VII. SUPPLY OPTIONS USING LOCAL ENERGY RESOURCES

A. The Resource

Renewable energy sources and the use of domestic and industrial wastes can constitute viable energy supply solutions at a local level. The various issues that will be dealt with in this Chapter are evaluation of the local resource, production and distribution technologies, conditions necessary for market development, environmental and energetic impact.

Most cities throughout the world face similar problems with regard to the management of refuse. It is becoming increasingly costly to maintain existing land fill and waste water treatment methods, and inadequate waste treatment can present serious health and environmental problems. In some cities, the large volumes of domestic, commercial and industrial waste have been treated as a resource rather than a burden. New strategies have been adopted that use the energy generation potential of waste to simultaneously reduce environmental impact, reduce disposal costs and to create a new income stream.

Waste organic materials have an energy value and hence can be used as a source of renewable biomass. Biomass refers to organic matter which can be converted to energy. Some of the most common biomass fuels are wood, agricultural residues and crops grown specifically for energy. Biomass dominated global energy consumption until the middle of last century. It still remains an important energy source and contributes about 14% of the world’s energy and 38% of the energy in developing countries.

Substantial energy content is dissipated in the form of discarded waste every year. Using conversion systems and techniques already commercially available or being demonstrated, a large component of this ‘technical potential’ can be economically exploited at current energy prices. Further technological development and the increasing costs of waste disposal will result in a dramatic increase in the generation of energy from waste.

Waste resources include Municipal Solid Waste (MSW), sewage sludge and effluent, food-processing residues, and industrial effluent. They are generally divided into two streams: *wet* and *dry* waste.

MSW is not an energy resource but the end stage of many very complex and ever changing production and consumption processes. It “contains nothing in particular and a bit of everything in general”. Worldwide, the dominant methods of MSW disposal are to place it into landfills or on open rubbish tips. Although these disposal methods often have low initial costs, they may contribute to serious local air and water pollution, and in some instances have resulted in pest infestations and outbreaks of diseases in local communities. They also release methane, an explosive gas with a high global warming potential.

In many parts of the world, it is becoming increasingly difficult to locate suitable landfill sites. Recycling, incineration and waste-to-energy systems are increasing in popularity, particularly in the major population centres. Recycling programmes exist in many urban local government areas, particularly for paper, aluminium, steel, glass, plastics and to a lesser extent hazardous materials such as batteries (lead acid) and hydrocarbon products. These have gradually reduced the amount of solid waste going to landfill sites. As part of the transition towards more sustainable lifestyles, the processing of MSW is essentially and inherently a fractionation and refining process hopefully generating a range of commercial co-products, of which energy, in the form of heat, gas, oil, or power, is only one component.

Liquid by-products of effluents from industrial processes and sewage treatment usually have a high water content, hence the use of the term "waste water" to describe these products. Liquid waste streams are generated by washing meat, fruit and vegetables; blanching fruit and vegetables; pre-cooking meats, poultry and fish; wool scouring; dairy whey; grease traps; spent brewery wastes and wine making and, other cleaning and processing operations.. These effluents contain sugars, starches and other dissolved organic matter, but in a relatively dilute form. The potential exists for these industrial wastes to be anaerobically digested to produce biogas, or fermented to produce ethanol, and many commercial examples of these waste-to-energy conversion routes already exist. Liquid waste in the form of recycled frying oils collected from restaurants and other olefinic wastes such as low-grade beef tallow may also be used to produce diesel fuel, called bio-diesel.

Gaseous by-products of industries associated with the extraction and refining of fossil fuels are also used to produce energy, yielding both financial and environmental benefits. Heat, another by-product of many industrial processes, can also represent either a pollutant or a resource. In some instances there is the potential for some of this heat to be captured and recycled to increase process efficiency, or it may be profitably used for local heating needs, or even converted into electricity for on-site use. Distributed power generation with Combined Heat and Power systems enables the exploitation of waste heat resources.

B. Technical Approaches

Organic waste-to-energy technologies can be broadly classified as either bio-chemical or thermo-chemical processes, and will be individually discussed below.

1. Biochemical Conversion

Digestion is a bio-chemical process by which organic waste is broken down by the action of bacteria into simple molecules, either aerobically (with oxygen) or anaerobically (without oxygen). Aerobic digestion takes place where the waste is aerated, such as in the early stages of decomposition of municipal solid waste and during composting. Anaerobic digestion takes place where the waste has restricted aeration, such as in the later stages of the decomposition of MSW or in the digestion of sludges or waste water in enclosed digestion vessels. Aerobic digestion produces carbon dioxide and water, whereas anaerobic digestion produces methane and water, and some carbon dioxide and hydrogen sulfide. The gas produced by anaerobic digestion can be combusted and used to produce electricity or heat, thereby converting the methane gas to carbon dioxide (with a lower global warming potential).

Anaerobic Digestion

Anaerobic digestion is the decomposition of wet and green biomass through bacterial action in the absence of oxygen to produce a mixed gas output of methane and carbon dioxide known as 'biogas'. Biogas can be used as a substitute for fossil fuels. Both liquid and solid wastes or green crops can be digested to produce biogas. The natural decomposition of organic wastes in the absence of oxygen (anaerobic decomposition) by mesophilic bacteria also occurs on the bottom of lakes and wetlands shown by gas bubbles rising, and is one of the major greenhouse gases resulting from hydropower installations when the surrounding land area is first flooded and the vegetation decomposes over fairly long periods of time.

