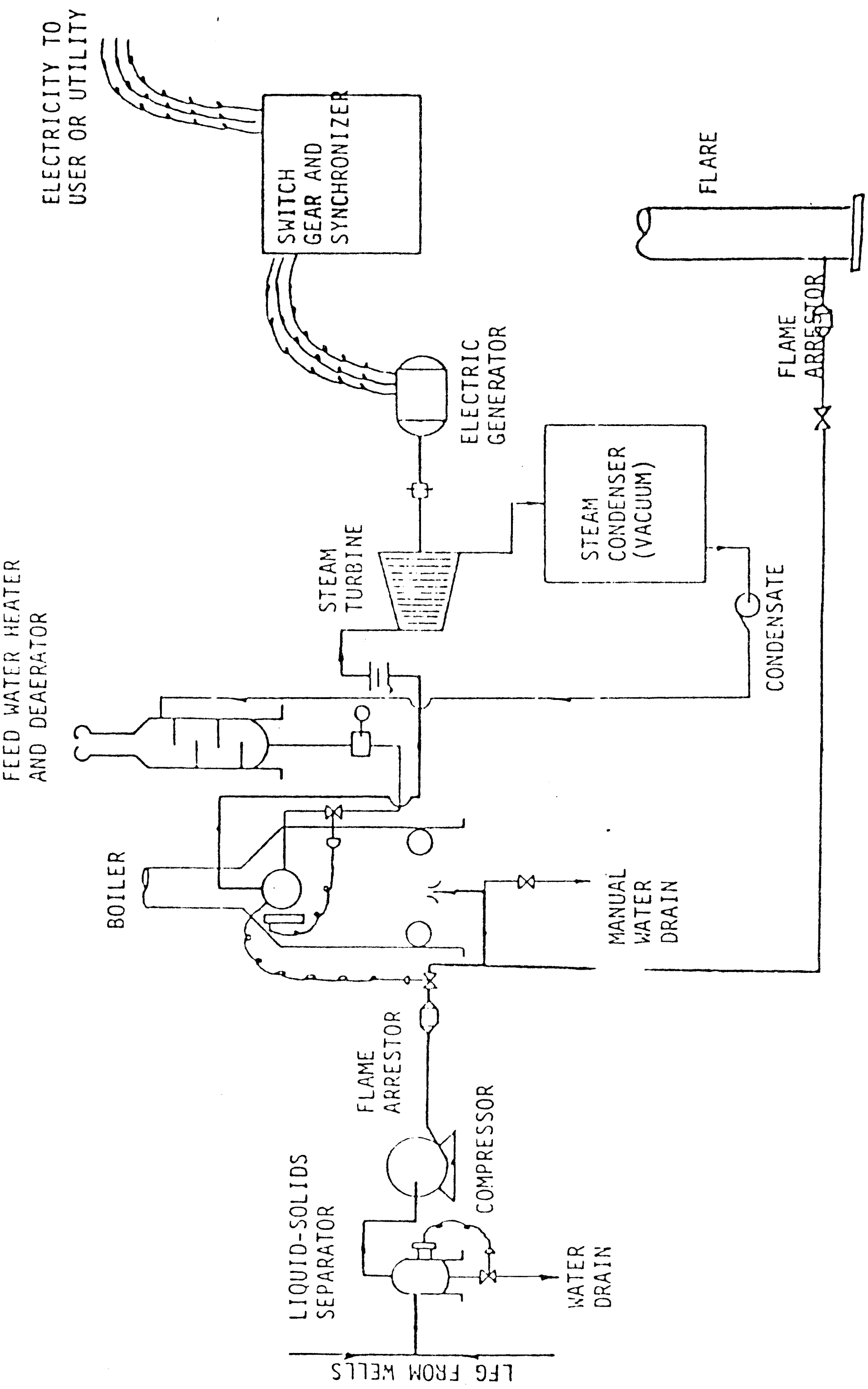
[1/] 1 BTU = 1.05 KJ.

