WASTE-TO-ENERGY

In a world with an increasing population and consumption there is a pressing need to use our resources in the best possible way. This involves reducing the generation of waste, high-quality recycling and use of the residual waste for efficient and clean energy generation.

PowerCo Energy Ltd is a developer and consultant within waste management in general and Energy from Waste. We are responsible for the planning, engineering, procurement and contract management of waste management facilities. Our services include the full range of technical advisory / owner's engineering / EPCM services which are required to plan, manage and implement a project, inter alia:

Waste strategy development
Technology assessments (including gasification, pyrolysis etc.)
Feasibility studies / business case preparation
Technical due diligence of projects and technologies
Site assessment
Conceptual design and layout
Risk and opportunity assessment
Project structuring and procurement planning
Value engineering
Preparation of technical specifications and tender documents
Evaluation of proposals, negotiations and contract closure
Contract management
Supervision and inspection during design, construction and commissioning
Site management
We work under different organisational structures (from public projects to PPPs) for a range of clients: Waste management companies (public or private), regional/local governments, developers, central government, banks, IFIs etc.

On operational facilities, we provide the full range of advisory services.
We provide a "one-stop-shop" Energy from Waste consultancy with a global knowledge centre in UK and a network of offices and resources to serve our clients regionally from the UK

Waste to energy facilities

A robust thermal waste-to-energy facility is a cornerstone of most modern waste management systems. A waste-to-energy facility may generate a range of energy outputs: electricity, district heating, steam for industrial processes, desalinated seawater or district cooling. In this way, residual waste – i.e. waste that cannot be recycled in an economic or environmentally beneficial way – can become a resource by turning it into energy for the benefit of people, businesses, countries and the environment.

A waste-to-energy facility can therefore be a valuable local source of secure, stable and climate-friendly energy. It will substitute fossil fuels and contribute to national energy self-sufficiency and will in many cases fully eliminate the need for landfilling

Incineration

Conversion can be accomplished using MASS BURN techniques which is in fact the most widely used methodology throughout the US and EU. High tech incineration as well as collection techniques from landfill gasses are effective and commonly employed due to their relative costs compared to plasma (the most expensive) and pyrolysis.

With growing population and rapid development, pollution of terrestrial environment from municipal, industrial and agriculture activities are rapidly growing. Every day, huge amount of waste is generated by various human activities. Waste is not a problem but an inescapable reality of modernization, if not managed properly can be disasters. Waste has a huge potential to either pollute or provide useable energy. Improper management of waste can pollute air, water and land.

Improper waste disposal creates nuisance, affect public health, and is a significant factor contributing in global warming due to greenhouse gas emission in the atmosphere. Waste-to-Energy (WTE) approach can not only turn waste disposal challenge to an energy recovery opportunity but can significantly reduce the emission of greenhouse gases in the atmosphere. Several Waste-to-energy (WTE) options are available throughout the world to handle various kinds of waste steam and amounts. Selection of appropriate technology for a situation is a crucial task that require careful analysis of waste stream and evaluation of various technological options and identifying the most suitable technology for a waste stream and situation.

The Ogun State, Nigeria have identified an effective WTE options to help develop IPP policies for the City of Abeokuta as a viable WTE projects A detailed discussion on distinctive waste conversion and power generation technologies are presented in the following:

- Incineration Processes

This WTE technology is described in a general way, and the presented as a broad overview

Technologies Evaluation

To ensure WTE technologies is the optimum solution a detailed review has been undertaken to ensure incineration is the optimum and suitable for country conditions.

The scope of the investigation are conducted by categorical waste:

- Municipal Liquid Waste Treatment and Energy Recovery
- Municipal Solid Waste Treatment and Energy Recovery
- Industrial Waste Treatment and Energy RecoveryMethodology

The database of various international agencies are researched

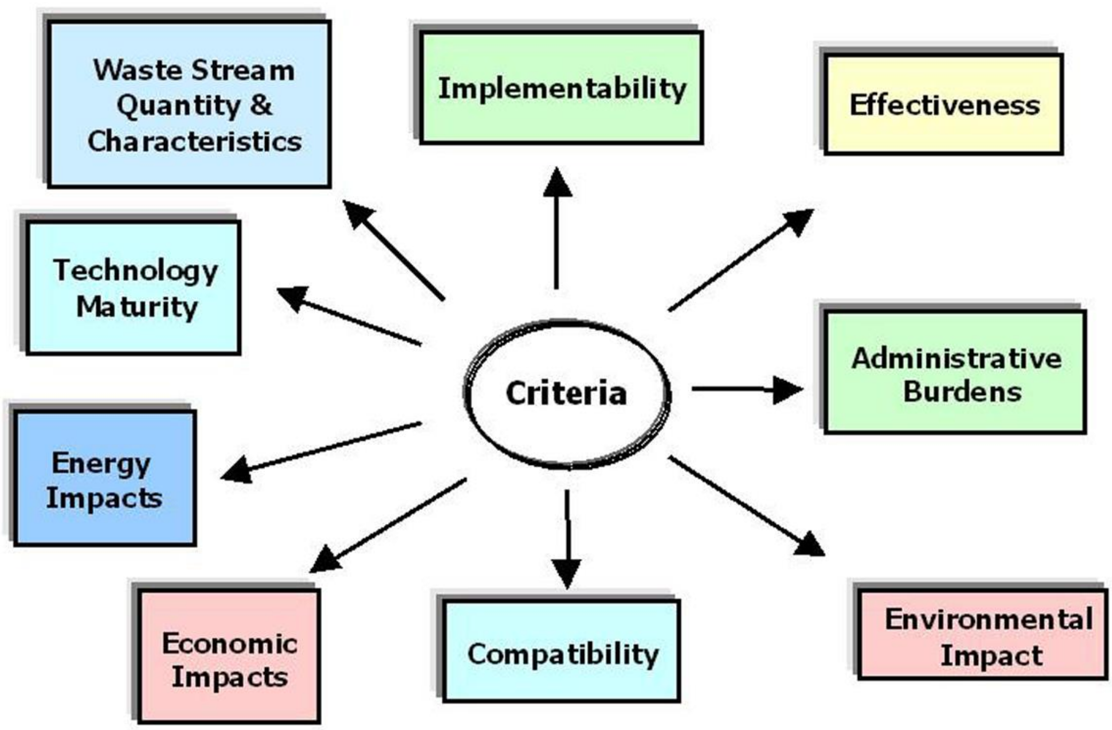
- International Energy Agency
- United Nations Environmental Programmed
- The world-Wide Information System for Renewable Energy