The breakdown of organic materials involves a number of biological steps, each involving a defined class of bacteria. These bacteria absorb energy for their survival from the gradually decomposing biomass which is finally converted to methane, carbon dioxide and water. The process can be encouraged by placing the organic material in large airtight tanks known as digesters, and biogas produced is captured for use. Digesters range in size from around 1m^3 for a small household unit to as large as 2000m^3 for a large commercial installation. As a result, odours are removed and the pollution potential of the waste is reduced.

Biogas can be burnt directly in thermal applications displacing natural gas in cooking and space heating, or used as fuel in internal combustion engines to generate electricity. Some recent applications have used scrubbing techniques to upgrade the quality of the gas by removing carbon dioxide and hydrogen sulfide.

Case Studies 59 on the Anaerobic Digestion of Food Wastes, 60 on Industrial Food Wastes and 61 on the Utilisation of Biogas from Brewery Wastes.

Aerobic Digestion

Aerobic digestion, the bacterial decomposition of organics in the presence of oxygen, takes place during composting processes. Thus during the initial stages of the decomposition of landfill and during some waste water treatment processes.

Aeration is a very energy intensive operation, and does not have the potential for net energy gain that is possible by closed vessel anaerobic digestion. Where it is used for waste water treatment, aerobic digestion tends to produce greater quantities of sludge and have a greater overall environmental impact than comparable anaerobic processes. It is often argued that closed vessel anaerobic digestion involving methane capture and use is a more desirable process than aerobic composting. This is because aerobic composting may become poorly oxygenated, and under these circumstances will become anaerobic and produce methane that will escape into the atmosphere. This presents a higher greenhouse potential and a is potential flammable hazard.

Landfill Gas

Improved designs and management of landfill facilities can overcome litter, odour and leachate problems associated with landfill by lining and covering the tip, and by controlling access to trucks or rail wagons delivering wastes from local land transfer stations where recycling is encouraged. This cost is passed on to the users of the facility in terms of depositing the waste material.

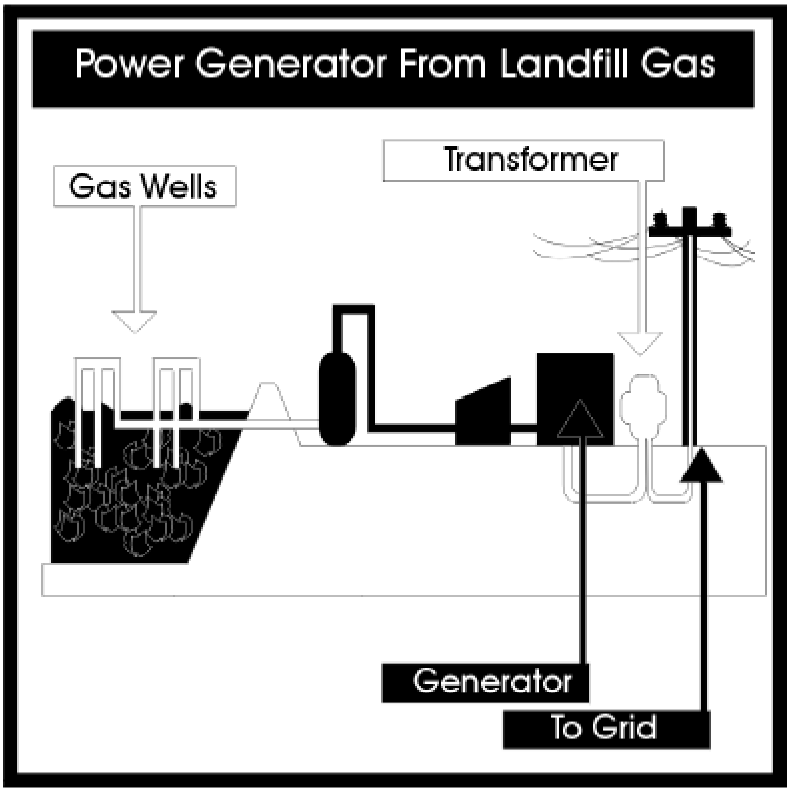

Figure 7.1: Schematic diagram of the generation of power from landfill sites.

Many communities aim to minimise the volume of materials going into landfills by encouraging the use of garden refuse for mulch and compost, recycling glass and metals, and utilising any combustibles for "waste-to-energy" projects. Regardless, at this point in time the majority of wastes end up in a landfill. The aim then should be to avoid methane emissions for both environmental and safety reasons, since the gas is flammable and has caused explosions in nearby buildings after seeping through the ground and accumulating.

Landfill gas is an adventitious fuel that is a by-product of current land filling practices and hence occurs only after MSW has been unsuitably disposed of. The anaerobic digestion of the buried solid organic waste produces the landfill gas naturally, as the bacterial decomposition of the organic matter continues over time. It is an extremely inefficient way of recovering energy from MSW.

Unless properly captured and extracted, methane produced in landfill sites normally escapes into the atmosphere contributing to greenhouse gas emissions and creating a potential combustion hazard. In the extraction process, the gas is removed via perforated pipes that have been inserted into the landfill. Landfill gas travels through the pipes under natural pressure or a slight vacuum, to be collected and used as an energy source, rather than simply escaping into the atmosphere. The burning of the methane to produce carbon dioxide and water also reduces the greenhouse impact of landfill, as carbon dioxide is a less potent greenhouse gas than methane.

In theory, up to $300m^3$ of biogas per tonne of waste can be extracted from a landfill gas site over a ten-year lifetime. This represents an energy content of about 5 GJ (gigajoules). In reality, because of the nature of landfill designs and construction, and the high component of non-putrescibles in the MSW, landfill gas projects produce only between 25 -50% of their theoretical gas potential. The assessment of landfill gas resources is discussed in Section D.

See Case Study 62 for an example of landfill gas projects.