Figure 27. Low or medium pressure/temperature steam generation from landfill gas



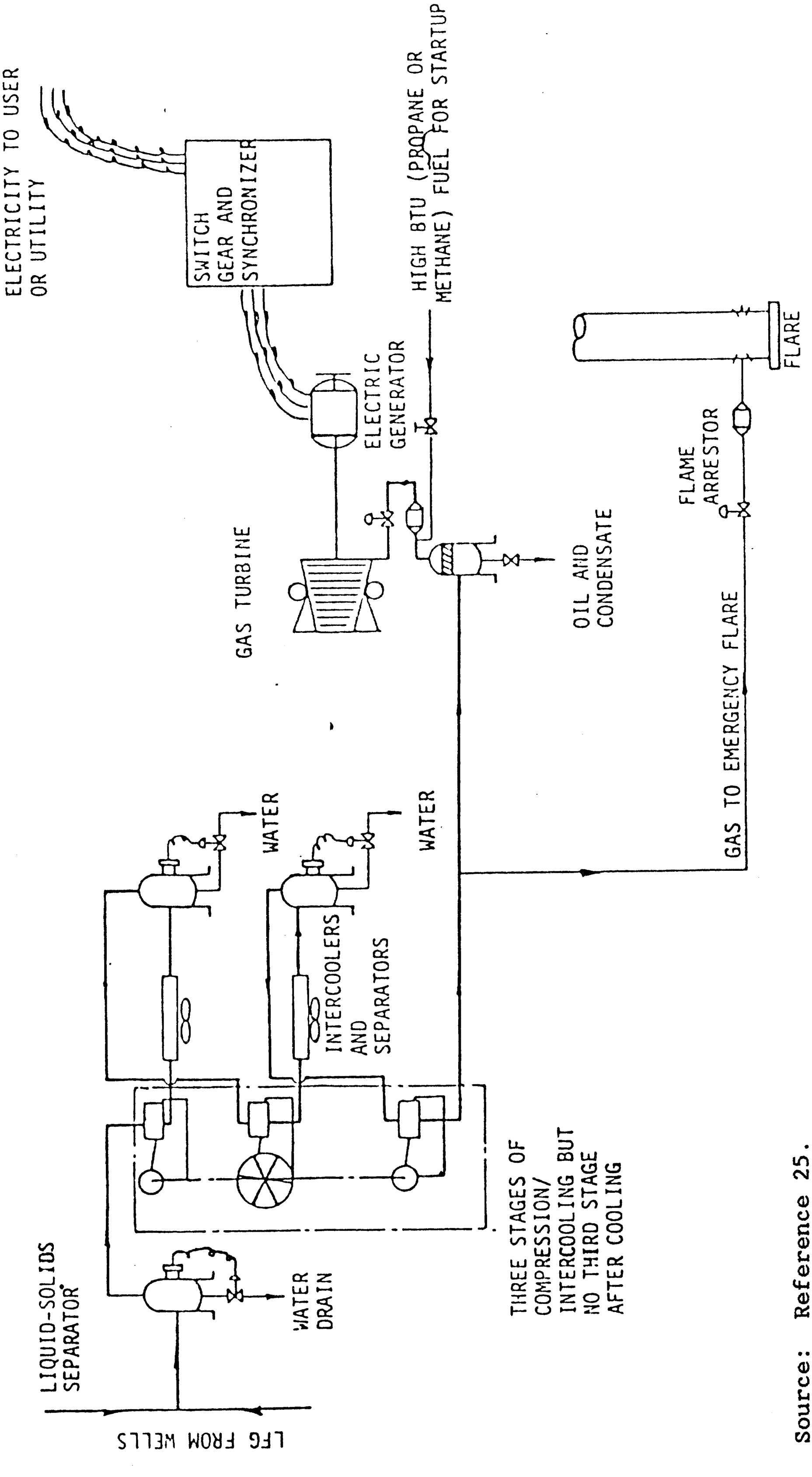
Source: Reference 25.

Figure 28. Electricity generation (steam turbine)



Source: Reference 25.

Figure 29. Electricity generation (gas turbine)



Source: Reference 25.