Technology Evaluation Criteria

WTE process is unique and so is the technology based on it. Determining appropriateness for a process based WTE technology and its preference over another process or technology required a detailed factual analysis based on set criteria. Such determining criteria for WTE technology needs to be based on practical approach and should consider a wide range of factors. The major factors can be grouped into six main groups as shown in **Figure 1**.

Figure 1

Viable Technology Evaluation Criteria



Incineration also referred, as combustion is a traditional technology for treating waste and recovering energy from it. Incineration of biomass is a type of thermal conversion Organic wastes such as municipal solid waste (MSW) and sewage sludge can directly be combusted or incinerated in waste-to-energy facilities as a fuel with minimal processing, known as "Mass burn or Mass burning". MSW can undergo moderate to extensive processing before being directly combusted as refuse derived fuel (RDF).

Concept

Incineration also commonly known as combustion, is a chemical reaction in which carbon, hydrogen, and other elements in the waste combine with oxygen in the combustion air in an exothermic reaction, which generates heat. Usually, excess air is supplied to the incinerator to ensure efficient mixing and maximum combustion efficiency in terms of complete oxidation. Excess air is also added to the incinerator to regulate the operating temperature and to control emissions. Excess air requirements will differ with waste moisture contents, thermal content of the wastes, and the type of combustion technology employed.

The principal products of combustion include carbon dioxide, carbon monoxide, water, oxygen, oxides of nitrogen, and ash. **Figure 2** shows typical inputs and products of incineration.

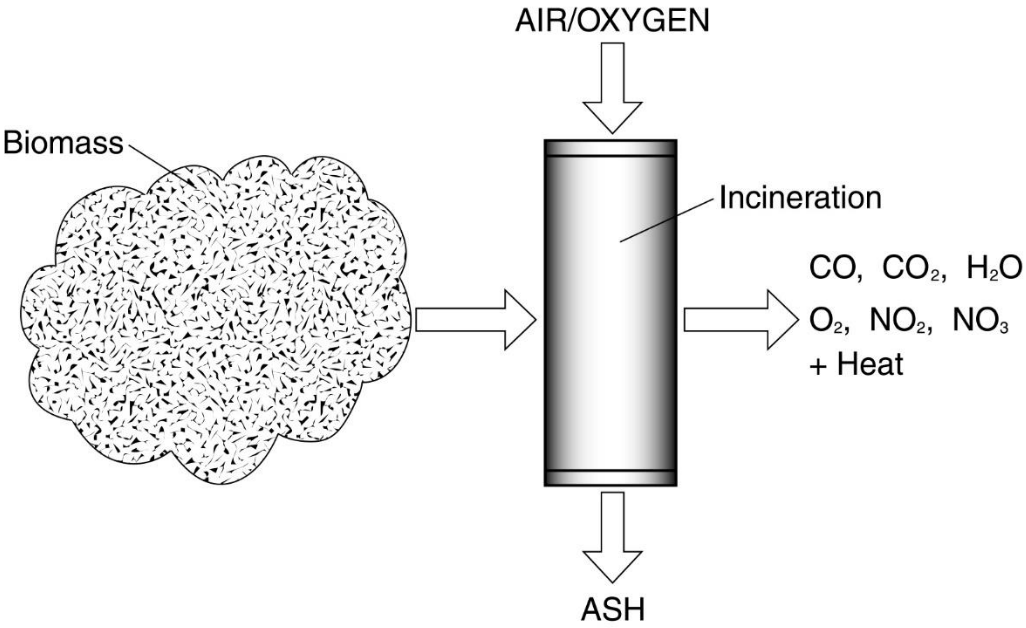
Application of Incineration

Incineration processes have been used for treating various waste streams including the following:

- Municipal solid waste
- Sludge
- Liquid waste
- Agriculture waste
- Hospital waste
- Various industrial wastes
- Waste tyres

Figure 2

Incineration Processes



Incineration Process Steps

A typical incineration system consists of following four steps:

- Drying
- Devolatilization
- Ignition
- Combustion of fixed carbon

These steps are briefly discussed below:

Drying

Drying is the first step, where heat is used to raise the temperature of the moisture in MSW and evaporate it.

Devolatilization

After the moisture is evaporated, the combustible volatiles are released. The combustible volatiles in MSW are released ((between 350 and 980º F (175 and 525º C))

Ignition

Combustion begins as the volatiles reach ignition temperature in the presence of oxygen.