Dedicated Anaerobic Digestion of Solid Organic Waste

Anaerobic digestion of MSW provides a more controlled and reliable means of extracting energy than by collecting landfill gas and is becoming a more common path for treatment of MSW in many cities.

The benefits of anaerobic digestion include:

- improving landfill management
- reducing the volume and odour of landfill
- avoiding production of methane in landfills
- enabling recyclable material to be reclaimed
- collecting all of the gas produced
- producing another useful end product – soil conditioner

The methods that have been developed for dedicated anaerobic digestion of solid organic waste include dry continuous digestion, dry batch digestion, leach bed processes, wet continuous digestion, and multi-stage wet digestion. Examples of these technologies are the Valorga process in France, the Dranco process in Belgium, Kompogas in Switzerland, Funnel Industries in the US, Biocel and Paques in The Netherlands, Avecom in Finland, Italba and Snamprogetti in Italy, Herning in Denmark, BTA and ANM in Germany.

Anaerobic Digestion of Waste Water

Methane recovery and use in the treatment of waste water can significantly reduce the amount of energy required to run the plant, and in some cases enable energy to be sold. Process changes that enable the capture of methane are also able to improve the environmental performance of the plant.

Biogas from waste water treatment plant sludge digestion is typically 60-70% methane, 30-40% carbon dioxide (CO_2), up to 0.5% hydrogen sulphide (H_2S), with some other inert gases and water vapour. Scrubbing systems, which remove H_2S and CO_2 are often used.

See Case Study 63 on the Anaerobic Digestion of Municipal Wastewater.

Assessment of the energy production potential of municipal waste water is described in a following section.

2. Thermochemical Conversion

Thermal processing of organic waste materials can produce heat or a number of liquid or gaseous fuels. The three main options for recovering energy from solid refuse are by:

- mass burn (combustion or direct incineration) of MSW without pre-treatment.
- production of more or less refined fuels out of the main waste stream either partially processed or highly processed refuse derived fuels (RDF) in the form of pellets for later combustion in incinerators (such as rotary kilns) or via new pyrolysis or gasification techniques.
- the development of new approaches involving the recovery of chemicals such as plastic monomers combined with gasification, pyrolysis, hydrogenation and/or reforming of the gases and oils produced.

Direct Combustion and Incineration

Also described as mass burn or direct incineration, direct combustion is the burning of waste to produce heat for cooking, space heating, industrial processes or electricity generation. Ash from the incineration process can also be sold to the construction and road building industry to further reduce the amount of material to be ultimately disposed. Dry wastes are required for direct combustion, and dried sludge from waste water can also be used as a feedstock.

Small-scale applications (such as domestic cooking and space heating) can be very inefficient, with heat transfer losses of 30 - 90% of the original energy contained in the waste. This problem can be addressed through the use of more efficient stove technology and the use of dry, compact biomass fuels, such as wood.

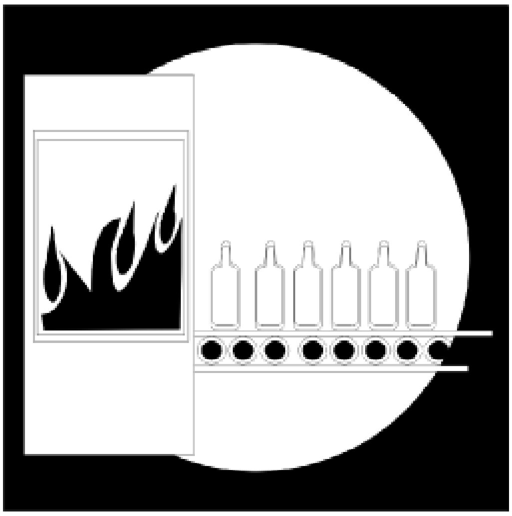

Figure 7.2: The burning of waste can produce significant amounts of heat and power for industrial and domestic applications.

On a larger scale, solid waste (including agricultural and forestry residues), can be combusted in furnaces to produce process heat to feed steam turbine generators. Power plant size is often constrained by the availability of local feedstock and is generally less than 25 - 40 MWe. However, by using dedicated feedstock supplies, such as the co-location of incinerators at waste disposal sites, the size can be increased to 50 -75 MWe, gaining significant economies of scale.

Mass burn technology involves the combustion of unprocessed or minimally processed refuse. The major components of a mass burn facility include:

- refuse receiving, handling and storage systems
- combustion and steam generation system (a boiler)
- flue gas cleaning system
- power generation equipment (steam turbine and generator)
- condenser cooling water system
- residue hauling and storage system

Early incinerators were characterised by a negative environmental image and poor performance. Concerns over direct combustion, particularly gas and smoke emissions as well as the disposal of ash means that direct combustion technologies are governed by more stringent government scrutiny and approvals, thereby increasing the establishment cost of these projects. Incinerators are often seen as a solution to the scarcity of urban landfill sites rather than as a means for efficient energy recovery from waste streams.

See Case Studies 64 and 65 on the use of incineration for electricity generation.

Refuse Derived Fuels

Using raw, unprocessed MSW as a fuel has its problems due to the heterogeneous nature of the material which varies from suburb to suburb and season to season. It also has a low heat value and high ash and moisture content. This makes it difficult for plant designers and operators to continuously provide acceptable pollution free levels of combustion. Processing of the waste to Refuse Derived Fuels (RDF) partially overcomes these problems. The fuel can then be used more successfully in either chain grate water-tube boilers or in circulating fluidised beds.