Several of the Federal Republic of Germany's landfills also use methane to produce power (35). However, it has been found that overall economics improve when energy utilization is raised (to about 83 per cent) by tapping the water used to cool the generators as an additional energy source. For example, a landfill at Pforzheim that produces about 180 cu m/h of gas for electric power generation, also supplies heat to a nearby nursery. A different system is used by a landfill in Braunschweig, where the gas is piped 1.5 km to the local waste water treatment plant to be used as a fuel to drive the surface activators of an activated-sludge basin. The cooling water is also used to heat the plant buildings.

In the United Kingdom, several landfill gas recovery projects have gone onstream since the first demonstration plant was started in 1980 at Stewarthy (near Bedford in England) by the London Brick Co. Ltd., in order to generate gas for firing bricks (where on this site the old quarry is being landfilled).

(c) Proposed system and its preliminary economics

The proposed scheme assumes the existence of a site of about 0.5 million cu m landfill space (like Cairo's first experimental site at El Douika) that has already been lanfilled and is to be used as a demonstration project for landfill gas recovery. For illustrative purposes, the simplest alternative of raw landfill gas recovery and on-site or close to site utilization has been adopted. The gas will be used as a medium heating value source directly after passing through a condensate and particulate separator.

The cost of gas recovery has then to be roughly estimated as being indicative of the possible economics of the system. It should be noted, however, that the size of the chosen demonstration site is small when compared with commercial sites of a normal size, therefore the economics of larger commercial systems would be much better.

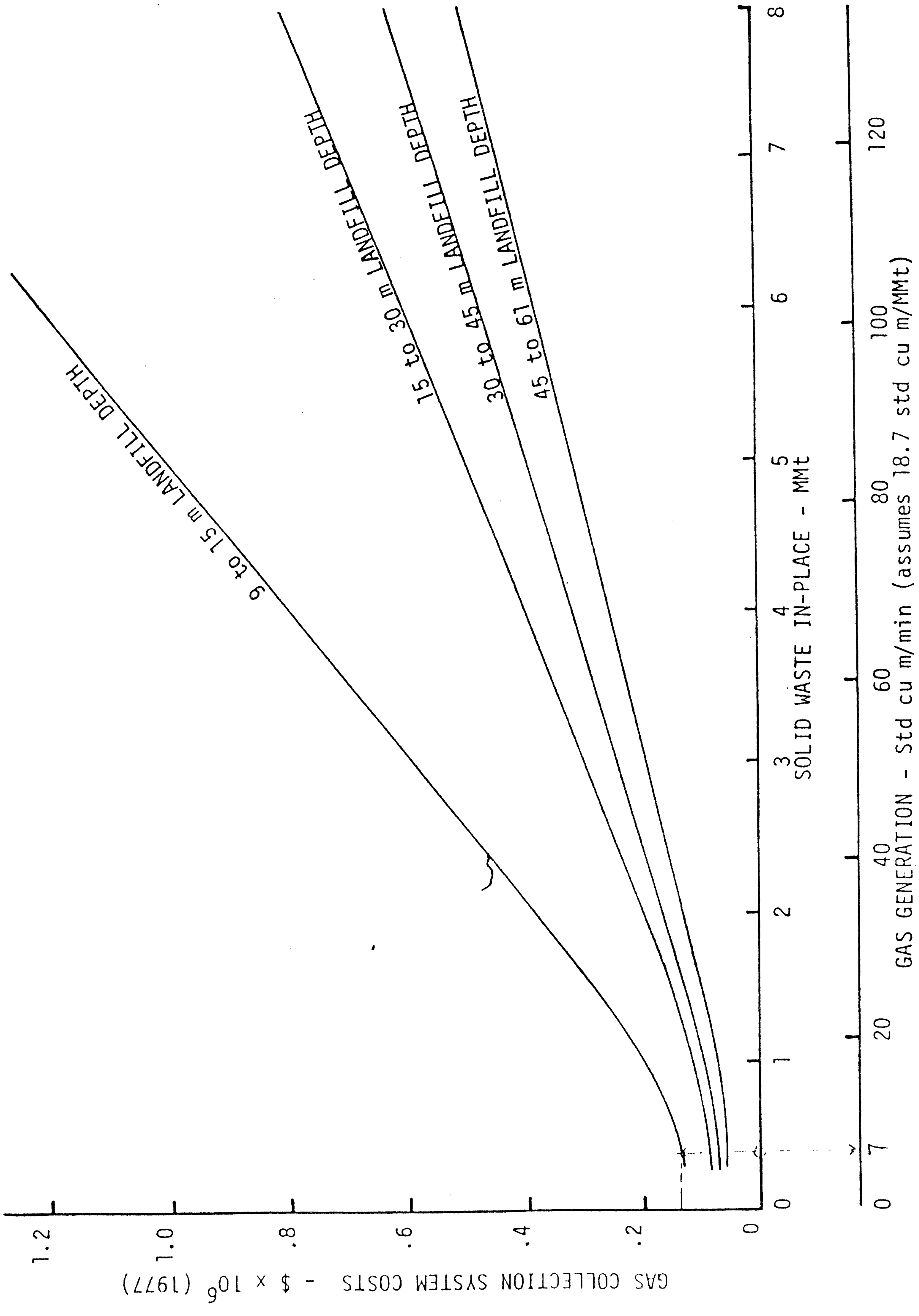
The costs of landfill gas recovery systems that consist of a number of wells, a collection pipeline system and appropriate ancillaries, taken from figure 30, are based on the experience of a number of lanfill gas projects (33). The figures are for the year 1977, and have therefore been scaled to 1987 levels by applying a compound rate of 6 per cent per annum. The most conservative conditions were taken, namely: the shallowest landfill, low gas generation (as in comparison with American MSW, Egyptian waste is rich in biodegradable organic matter), and a very small landfill size (solid waste in place being about 400,000 tons).