Combustion of Fixed Carbon

Combustion of the volatile matter is completed (with the fixed carbon being oxidized to carbon dioxide).

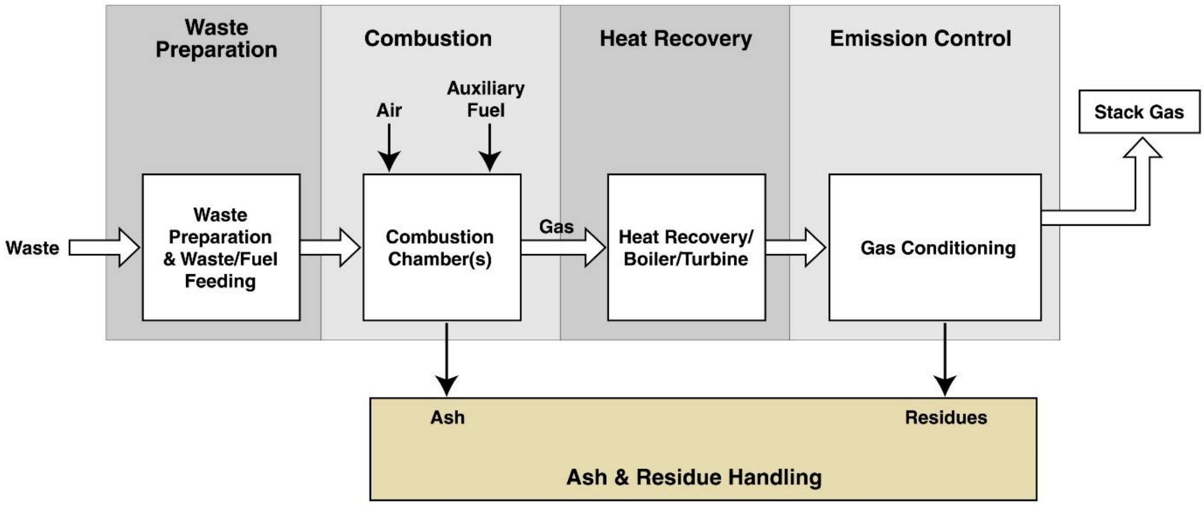
Incineration Process Flow

Waste-burning facilities (incineration) with energy recovery generally have following broad process steps as shown in the

- Waste preparation (storage, handling, feeding)
- Combustion
- Flue gas cleanup
- Energy recovery
- Emission control and exhaust
- Residue and ash handling

These process steps are very similar in all the incineration systems. However, some of the steps may vary with type of the system used. Incineration process steps, relative advantages and limitations are briefly discussed with each incineration systems discussed herein. System aspects such as general operation consideration, emission and environmental aspects; combustion by-products and ash handling that are mostly common for all the incineration systems.

Figure 3
Incineration Process Flow



Incineration Technology System Approach

Various technological approaches are currently available for waste incineration. However, predominate technological approaches, also referred as system approaches are classified into two broad groups:

- Mass Burning Systems
- Refuse Derived Fuel (RDF) systems

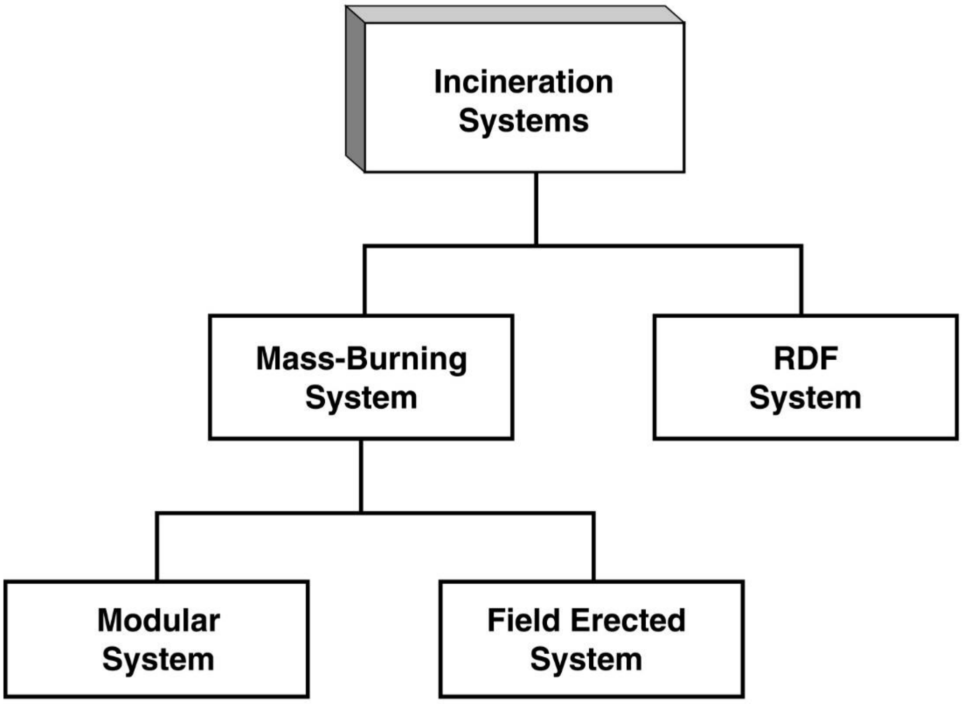
Mass burning is further classified into Field Erected Mass burning Systems (FEMBS) and Factory-Fabricated Modular Mass Burning Systems (FFMMBS) as shown in **Figure 4**.