Waste with a high organic (carbon) content is suitable for briquetting and pelletising after non-combustible and recyclable materials have been separated. These processes involve the compaction of the waste at high temperatures and high pressures. The organic matter is compressed in a die to produce briquettes or pellets. It is important to note that using processed waste (where recyclable and non combustible components have been removed), for power generation will dramatically increase the efficiency of the waste-to-energy process, but at an increased cost due to the increased handling of the product.

Depending on the composition of the refuse, and the technology used, several types of RDFs can be made, such as coarse, fluffy, powdered or densified. Typically, after the removal of non-combustibles, MSW is comminuted by a flail mill. A magnetic separator then removes ferrous materials before screening out the larger particles. The remainder is shredded into small particles to make RDFs which are burnt in dedicated boilers or can be co-fired with another fuel such as coal, lignite, or increasingly biomass (wood or agricultural residues).

These products have a significantly smaller volume than the original waste and thus a higher volumetric energy density making them a more compact source of energy. They are also easier to transport and store than other forms of waste derived energy. The briquettes and pellets can be used directly on a large scale as direct combustion feed, or on a small scale in domestic stoves or wood heaters. They can also be used in charcoal production. RDF pellets have a heat value of around 60% of coal.

High temperature incineration of waste is common in the industrialised regions of Europe, Japan and the north eastern United States where space limitations, high land costs and political opposition to locating landfills in communities, limit land disposal. In other countries including developing nations, relatively low land and labour costs, lack of high heat value materials in the waste stream such as paper and plastics, and the high capital cost of incinerators have discouraged waste combustion as an option.

Gasification

This process of partial incineration with restricted air supply to create an air-deficient environment, can be used to convert biomass and plastic wastes into synthesis gas with a heating value 10-15% that of natural gas. When integrated with electricity production it can prove economically and environmentally attractive, though it appears better suited for clean biomass, such as wood wastes. The synthesis gas (CO + H) in turn can be converted to methanol, synthetic gasoline, or used directly as a natural gas substitute and even blended with natural gas in a gas supply line. Even at a larger scale (say >50MW), such processes are not usually cost effective compared with using natural gas.

In principle, gasification is the thermal decomposition of organic matter in an oxygen deficient atmosphere producing a gas composition containing combustible gases, liquids and tars, charcoal, and air, or inert fluidising gases. Typically, the term *gasification* refers to the production of gaseous components, whereas pyrolysis, or pyrolisation, is used to describe the production of liquid residues and charcoal. The latter normally occurs in the total absence of oxygen, while most gasification reactions take place in an oxygen-starved environment.

In a gasifier, the biomass or waste particle is exposed to high temperatures primarily generated from the partial oxidation of the carbon. As the particle is heated, the moisture is driven off. This could range from below 10% to over 50% of the incoming fuel weight. Further heating of the particle begins to drive off the volatile gases. For wood, this volatile content could be as much as 75 to 80% of the total dry weight. Discharge of these volatiles will generate a wide spectrum of hydrocarbons ranging from carbon monoxide (CO) and methane to long-chain hydrocarbons comprising tars, creosotes and heavy oils. After reaching about 900°F, the particle is reduced to ash and char. In most of the early gasification processes, this was the desired by-product. In gas generation, however, the char provides the necessary energy to effect the heating and drying previously cited. Typically, the char is contacted with air or oxygen and steam to generate CO and CO_2 and heat.

There have been some interesting and innovative ideas put forward for using small scale gasifiers to dispose of special wastes such as clinical waste by mixing it with other biomass sources such as cotton waste using an entrained flow, down draft gasifier.

The Texaco Gasification Process is an example of a proven large scale gasification technology being actively marketed for a wide range of applications, including MSW processing. The core of the process is a pressurised gasifier operating at 20 to 80 bar, 1,200 to 1,500 °C, and using an oxygen supply. The product is synthesis gas for which the potential use could be power generation, say in a combined cycle power plant, large scale cogeneration, or chemical synthesis of a new polymer.

In Germany, Veba-Oel uses a similar gasification approach to produce an oil substitute (40,000 t/y) followed by hydrogenation at 300 bar in its oil refinery. The process is apparently affected by a poor energy balance and negative public perception of it as an energy source rather than as a materials recovery operation. Texaco consider that a 100t/day plant (that is about 30,000t/y of pre-sorted waste) would cost about US $40 million (without the ancillaries and downstream processing plant) and would be economical in the USA.

Gasifiers can utilise fluidised bed technology in order to increase efficiency, whilst treating a feedstock that varies in gasification properties. Fluidised bed gasifiers produce a combustible gas that can be fired in a boiler, kiln, gas turbine or other energy load. EPI produced the first fluidised bed gasifier power plant in the US and are currently introducing the gasifier approach as an add-on to utility coal-fired power plants to provide a means to convert a portion of the fuel supply to clean, renewable biomass fuel. In a fluidised bed gasifier, the bed material can either be sand or char, or a combination of these products.