Table 23 lists the preliminary capital and annual operating costs data for the proposed system at 1987 prices. These rough estimates give an energy cost of about $US 2 per million kJ. The cost could be as low as one third of this value for larger and deeper lanfill sites.

2. Option 1(b). Landfill composting with gas recovery (36-38) (controlled landfilling)

It is possible that, with the minor adaptation of sanitary landfill methods, a good compost (one that is much needed for agriculture and land reclamation) can be produced by an anaerobic extended pile system. This method has been used in various countries, notably India (38). A pilot scheme should be set up. If successful, it would have the following merits:

Figure 30. Capital costs of landfill gas recovery subsystem



(a) It affects material in addition to energy recovery;

(b) It extends the life of the landfilling site almost indefinitely. This is very important since in many cases, the locations for landfill siting are running short, and new sites become more difficult to find;

(c) It encourages more material recycling by adding sorting before landfilling in order to enhance the composting process and improve the compost product. However, some authorities advise that much caution is needed in sorting the material for recycling at a landfill site, in order not to lead to a resumption of uncontrolled dumping, disturbance and delay in site operation, and the inevitable loss of essential moisture from the refuse by evaporation.

Table 23. Preliminary cost estimates for landfill gas recovery, dehydration and compression

Output: 7 std cu m/min, dehydrated LFG at 17727 kJ/std cu m (475 BTU/std cu ft SCF) and 155 kN/sq m (22.5 pounds per square inch gauge (psig), or for 350 annual days of operation = 62.4 x 10 9 kJ/year energy.

Capital costs $US:	
Recovery subsystem (9-15 m average landfill depth)	240,000.00
Process subsystem (adapted from reference 25)	540,000.00
Total system	780,000.00
Annual production cost $US:	
Operating costs: (adapted from reference 25 to meet local conditions, including salaries and wages, consumables and parts, utilities and purchased services and maintenance)	50,000.00
Depreciation (10 years)	78,000.00
Total production cost	128,000.00
Energy cost ($US/million kJ)	2.05

The following system description is taken from reference 30. Of course, the biogas produced can be extracted as described before. No data is available at present on the costing of such a system.