Each of these options have many common components and design features to properly receive and process the municipal solid waste and the resulting products and residues. However, in the RDF systems the waste processing to form various kinds of RDF is involved before it can be incinerated. Following section gives, a brief overview of each of the above mention incineration systems.

Mass-Burning Systems

Mass-burning incinerators burns waste in the same physical form as it is generated and received. Mass-Burning facilities incinerates raw waste; it is not shredded, sized, or separated before combustion. Very large items such as refrigerators, or stoves and batteries/hazardous waste materials are removed before combustion. Non-combustible materials such as metals can be removed before or after combustion, but they are usually separated from the ash with magnetic separators. The waste is usually deposited in a large pit and moved to furnaces with overhead cranes.

Figure 4
Incineration Technology Approach



Mass burning systems can be categorized according to the method of construction and size into following two categories:

- Field Erected Mass Burning Systems(FEMBS)
- Factory-Fabricated Modular Mass Burning Systems (FFMMBS)

Field-Erected Mass-Burning System (FEMBS)

Field-erected Mass-Burning systems (FEMBS) are usually medium-to-large-scale (200 to 3000 tonne/day) refractory-lined furnaces that combust MSW under presence of air in a single combustion chamber. FEMBS typically include either waterwall furnaces with integral boilers or refractory-lined furnaces with waste-heat boilers. In waterwall Incinerators the furnace or combustion chamber and boiler are integral components, whereas refractory-lined furnaces consists of a convection-type waste heat boiler located downstream from the furnace.

In most of the systems, combustion occurs in single-chamber furnaces, usually equipped with grates that move the MSW through the furnace and help control burning. Some of the systems use a refractory-lined or waterwall rotary kiln. A schematic of a typical field-erected waterwall system is given in the **Figure 5**.

In a typical FEMBS facility consists of two or more combustors that are sized to properly fire or burn the area's municipal solid waste during its peak generation period. Typically, at least two combustor units are included to provide a level of redundancy and to allow waste processing at a reduced rate during periods of scheduled and unscheduled maintenance.

The generated steam in FEMBS is then passed through a once-through turbine generator to produce electricity or through an extraction turbine to generate electricity and provide process steam for heating or other purposes. Higher steam quality allows the use of more efficient electrical generating equipment, which, in turn, can result in a greater revenue stream per ton of waste.

Waste Storage and Handling

Field-erected mass burning systems use a pit to store incoming refuse. The capacity of the pit is usually several times greater than the plant's daily throughput for sustained adequate supply. The pit serves to isolate the waste, thereby controlling odours and pests and containing fires if they occur. The waste is retrieved from pit by an overhead crane equipped with a grapple. To some extent, the crane operator can control the type of waste that is fed to the furnaces and can separate out oversized and other undesirable waste items.

Waste Feeding

Field-erected mass burning systems are usually equipped with a feed hopper and chute arrangement that continuously feeds waste onto the first furnace grate by grate by gravity. Most systems include a horizontal hydraulic ram at the bottom of the chute to push waste onto the grates, allowing more control over waste feeding and firing.