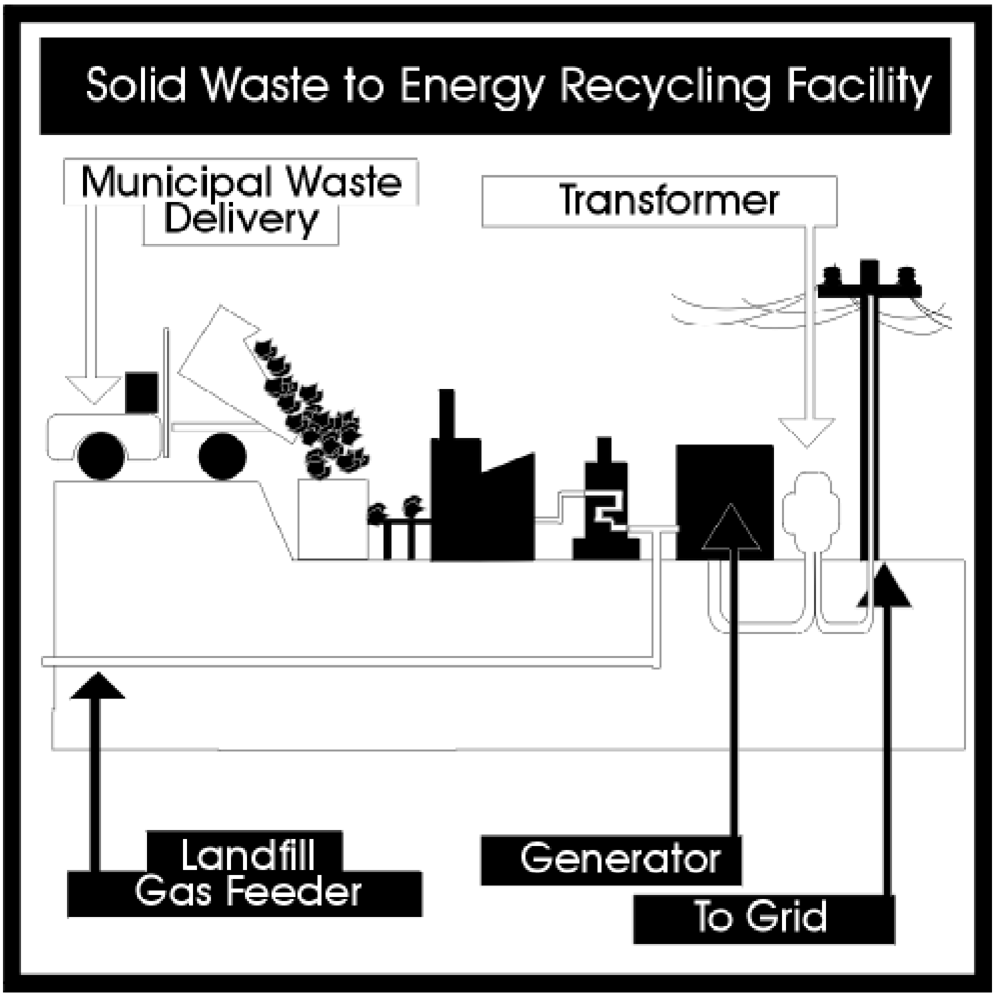

Figure 7.3: The SWERF process is an example of a gasification process which uses green wastes for power generation.

The fluidising medium is usually air, however oxygen and/or steam are also used. The fuel is fed into the system either above or directly into the bed, depending upon the size and density of the fuel and how it is affected by the bed air velocities. During normal operation, the bed media is maintained at a temperature between 1000°F and 1800°F. When a fuel particle is introduced into this environment, its drying and pyrolysing reactions proceed rapidly, driving off all gaseous portions of the fuel at relatively low temperatures.

The remaining char is oxidized within the bed to provide the heat source for the drying and de-volatilizing reactions to continue. In those systems using inert bed material, the wood particles are subjected to an intense abrasion action from fluidised sand. This etching action tends to remove any surface deposits (ash, char, etc.) from the particle and expose a clean reaction surface to the surrounding gases. As a result, the residence time of a particle in this system is on the order of only a few minutes, as opposed to hours in other types of gasifiers.

The large thermal capacity of inert bed material plus the intense mixing associated with the fluid bed enable this system to handle a much greater quantity and, normally, a much lower quality of fuel. Experience with EPI's fluidised bed gasifier has indicated the ability to utilize fuels with up to 55% moisture and high ash contents, in excess of 25%. Because the operating temperatures are lower in a fluidised bed than other gasifiers the potential for slagging and ash fusion at high temperatures is reduced, thereby increasing the ability to utilise high slagging fuels.

Case Study 66 on the Solid Waste to Energy Recycling Facility, Case Study 67 on the Energy from Gasifier Based Power Plant and Case Study 68 on the gasification of waste plastic.

Pyrolysis

Pyrolysis is a medium to high temperature process for converting solid feedstock into a mixture of solid, liquid and gaseous products. It is defined as incineration under anaerobic conditions, and is another option for waste-to-energy currently under investigation. Pilot projects using pyrolysis for plastic wastes and for mixed municipal solid waste potentially have very high energy efficiency. Combined pyrolysis and gasification systems as well as combined pyrolysis and combustion have also been developed and implemented.

A number of approaches treat organic waste less severely than the Texaco approach to produce what are effectively oil substitutes through various pyrolytic or cracking processes. Examples of such processes include the Conrad and Toshiba processes.

In the US the Conrad process was used to process urban waste to recover material from chemical polymers. This was a small-scale unit processing 5000 t/y through a rotary kiln and a liming stage to produce an oil-like product. The Conrad process has been banned because the oil substitute was considered by the authorities as an energy product and as such the overall process was not achieving the required level of material recovery.

The Toshiba pilot process has a capacity of 250 kg/h over an 11hour work day. It processes mixed plastics from Toshiba's factories in Japan to produce a range of oil substitutes. The process is essentially a series of cracking units. A high density alkaline solution is used to neutralise the chlorine (e.g. from PVC) and some of the additives that resist heat cracking.

A second high pressure cracking unit boosts reclamation further. Economic data is not yet available but other Japanese companies are pursuing similar routes.

Net greenhouse emissions from waste-to-energy facilities are usually low and comparable to those from biomass energy systems because the energy generated is largely from photosynthetically produced materials such as paper, MSW and organic wastes as opposed to fossil fuels. Only the combustion of fossil fuel based waste such as plastics and synthetic fabrics contribute to net greenhouse releases, but increased recycling of these materials will generally produce even lower emissions.