Method of landfill site composting:

(a) An experimental pilot scheme needs to be set up at one of the sanitary landfill sites;

(b) An area should be levelled and an enclosing bund three metres high should be formed to accommodate compacted refuse in a single layer of about 10,000 cu m (or alternatively, a suitable area could be excavated). The area would need to be about 4,000 sq m. The depth of the compacted layer of refuse should be 3 m;

(c) Refuse would be placed and consolidated in the usual landfill manner, but before covering the surface should be well watered (up to 300 litres per sq m), and the whole area should be covered as quickly as possible with 0.5 metres of cover material;

(d) Apart from temperature monitoring during the first 14 days after being deposited, the area should be left undisturbed for 12 months. Samples of the refuse compost should then be taken for agricultural analysis. If biological breakdown is satisfactory, the cleaning and screening process can then commence. If not, a further period of, say, six months should elapse before the material is removed;

(e) The sand cover should first be carefully stripped off the refuse. The refuse-compost should then be excavated and processed by portable rotary mechanical screens in order to remove inert and non-composted material. Mesh screens similar to those used at the Shoubra compost plant would be satisfactory;

(f) The reject material from the screens should be landfilled in the usual way;

(g) The liquid applied to the surface of the deposited refuse could be the contents of cesspits or settled sewage.

3. Option 2. Anaerobic digestion of sewage sludge

As described above, sludge management plays a basic role in the treatment and disposal of municipal waste water. Slurries that are high in suspended solids, commonly referred to as sludges, are produced by the concentration of solids originally present in the waste water (raw primary sludge), or the formation of new suspended solids from dissolved solids after secondary treatment, for example. Such sludges cannot be utilized or disposed of properly without some sort of treatment. For example, raw primary sludge is odorous and full of unwanted constituents like pathogenic organisms, and cannot be discharged without prior treatment. In many municipal waste water treatment plants, particularly in developed countries, sludge stabilization by anaerobic digestion is now common practice.

Though the option here is specifically for sewage sludge, anaerobic digestion has many potential applications in the field of industrial waste water treatment. An example has already been described in the context of the Egyptian case (the case of the distillery and organic chemicals manufacturing plant, near Cairo). Candidate feedstocks for anaerobic digestion include food-processing waste water that contains readily degradable organic material whose carrying water has a normal complement of inorganic ions (39).

(a) Rationale

(1) Many developing countries like Egypt are planning, building or rehabilitating proper municipal waste water facilities for which sludge stabilization by anaerobic digestion is a promising option;

(2) The technology has been in practice for a long time, and has proven its worth both technically and economically;

(3) Full resource recovery in terms of materials (digested sludge that can be used as organic fertilizer) and energy (biogas) can be effected;

(4) The biogas that is generated can be utilized internally within the waste water treatment plant, and will provide around 60 per cent of its total energy requirements;

(5) Because of its inherent energy efficiency and low chemical requirements, anaerobic digestion has become the most widely chosen stabilization process for medium- and large-size municipal treatment plants (5), and it also offers the potential for offsetting a sizable portion of sludge treatment costs through energy recover in the form of biogas.

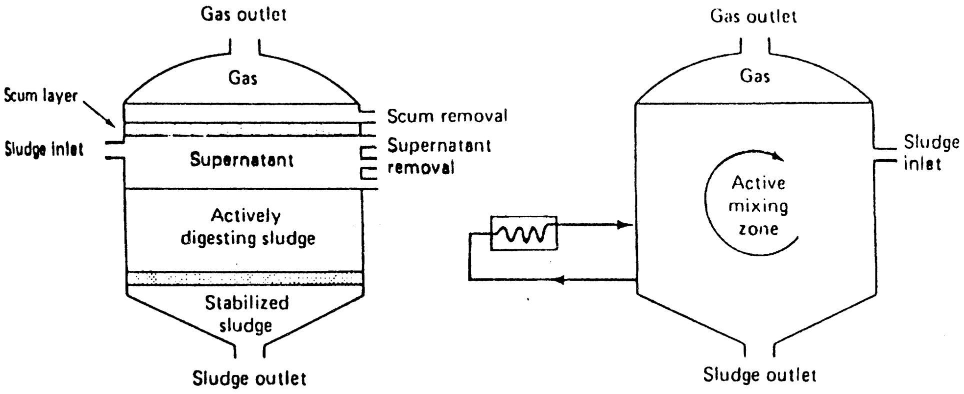
(b) Background and basic principles

The general features of anaerobic digestion technology were outlined earlier. Further information specifically related to municipal waste water sludges will be presented here.