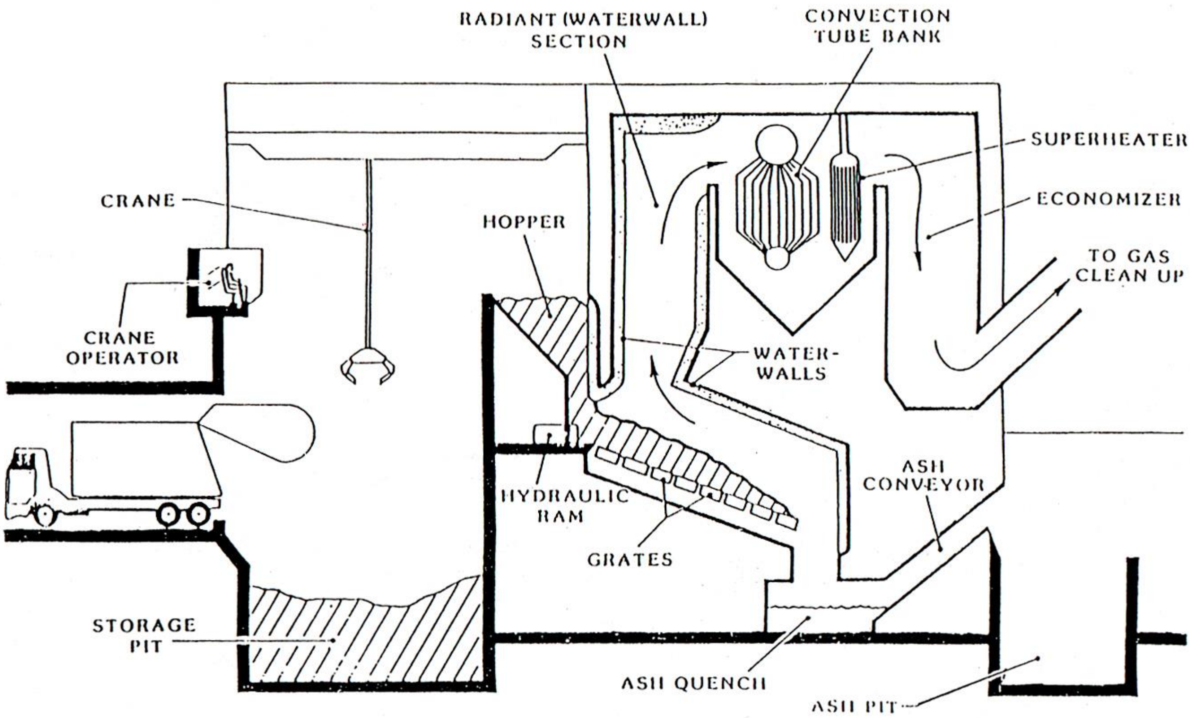
Combustion

The method of moving waste through the furnace and mixing it with air are key elements of the incineration process to achieve good combustion. In the Field-erected mass burning systems, this process is usually accomplished by burning the waste on grate system that slopes from the front of the furnace, where waste enters to the rear of the furnace, where residual ash is removed. The grates are also designed to agitate the waste and mix it with air. The action of the grates combined with gravity causes the waste to tumble slowly downward as it burns. Combustion air is supplied from below (underfired air) and above (overfired air) the grates. Underfired air is mixed with the refuse by the action of the grates, initiating combustion and supplying oxygen to the refuse burning on the grates. Overfired air is introduced to the furnace and mixes with the combustible gases off during devolatilization, ensuring their combustion. Several grate designs including several patented designs are used in waste burning facilities. Each grate system provides a unique grate feature.

A refractory-lined or waterwall rotary-kiln can be used for combustion in place of or in combination with, a grate system. In refractory-lined furnace, the temperature of combustion is controlled by the amount of excess air provided. Refractory-lined combustion typically uses excess air in the range of 150 to 250 percent. Increasing the excess air cools the furnace but reduces the energy recovery efficiency.

In waterwall furnace, radiant heat from combustion is absorbed by water-tubes in the furnace wall therefore less excess air (100 to 150 percent) is required for cooling the combustion process. The thermal efficiency of waterwall boilers is typically about 70 percent, compared to 60 percent for refractory-lined systems.

Figure 5
Schematic of a Waterwall System



Energy Recovery

The energy is recovered as steam, by either a waterwall or waste-heat boiler. In waterwall systems, combustion and heat transfer occur in an integrated unit; hence, these systems are often referred to as ‘integral’ boilers. Heat transfer occurs in both radiant and convection sections. The radiant or waterwall section is the combustion chamber lined with waste-filled tubes that absorb the radiant energy released during combustion. In the convection section, the hot gases from combustion pass through banks of water tubes and heat is transferred to the water in tubes by convection.

In refractory-lined systems, all heat transfer occurs downstream of the furnace in a water-tube waste-heat boiler that is essentially identical to the convection section of waterwall. In both waterwall and refractory-lined systems, additional convection sections can be included to superheat the steam (super-heater) and to preheat boiler feed-water. In both types of systems, the temperature of the gases leaving the last boiler section is not permitted to fall below 230 ° C to 260°C to ensure that condensation of corrosive acids does not occur.

Emission Control

The gas leaving the combustion contains various air pollutants such as particulates, SO2, NOx, CO, HCl, metals, and various organics such as dioxins, furans, and polynuclear aromatic hydrocarbons. These emissions are controlled before discharging the gas into the atmosphere.

Electrostatic precipitator is generally used to reduce particulate levels of the emission. However, various types and designs of air pollution control equipment are used in incineration facilities. Dry scrubbers and baghouse filters used in combination are more efficient than most electrostatic precipitators in removing acid gases and particulates from stack gases. Nitrogen oxide and mercury emissions must also be controlled.

Advantages

- Mass-burn systems as compare to modular systems generate a higher-quality steam, allowing for higher revenues per ton of waste.
- Mass-burning systems have larger capacities and higher thermal efficiencies.
- These facilities can accept refuse that has undergone little pre-processing other than the removal of oversized items.
- It avoids many of the refuse handling problems caused by the extreme heterogeneity and variability of MSW.
- The net energy conversion can be equal to or better than that for RDF systems since minimal energy is used for front-end processing and no burnable material is removed.
- Since most of the burning occurs on the grate, less particulate matter is entrained in the gas stream and air pollution control costs are thus reduced.
- The unit footprints are smaller and therefore land requirements are less than for RDF.

Limitations

- Higher costs than modular systems.
- Controlling combustion is difficult where MSW is not processed prior to burning.
- Requires more field erection time and costs as compared to modular systems.

Factory-Fabricated Modular Mass Burn Systems (FFMMBS)

Factory-Fabricated Modular Mass Burn Systems (FFMMBS) also known as Modular Combustion Systems, are small mass burn facilities. Modular combustion systems comprised of modules for waste feeding, primary and secondary combustion chambers, energy recovery, and ash handling. The modules are usually prefabricated and shipped fully assembled to the construction site where they can be mounted on footings. The installation is housed usually in an inexpensive prefabricated building with sufficient additional space for waste storage and handling, usually in the form of a concrete tipping floor.

The system configuration depends on the requirements of the installation. However, modular systems range between 5 to 120 ton/day and typically in the 15 to 100 ton/day capacity range. Typical facilities have between one and four units for a total plant capacity. Capacity of an incineration facility can be increased by adding modules, or units, installed in parallel to achieve the facility’s desired capacity. For example, a 200 ton/day facility may consist of four, 50-ton/day units or two, 100 ton/day units. The number of units may depend on the fluctuation of waste generation for the service area and the anticipated maintenance cycle for the units.