The promise of pyrolysis technologies lie in their ability to transform waste into gaseous and liquid chemical and fuel products, but the major disadvantage has been the unproven technical and economic feasibility of a large-scale facility. A full scale pyrolitical process has recently been instituted in Western Australia which offers an alternative to incineration or anaerobic digestion of sewage sludge or dumping it out at sea as is still often the case unfortunately. This is the innovative "Enersludge" process which converts sludge into useful bio-oil. The concept was first promulgated by Professor Bayer in Germany in the early 1980's but it is only recently that environmental pressures and the economics of other treatment options have made it competitive.

The process was commercialised by Environmental Solutions Ltd. and the first plant installed at a wastewater treatment plant in Australia. In essence this plant uses standard technology fairly common in Europe, to produce dry pellets from the raw sludge which have a soil fertiliser and conditioning value and are free of pathogens. The innovative part of the Enersludge process is the addition of a pyrolysis unit which produces gas, char and oil. The gas and char are used to heat the plant leaving the bio-oil for revenue earning activities - either for direct sale or for use on-site in an internal combustion engine to produce electricity and offset purchases. Prior to this the sludge was treated in one primary and two secondary covered anaerobic digesters and 12 aerobic digesters and the odours were cause for complaint by neighbouring properties.

Combustion Technologies

Technology for coal combustion has been adapted for combustion of biofuels and waste products. Combustion of biomass is more complex than coal combustion, due to the inhomogeneity, variation in moisture content and composition of the feedstock. Chain-grate boilers and fluidised beds are commonly used to improve the efficiency of combustion and heat transfer, whilst meeting environmental standards.

Fluidised bed combustion systems use a heated bed of sand-like material suspended (fluidised) within a rising column of air to burn many types and classes of fuel. This allows oxygen to reach the combustible material much more readily and increases the rate and efficiency of the combustion process. The technique results in a vast improvement in combustion efficiency of high moisture content fuels, and is adaptable to a variety of waste type fuels.

In a circulating fluidised bed boiler, a portion of air is introduced through the bottom of the bed. The bed material normally consists of fuel, limestone and ash. The bottom of the bed is supported by water cooled membrane walls with specially designed air nozzles which distribute the air uniformly. The fuel and limestone (for sulfur capture) are fed into the lower bed. In the presence of fluidising air, the fuel and limestone quickly and uniformly mix under the turbulent environment and behave like a fluid. Carbon particles in the fuel are exposed to the combustion air. The balance of combustion air is introduced at the top of the lower, dense bed. This staged combustion limits the formation of nitrogen oxides (NOx).

The bed fluidising air velocity is greater than the terminal velocity of most of the particles in the bed and thus fluidising air elutriates the particles through the combustion chamber to the U-beam separators at the furnace exit. The captured solids, including any unburned carbon and partially oxidised carbon, are re-injected directly back into the combustion chamber without passing through an external recirculation. This internal solids circulation provides longer residence time for fuel and limestone, resulting in good combustion and improved sulfur capture.

Innovative cyclone combustors with integral ash removal designed into the system also have good potential for use with RDF and other bio-fuels.

New combustion technologies with higher efficiencies of energy production and lower emissions are currently being developed. Fluidised bed combustion is a very efficient and flexible system that can be used for intermittent operation, and can run with solid, liquid, or gaseous fuels. Despite high operating costs, this low pollution combustion technology is increasingly used in Japan and has also been used in Scandinavia and the USA.

Emerging Processes

Technology is moving fast in this area with a number of new approaches or renewed technologies. One example is the EnerTech SlurryCarb process currently being demonstrated in the US and based on a pre-treatment of MSW in water slurry form to facilitate the removal of recyclables. The slurry is then subjected to high pressure and temperature conditions and partial dewatering to turn it into a higher calorific value RDF amenable to gasification for combustion in a high pressure steam boiler or to power a gas turbine. If successfully demonstrated this process, albeit expensive, will have very low pollution levels and significantly higher thermal efficiency than mass burns.

Another example is a bio-thermal waste treatment developed by Ecoenergy Oy, Espoo, Finland called the WABIO process. Waste is pre-treated and divided into organic and combustion fractions. The organic fraction is degraded into biogas and compost matter. The RDF is burned in a specially designed fluidised bed boiler unit. The temperature is kept below 900°C to avoid the formation of thermal NOx and dangerous slagging compounds that could threaten the life of the boiler. From 1t of municipal waste, 535kg of RDF is produced.

The VALORGA process, developed in France and recently adopted by Babcock-Borsig Power, uses a similar approach to WABIO. MSW is shredded and sorted mechanically (with manual polishing) to recover glass, metals, plastics, inerts such as sand and gravel, and to remove sources of toxic compounds such as batteries. The remaining fractions (including hospital waste) are separated into a dry RDF that is directed to a rocking kiln for steam raising and base load power generation. The fermentiscibles are sent to a proprietary, high solids (above 45% solids), computer controlled, high yield methane digester. The methane is used to produce peak load power. The organic residues are composted to produce a sterile high quality soil conditioner. A plant processing 120,000 t/y of fermentescibles could generate 31 GWh of power from the methane produced and 57,000t of soil conditioner. The trend in favour of such new energy technology integrated within an overall waste management strategy focusing on materials and energy recovery is illustrated further by the recently announced French government's plan to phase down landfills and develop up to 150 new MSW conversion facilities.

The CONVERTECH technology is directed at the processing of biomass into valuable products such as chemicals, reconstituted wood products like panel boards, heat and power. As such it is not specifically designed to handle mixed waste. In the long run, in the field of waste management, its main application is in the treatment of MSW to produce a dry, cleaner burning RDF.