Anaerobic digestion has been used in sewage treatment facilities since before the turn of the century. Many new high-rate process innovations have been introduced to increase the efficiency of the system. Of these, two-phase digestion, the anaerobic contact process, the upflow fixed bed and the sludge blanket reactor are most interesting.

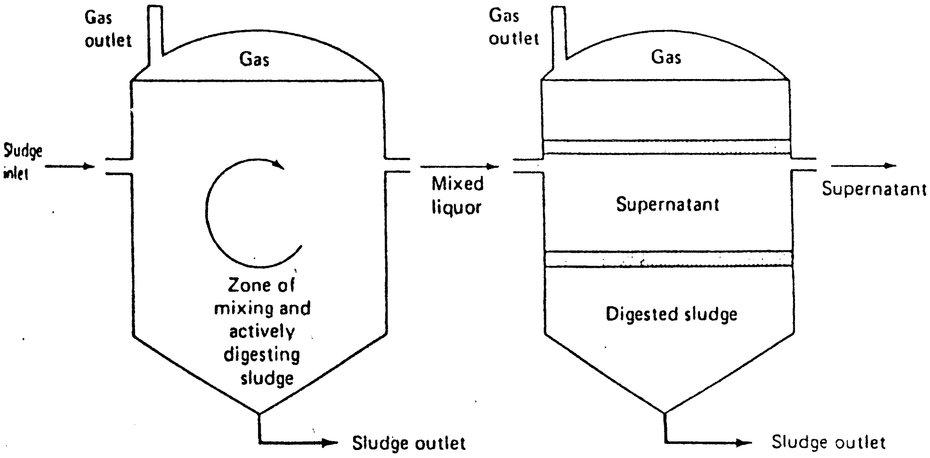
Anaerobic bioconversion technology has certain disadvantages as well, which normally limit its use to small-scale applications in particular. These are its high capital cost and vulnerability to operational malfunctions as a result of organic shock loadings, and toxicants emanating from industrial waste that have failed to undergo proper in-plant pre-treatment. Thus, the conventional one stage process is usually only economically feasible in relatively large treatment plants. A sludge treatment plant catering for 200,000 inhabitants would come close to the break-even point, and would need about 5,000 cu m. of digester capacity (40). There are claims that some new innovations like the two stage anaerobic process would alleviate the disadvantage of conventional techniques. It is claimed that the digester capacity compared with a one stage process, could be reduced to less than 30 per cent under optimum conditions, and that plant costs would accordingly be reduced to about 40 per cent. Schematic flows of the standard and high rate, as well as the two stage digestion processes are shown in figure 31 (5). Standard-rate digesters require 30-60 days solid retention period and a capacity of 0.03-0.10 cu m/capita (depending on the type of sludge, the lower figure being for primary sludge); on the other hand, high-rate digesters only require 10-20 days solid retention period and a capacity of 0.02-0.04 cu m/capita.

Figure 31. Typical anaerobic sludge digesters



(a) Standard-rate sludge digestion

(b) High-rate sludge digestion



(c) Two-stage sludge digestion

The standard-rate digester, the older type, consists of an unstirred, unheated tank with a retention period of several months. In contrast, high-rate sewage digesters are heated and stirred in order to obtain even the suspension of sludge particles and to prevent scum formation.

Sewage sludge digesters vary in size and typically fall within the range of 500-1,000 cu m, with the gas being collected either under a fixed roof or in a floating steel gasholder. Concrete is the usual construction material used for digesters.

A great deal of interest has been shown in using the methane-rich digester gas as an energy sources to heat the digesters and buildings, and to drive engines or generate electricity. One of the ways of estimating digester gas capacity is work on a figure of 0.03-0.04 cu m per person per day (5), though lower figures (0.015-0.022 cu m per person per day) have also been reported (41).

The gas collection system should incorporate fixed or floating covers, gas piping and pressure relief valves, adequate flame traps, gas compressors, gas meters and a gas storage tank.

(c) <u>System description and its economics</u>

The use of anaerobic digestion as an option for sewage sludge was proposed in two studies relating to renewable energy in Egypt (42 and 43).