Because of their small capacity, modular combustors are generally used in smaller communities or for commercial and industrial operations and most modular units produce steam as the sole energy product. A typical schematic of a Factory-Fabricated Modular Mass Burn System is given in the **Figure 6**

Waste Storage and Handling

In Modular systems, refuse vehicles deposit their loads onto a concrete tipping floor. Tipping floor is an inexpensive approach to storing and handling MSW. Skid-steer front-end loaders separate out bulky and other undesirable items and push the remaining material to a convenient area for storage. It is less effective than a pit in controlling odours and pests and in containing fires. In addition, this approach to waste storage requires more area, which could be undesirable at sites where is limited. Consequently, some of the larger modular systems are equipped with a pit and crane for storage and retrieval of MSW.

Waste Feeding

In most of Modular systems, waste is charge to the furnace intermittently using a horizontal hydraulic ram. A front-end loader fills the hopper, with the load size depending on the current furnace temperature, and the operator manually activates the feed cycle. However, some modular systems continuously feed waste using a chute like chute as used in field-erected systems.

Combustion

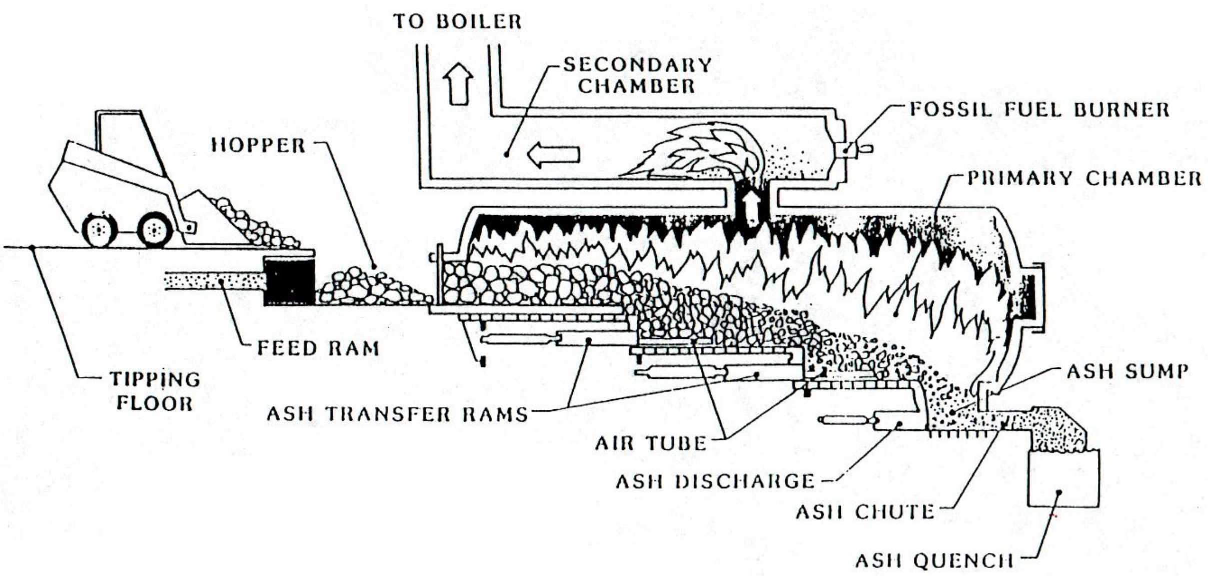
Combustion is typically achieved in two stages. The first stage may be operated in "starved air" or in a condition in which there is less than the theoretical amount of air necessary for complete combustion. The controlled air condition creates volatile gases, which are fed into the secondary chamber, mixed with additional combustion air, and under controlled conditions, completely burned. Combustion temperatures in the secondary chamber are regulated by controlling the air supply, and when necessary, using an auxiliary fuel.

In Modular systems, the flow of combustion air in the primary chamber is limited to reduce turbulence and thus reduce the amount of particulate matter that becomes entrained in the gas stream. Thus, modular systems may require no additional air pollution control beyond the secondary chamber, which represents a major capital and operating cost savings. The principal disadvantages of the two-stage combustor are that waste burnout is not as complete as with excess air field-erected systems, reducing the efficiency of energy recovery and slightly increasing the quantity of residue to be landfilled.

Most existing Modular systems employ a step-hearth design (hearth design is discussed later in this chapter) in the primary chamber and use water-cooled hydraulic transfer rams to move waste through the chamber. The transfer rams are housed in the riser of the previous step, and when activated, push the waste down onto the next step. A few modular installations employ grate systems like those uses in field-erected installations. Grates agitate the waste more thoroughly and allow more underfired air to reach it, thus promoting better burnout. Other primary combustion chamber designs, including rotary-kiln and rotary-hearth systems, are also used in modular systems.

Figure 6

Typical Factory – Fabricated (Modular) System



Energy Recovery

In Modular systems, energy is usually recovered as steam in waste-heat boilers, although some manufacturer uses a waterwall primary chamber to enhance energy recovery. Waste-heat boilers can be either fire-tube or water-tube systems, depending on the requirements of the energy user. In fire-tube boilers the hot combustion gases flow through tubes encased in a water-filled vessel, and heat is transferred to the water. These types of boilers are generally used to produce low-pressure saturated steam in small-scale systems. Up to approximately 1965 kpa and 50 tonne/day unit, fire-tube boilers can be considerably cheaper than water-tube systems. Beyond these limits, fire-tube boilers require heavier construction, which dramatically increases costs. In cases where large boiler modules and/or high-pressure steam are required, water-tube waste-heat boilers like those used in field-erected systems are generally more applicable.