In this context and from a long-term perspective, mention must be made of current trends in R&D in both biomass and MSW processing which show a renewed interest in fast pyrolysis and solvolysis approaches. Fast pyrolysis refers to the heat treatment of particulate organic matter at 300°C to 1300°C under steam or other non-oxidising gases at pressures ranging from atmospheric to above 30 bar to produce pyrolytic oils and/or medium to high energy value gases. Solvolysis refers to the use of organic solvents at 200°C to 300°C to dissolve the solids into an oil-like product (bio-oil). Such products offer the prospect of gas turbine firing with thermal efficiencies of over 40% which are substantially higher than those presently achieved with steam turbines powered with current RDF combustors/boilers (typically 25%).

4. Other Local Sources

Solar Power

The sun may be a local resource suitable for some applications within a city environment. It is highly desirable to optimise the use of this resource for heating needs. Designing buildings to make optimal use of passive solar heating and use of solar hot water systems are discussed in Chapter 2 of this book. Use of solar energy to produce power may be another option worth considering. The technologies that produce power from the sun use either the heat of the sun – solar thermal power – or use the energy of the sun to create a photocurrent in a solar panel – photovoltaic (PV) power.

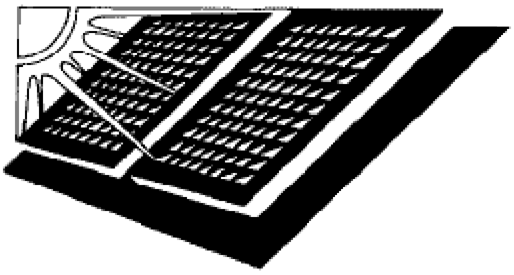

Figure 7.4: Photovoltaic power systems can produce reliable power for a wide variety of applications.

Currently, the costs of photovoltaic generation are greater than fossil fuel based technologies and there are many arguments that suggest that it has little prospect as a large scale power generation source in the near future. On the other hand, the economic performance of photovoltaic power is rapidly improving and it is already a viable source for remote and stand-alone operations, where the costs of grid connection outweigh the additional costs associated with PV. This source is well worth considering for applications such as cathodic protection of structures, motorway signs, street lighting and telephones. One of the benefits of photovoltaic power is that, once in place, it requires very little maintenance.

Wind Power

Wind energy, a source also derived from the sun, can present an economically viable option in locations with sufficient wind strengths. The technology has progressed rapidly since the 1980s, and is now widely considered as a serious option for large-scale generation.

C. Benefits and Limitations of Waste-to-Energy Projects

Wastes generally have a low energy density, can be difficult to handle and process and are often some distance away from the energy market. These are important factors in the project feasibility equation. Other constraints are due to existing cost structures and historical impediments. Existing power pricing structures typically do not reflect externalities such as environmental or social costs of traditional power generation. In addition, cost of waste disposal frequently omits the external environmental and social costs that often persist well beyond the useful lifetime of the operation. Historical impediments include factors such as pre-existence of plant infrastructure and equipment. This is often the case with existing municipal waste water treatment plants. Nevertheless, a thorough investigation of existing processes and practises is likely to reveal profitable energy saving strategies, even if the full implementation of a waste-to-energy scheme is not found to be financially competitive.

Treatment of these wastes and their management can also affect the release of greenhouse gases by:

- reducing emissions of methane from land filling and decomposition of wastes
- reducing fossil fuel use by substituting energy recovery from waste combustion
- reducing energy consumption and process gas releases in mining and manufacturing industries due to recycling
- maintaining carbon stocks in forests due to decreased demand for virgin paper as a result of recycling,
- reducing the energy used in the transport of wastes for disposal or recycling. Except for the long-range transport of glass for reuse or recycling, emissions from transport of waste materials are usually one or two orders of magnitude smaller than emissions from the other four factors listed above

See Case Studies 69 and 70 on the management of wastes.

There are four main issues, which have raised concerns by local communities and environmental groups and have therefore prevented wide scale adoption of waste-to-energy technologies to date:

- Waste-to-energy schemes promote the generation of rubbish and discourage the philosophy of *Reduce, Reuse and Recycle.*
- Combustion of waste products for direct generation of power is perceived as environmentally unsound, particularly the management of emissions, ash and smoke.
- Communities have heard the concerns about waste incinerators in other localities, and think these are older inefficient designs rather than state-of-the-art technologies.
- Good communication, careful planning and public education relating to overseas experiences and the performance of modern conversion equipment are needed to overcome these concerns.

D. Project Evaluation

1. Land fill Gas Projects

The two main drivers for land fill gas (LFG) recovery are the need to control methane emissions and the potential for creating a new revenue stream.

Key questions in assessing the potential of a landfill site are:

- How much will the additional infrastructure cost?
- How large is the revenue stream that will be received from the sale of LFG or energy?
- Is there a gas user in close proximity to the landfill, or will additional expenditure be required in transporting the gas?
- If electricity is to be produced, will the local utility buy from you?
- What are the buy-back rates?

It is important to gain a good estimate of the:

- quantity of gas that can be supplied
- reliability of supply
- period of time over which the supply can be guaranteed.

The factors that influence the methane production of a landfill are:

- Fraction of Degradable Organic Carbon (DOC). Commercial and industrial waste tends to have a high DOC fraction due to a high paper content. The DOC fraction in MSW varies widely depending upon the relative proportions of food, garden waste, paper etc.