The system proposed in the first study (43) was based on a typical Cairo or Alexandria waste treatment facility with an input capacity of 400,000 cu m/day. The sludge digestion system consists of five two stage digester vessels, each measuring 100 ft by 31 ft, five filtration units, each powered by a 75 hp vacuum pump, a series of six 10 hp pumps, a series of five 5 hp pumps and steel piping. Also included is a wet-well for water purification. Such a system is claimed to be representative of American sewage treatment systems. The output of this system would incorporate 1.1 million cu m of biogas with a heating value of approximately 700 BTU/std cu ft, i.e. a total energy output of 8.2×10^{11} J per day, in addition to about 315 tons/day of effluent suitable for use as a fertilizer/soil conditioner. It has been estimated that the anaerobic digesting system for an existing sewage treatment plant with an input capacity of 400,000 cu m/day would cost about LE 2.2/cu m of capacity.[1/] Annual operating and maintenance costs were assumed to be 5 per cent of the capital cost, and the life of the plant was assumed to be 20 to 30 years. If the resulting fuel gas were used to generate electricity, its estimated cost would be in the order of LE 0.006 to LE 0.009 per kWh, compared with marginal generating costs on the existing Egyptian grid of LE 0.002 to LE 0.030 (subsidized prices), or LE 0.013 to LE 0.047 (world prices).

The option in the second study (43) is thought to be one of the most promising. Analysis was based on two American systems: a system planned for the sanitation district of Los Angeles County, California, and another being

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[1/] The equivalent at the time of the study was LE 1 = $US 1.4; now $US 1 = LE 1.36.

tested in the city of San Diego, California. Both systems were scaled down to the typical Cairo area, estimated to be about $0.03-0.05/kWh equivalent to petroleum at about $17-28/barrel). For a 400,000 cu m/day sewage treatment plant, it is estimated that the total capital cost (1985) would be about $7 million, and that the daily electricity output would be about 54 MWh. Such a system would have numerous potential application sites.

4. Option 3. Energy from rice husks

This is an example that typifies the use of agro-industrial waste. The use of such residue for power production is not new: sugar mills, for instance, have been burning bagasse for many years to provide steam. The world-wide utilization of rice husks for energy purposes was formalized a hundred years ago (44).

(a) Rationale

(1) Because of the special characteristics of rice husks, on-site energy recovery is one of the most probable uses. Its apparently low density (about 0.1 g/cu cm) makes it difficult and costly to transfer, handle or store;

(2) The high silica content of the husks (about 17 per cent) makes recovery as an abrasive ash a worthwhile by-product of the energy recovery system;

(3) The calorific value of rice husks is about 3,200 kcal/kg (about one third that of oil, and about the same as wood waste);

(4) Various technologies that utilize rice husks for energy are now available, and considerable progress has been achieved over the past decade;

(5) Rice husks produced from scattered rice mills provide a good opportunity to decentralize electricity generation using thermal gasification technology;

(6) In Egypt, more than 400,000 tons/year of husks are produced: 60 per cent come out of village huller mills, while 40 per cent are produced in government-owned rice mills (which number about 54). Only about 8 per cent of the available rice husks in Egypt are used as fuel in boilers to produce the steam powering the prime mover of the mill. The black ash (char) that remains after burning the rice hulls is used as a raw material in the manufacture of heat-insulating refractory bricks, or as an abrasive for polishing metal. At one time most of the husks produced in government mills were used both as an ingredient and as a fuel mixed with furnace oil in the manufacture of redbricks. They are no longer used as the Government banned soil-stripping (and thus redbrick manufacture), and accordingly most of the rice husks produced now accumulate in mills and have little profitable use.

(b) Background and basic principles

Burning is one of the oldest and commonest methods of disposing of rice husks (45). They may be burned directly to generate steam, or they can be pyrolyzed or gasified in order to provide gas for power (in the case of pyrolysis, along with tarry products, which also have a fuel value). Husks are an almost sulphur-free source of energy.

Husks may be burned to varying degrees in order to yield charred hulls, high carbon ash, low carbon ash and essentially carbon-free ash. The predominant component of ash is silica (around 95 per cent). Thus, the ash could almost be considered to be a slightly impure silica. The complete combustion of char in a controlled oxygen atmosphere produces a valuable ash which mainly consists of amorphous silica (46).