Emission Control

Emission control follows the same as discussed in the case of Field-erected Mass-Burning systems (FEMBS).

Advantages

- Capital costs per ton of capacity are lower – more cost-effective than other combustor alternatives.
- Because of their relative size, modular combustors and waste heat boilers can be factory-assembled or fabricated and delivered, minimizing field erection time and cost.
- Economic viability in low-volume waste generation areas.
- Flexibility in addressing various potential energy markets with system sizing.

Limitations

Because of the nature of these facilities, energy production per million kw of heat input or plant efficiency is likely be lower than other incineration technologies.

Refuse-Derived Fuel (RDF) Systems

"Refuse-Derived Fuel" commonly refers to solid waste that has been mechanically processed to produce a storable, transportable, and more homogeneous fuel for combustion. RDF can be cofired with fossil fuels in existing large industrial or utility boilers or it can be used as the sole or primary fuel in specially designed "dedicated" boilers. Cofiring of RDF has the obvious advantage of capital cost savings since a new boiler is not required. However, RDF as the primary fuel burning in a dedicated boiler has become more common since the dedicated boiler can be designed to accommodate some of the characteristics of RDF that can cause operating problems in existing boilers designed for conventional fuels.

The early RDF projects, developed in the 1970s, were intended to produce a fuel to be used in existing utility or industrial steam generators with little or no modifications to the fuel combustor or its auxiliary equipment. Several projects were developed, but few of those projects are operating today. The predominant RDF systems operating today have incorporated the lessons from the earlier projects and are now considered a proven technology. RDF fuel is conveyed, transported, and stored more readily than waste itself. Most RDF combustion facilities generate electricity. On average, costs per ton of capacity are higher for RDF combustion units than for mass-burn and modular units.

A typical RDF schematic is given in the **Figure 7**.

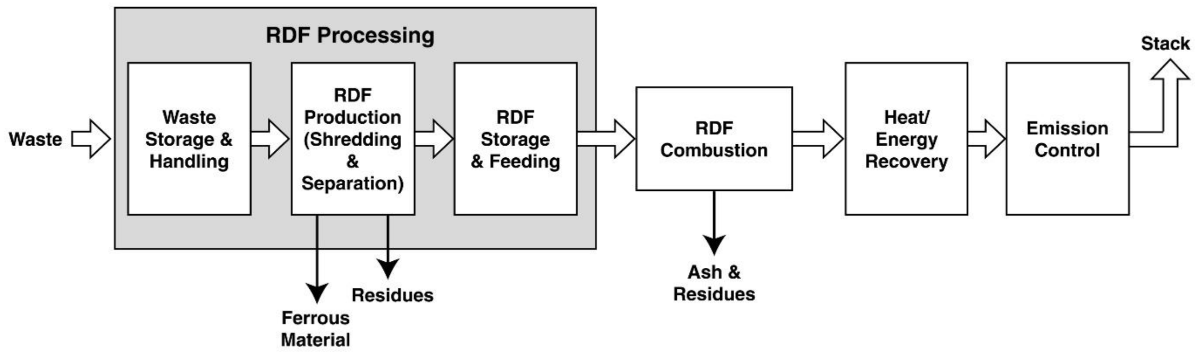
RDF Processing

Waste is pre-processed in a facility to produce Refuse-Derived Fuel (RDF). Non-combustible materials are removed, increasing the energy value of the fuel. The extent to which non-combustible materials are removed varies. Most systems remove metals with magnetic separators; glass, grit, and sand may be removed through screening. Some systems utilize air classifiers, trommel screens, or rotary drums to further refine the waste. The following are typical RDF process steps:

- Waste storage and handling
- RDF production (shredding and separation)

- RDF storage and Feeding

Figure 7
Typical RDF Facility



Waste Storage and Handling

MSW storage and retrieval in RDF production plants presents difficulties since a more continuous feed is usually required for the first processing step. Another consideration of critical importance for RDF systems is the removal of materials that can cause explosions during processing, particularly in the shredders. While pit and crane systems like those used in most mass burning plants are found in RDF facilities. Intermediate steps to permit initial separation and continuous feeding are usually included. The two common storage systems are "tipping floor with conveyors" and "pit with hydraulic rams". Once produced, the RDF is usually stored prior to combustion.

RDF Production (Shredding and Separation)

Unlike Mass-burn systems, in the RDF incineration systems, waste is processed to produce fuel or RDF. Mainly there are four kinds of RDF that are produced by dry RDF processing. The production process of all four are similar through the fluff stage. Additional processing is required to obtain powder and densified types of RDF. The following **Table 1** describes the characteristics of each RDF type:

Coarse RDF (cRDF), Fluff RDF (fRDF), and Densified RDF (dRDF) are mostly produced on a commercial basis.