- Moisture content and pH. Methane production exhibits an upward trend with moisture content, regardless of age, refuse density and composition. The optimum pH for methane production is between 6.8 and 7.4. Methane production rates decrease rapidly below 6.5 and carboxylic acid formed during decomposition can retard the onset of methane production by months and potentially years.
- Density and particle size of waste. Methane production tends to increase with density and increase with decreasing particle size.

- Filling practises affect the density of decomposable material in a landfill. Anaerobic digestion commences more quickly if the waste is frequently covered, but the covering material may decrease the proportion of decomposable material in the landfill.

These factors are influenced by the amount and type of waste and are directly related to population growth, per capita waste generation, waste segregation practises, recycling, composting and other methods of waste treatment, including co-disposing of other liquid and solid waste. The yield of land fill gas varies widely between landfills.

Methane production potential can be found by one of several ways:

- performing theoretical calculations using stoichiometric calculations some of which are given below
- conducting laboratory tests and simulating the landfill behaviour, and
- conducting field tests of actual landfills

There is a lag-time between the deposition of waste and the onset of methane generation. This is usually of the order of one year. Once methane generation is established, emissions continue for several decades as the waste decays. The amount of methane produced can be estimated with a knowledge of the quantity of cellulose and hemicellulose in the waste. Using this approach, methane production from cellulose is approximately 415 litres per dry kilogram and 424 litres per dry kilogram of hemicellulose. Another method is to perform a Biochemical Methane Potential (BMP) test by measuring the anaerobic biodegradation of a sample of refuse in a small batch reactor. This will indicate a lower value than the stoichiometric estimation. Significant variations in the yield and production rate have been found by this method, ranging from 42 to 120 litres per kg of dry refuse. Field studies have measured values of 38.6 to 92.2 litres per kilogram of dry refuse and suggest that some regions may not produce significant volumes of methane. A figure commonly used to estimate the methane production in field scale landfill is 0.0067 cubic metres of methane per kilogram of wet refuse per year, which corresponds to a yield of approximately 8.4 litres of methane per dry kilogram of refuse. When the LFG flow has been estimated, a comparison of the discounted present value of the gas and the cost of implementing the project will indicate whether the project is worthy of progression.

As well as for electricity production, land fill gas can be used in thermal applications, where the gas is burnt to provide heating for buildings and industrial processes. Whilst this application can be less economic than electricity production, due to transmission costs associated with taking the gas to the desired location, use of gas on-site (such as the construction of facilities on reclaimed landfill sites) increases viability. LFG can also be processed to extract a gas that is almost 100% methane - chemically equivalent to natural gas. This process is only economically viable at very large landfills due to the upfront costs associated with the refining technology.

2. Dedicated Anaerobic Digestion of Solid Organic Waste

The use of anaerobic digesters for the processing of organic solid waste is a potentially efficient alternative to land fill. Waste managers need to consider a number of variables such as composition of the waste, total quantities, rate of refuse supply, gas production potential of the waste and environmental impacts of waste practices. Calculation of the carbon available for biogas formation allows an estimate of the energy production potential of the waste.

3. Anaerobic Digestion of Waste Water

Financial viability of these projects depends upon the proximity of the biogas user to the production facility, quantities that can be supplied, reliability of the supply and duration of the supply. Where the option to generate electricity on-site is under consideration, electricity buy-back rates for supplying electricity into the grid will be important. Additional considerations include the:

- extent to which any existing plant can be adapted to maximise biogas recovery
- reduction in energy required for the process
- reduction in the amount of sludge requiring disposal
- value of the land that can be freed for other purposes

Where industrial waste water is to be disposed there may be an additional advantage to using anaerobic treatment with biogas recovery, by a reduction in trade waste charges.

Income, and avoided costs, will comprise:

- reduction in trade waste charges
- revenues from sale of gas
- revenues from sale of electricity
- revenues from sale of compost-like residue
- reduction in greenhouse emissions
- reductions in local disamenity due to odour etc.
- reductions in local disamenity due to effluent discharge

In order to assess the feasibility of a biogas production plant, the amount of methane that could be produced and the value of corresponding energy production should be determined first. The energy content of one cubic metre of methane is around 33, 810kJ therefore the potential for biogas energy production by the facility can be estimated accordingly.

4. Incineration

"Incineration" is a generic term that encompasses a wide range of options that differ markedly in technology, economics and environmental impact. In the USA, New Zealand, and Australia where there is land available, a number of incineration schemes have been considered over the last decade but so far few, have found economic acceptance relative to land filling.

Present trends indicate a move away from single solutions (such as mass burn or land fill) towards the integration of more advanced incineration technologies within overall waste management strategies. Based on setting priorities for waste treatment methods, these strategies include waste minimisation, recycling, materials recovery, composting, biogas production, energy recovery through RDFs, and residual land filling. This approach favours the integration of incineration within a range of complementary approaches. In the process, mass burn incineration tends to be replaced by more specific and efficient techniques such as RDF incineration, gasification or pyrolysis.

The incinerators required by different waste-energy combustion routes (mass burn, RDF, incineration, gasification, pyrolysis) are markedly different and so are their costs and environmental impacts. Mass burn is typically a low efficiency approach. While it eliminates large amounts of refuse, little energy is recovered. Typically, MSW has an average heat value of 8 to 12 MJ/kg compared with 19 MJ/kg for dry wood, 15 MJ/kg for lignite or 22 MJ/kg for steaming coal. Mixed plastics have an average heat value of 33 MJ/kg. Wet compostable material is in the range of 4 to 6 MJ/kg compared to natural gas which has a value of about 39 MJ/Nm3 (56 MJ/kg). In its modern versions the mass burn process is costly as substantial "end of pipe" technology must be applied for environmental control of emissions. New technology, however, is being developed that improves performance and reduces costs.

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