Mahin (48) recently made a comprehensive review of the past, present and potential use of rice husks in the production of mechanical and electrical power in developing countries, with particular reference to rural areas. For the most part the following account is abstracted from this source.

Energy can be produced from rice husks using steam technology via husk-fired boilers, or through gasification systems. The latter type of technology will be emphasized here.

Rice husks are burned as boiler fuel in three different situations in medium-sized or larger rice mills:

(1) In older mills the steam from husk-fired boilers is used to provide mechanical power for rice milling in steam engines or turbines;

(2) In another group of mills, the steam from husk-fired boilers is used as a source of heat for the parboiling of rice;

(3) In some larger mills, steam is used to generate electricity in steam engines or turbines.

Husk gasifier systems were employed as early as 1910. Between 75 and 100 up-draft gasifiers (air enters at the bottom and gas is present at the top) were built by Italian and British firms. In the late 1970s, when renewed interest in producer gas systems was sparked by the rapid oil price increases, technology turned to down-draft systems. These gasifiers produce gas with a lower tar content than that produced by up-draft gasifiers. Early developments with narrow-throated down-draft gasifiers revealed the existence of severe problems with rice husks. Recent developments, particularly the throat-less Chinese gasifiers, have met with greater success.

The Chinese unit consists of a throat-less cylinder surrounded by a jacket of cooling water; it has a powered rotating grate and a water-sealed ash pit. An evaluation of the system indicates that it shows much promise.

In addition to the gasifiers, the gasification system includes gas-cleaning trains and the use of gas in internal combustion engines, as well as a generator for electricity production.

Gas-cleaning in the case of rice husks creates more of a problem than does that connected with other biomass sources. First, the gas contains unusually large quantities of entrained ash and char, owing to the high ash content of the husks and its special ash characteristics. Secondly, the gas from throat-less gasifiers contains a high percentage of tar owing to the failure to achieve high temperatures in the hearth of narrow throat gasifiers. The Chinese husk gasifier is said to produce gas containing 2 to 3 grams of ash and other particulates, and about 500 mg of tar per cu m.

The gas-cleaning system usually consists of a cyclone dust separator, a rice char filter, and a wet (water) scrubber. The effectiveness of such a system is extremely important when determining the effectiveness of a gasifier system that provides gas for an engine.

The energy content of producer gas from the Chinese husk gasifier is said to range from 3.2 to 4.2 MJ/cu m. A spark-ignition engine can be operated on 100 per cent producer gas, whereas with a diesel engine some diesel fuel is needed to ignite the fuel mixture. The maximum diesel displacement with gas is around 80 per cent.

(c) The proposed system and its economics

The system proposed here is based on the use of a Chinese husk gasifier in a normal-sized rice mill. Part of the husks will be utilized for energy production, in particular, electricity for the mill needs. Additional electricity could be generated for other nearby uses, for example in rural electrification or rice irrigation.

A typical system of this kind for rice-husk gasification in Mali was recently described (48). The results indicate that the generated electricity costs a little less than $0.1/kWh, while the power from a diesel system (at $0.45/litre) costs about $0.18/kWh. It should be noted that the value of the silica ash by-product was not included in the calculations.

In all gasifier systems, the economic attractiveness of the system depends on the ability to achieve substantial net savings in fuel costs that will offset the additional capital and operating costs of the gasifier system, when compared with a system that uses petroleum fuels (47). The most economically attractive rice husk gasifiers are those that can operate for rather long annual periods and that produce a substantial surplus of power over that required for rice-milling, in view of the spread of fixed capital costs over a large number of power units.

A preliminary assessment (47) of the pay-back period for a $2,500 gasifier (small system) and cleaning train for use with an existing engine could be obtained by making the following assumptions:

15 hp engine
0.25 litre/hp/h diesel consumption without a gasifier;
$0.30/litre diesel price;
1,800 h annual operating period;
70 per cent diesel displacement rate.

If a gasifier system were to be used, the annual fuel cost saving would be $1,418, and the pay-back period would be in the order of 2 years.

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