Based on the production process, RDF production systems can be re-grouped into following three categories:

- Shred-and-Burn Systems

- Wet RDF Processing Systems
- Dry RDF Processing Systems

Table 1

Classification of Refuse-Derived Fuels

Type of RDF	**Description**
Coarse Refuse-Derived Fuel (cRDF)	MSW processed to a coarse particle size with or without ferrous-metal separation. So that 95% by weight passes through a 6 inch square screen.
Fluff Refuse-Derived Fuel (fRDF)	Shredded fuel derived from MSW and processed for the removal of metal, glass, and other entrained inorganic materials. The particle size is such that 95% by weight passes through a 2-inch square mesh screen.
Powder Refuse-Derived Fuel (dRDF)	The combustible waste fraction processed into the powdered form , 95% by weight passing through a 10-mesh (0.035 inch square) screen.
Densified Refuse-Derived Fuel (dRDF)	Combustible waste fraction densified into the form of pellets, slugs, cubettes, briquettes, or some similar form

Shred-and-burn systems.

Shred and burn systems are the simplest form of RDF production. Shred-and-burn systems require minimal removal of non-combustible waste. The process system typically consists of shredding the municipal solid waste to the desired particle size, magnetic removal of ferrous metal, with the remaining portion delivered to the combustor. There is no attempt to remove other non-combustible materials in the municipal solid waste before combustion. The municipal solid waste is shredded to a particle size that allows effective feeding to the combustor. Most systems operate the process system continuously, i.e. there is minimal RDF storage before being fed to the combustor.

Wet RDF processing.

A wet pulp process is used to make wet RDF. Water is fed into a pulper, which resembles a large blender that mixes water and solid waste. The combustible materials form a slurry which exits from the bottom of the pulper. Nonpulpable material (glass, metal) are rejected from the pulper. The slurry is dried to 50 percent solids before being used as a boiler fuel. An advantage of this process is that it eliminates explosives and dust inherent. However, odour problem occurs due to the recycled water in the pulping process.

Dry RDF processing.

Waste is unloaded into a pit or onto the receiving floor and them conveyed to a flail mill. The flail mill tends to separate the waste mass for further downstream processing. Magnetic separation of the ferrous metal is then separated. An additional RDF processing step is conducted by the use of a trommel screen. This equipment is a rotating, slightly inclined screen that allows waste to flow through the cylinder in a lift-and-drop fashion while removing many small-sized non-combustible materials through the screen holes.

The waste that passes through the trommel is fed into a shredder, which reduces the particle size of the waste. The shredder waste is fed into an air classifier. An air classifier is typically a vertical column in which an upward flowing air current separates the lighter, more combustible materials from the remaining non-combustible. During this separation process, some of the combustible material is diverted from the system and exits the system with the inorganics. This lowers the total energy available from a given quantity of MSW. The loss however, tends to be minor. If the smaller particle size is desired, then the waste would be shredded again at this point.

The lighter material obtained from the air classifier is fluff RDF. A problem common to all types of fluff RDF is limited storage capacity. The material will compress under its own weight, which makes retrieval for use difficult. In general, fluff RDF storage is limited to 24 hours.

The common first generation systems involved a shredder followed by an air classifier. Recent systems rely on screening to separate the non-combustibles from the fuel portion. The heavier, non-combustible materials could be further processed to recover ferrous or other materials. A problem with shredding as the initial process is that inert material, such as glass, tends to become imbedded or impregnated in the combustible material. Subsequent separation process fail to dislodge the material; the result is an erosive quality RDF with a high ash content, which can cause short-lived pneumatic conveyor tubes and boiler slagging problems. There are several configurations area in use to produce RDF.

The types of processing equipment employed and the configuration of a RDF production system depends on the requirements of the fuel user. Several RDF facilities using dedicated boilers have adopted the “shred-and-burn” approach, requiring minimal processing. Cofiring in a suspension-fired utility or industrial boiler usually requires more extensive processing to produce a finer, more uniform fluff RDF with most of the non-combustible removed.

RDF Storage and Feeding

Processed RDF is stored in a storing facility. RDF feeding may vary with the combustion system use. In suspension-fired boilers, the fuel is blown into the boiler, whereas grate burning boiler use a spreader-stoker to feed fuel on to the traveling grate.

RDF Combustion

RDF is characterized by wide range of material density, particle size, variable moisture content, high proportion of flake shape particles and presence of heavy inert materials such as glass, sand, dirt, metals etc. Due to its heterogeneous nature, makes this fuel difficult to burn, and require correct match of combustion and fuel preparation technology. However, following three main burning systems options for RDF combustion are generally used:

- Grate Burning Systems
- Suspension-Fired Boilers
- Fluidized Bed Combustors

Grate Burning Systems

Grate burning systems, are also referred to as “spreder-stroke”, they resemble with mass burning systems in that combustion occurs on a grate that moves the fuel through the furnace. More than one hour residence time in the furnace can be required to achieve full burn-out, and at least 40 to 60 percent excess air is required to achieve the necessary mixing of fuel and air. Grate burning boiler use a spreader-stoker to feed fuel on to the traveling grate. Because of their slow combustion rate, grate-burning boilers are well-suited to maintaining a constant energy output.

Suspension-Fired Boilers

In suspension-fired boilers, the fuel is blown into the boiler and all the three combustion steps-drying, devolatilization, and ignition occur very rapidly. This turbulent environment promotes good mixing of fuel and air, reducing excess air requirements to 5 to 20 percent. Suspension-fired systems can achieve thermal efficiencies as high as 88 percent. These boilers are very responsive to change in boiler feed rate that makes them less favourable for burning non-uniform fuel like RDF. Due to the lower heat content of RDF compared to coal, burning significant amount of RDF can result in reduction of the boiler’s output capacity. Furthermore, high levels of RDF can also destabilize combustion. Thus, RDF is used only as supplementary fuel in coal-fired suspension boilers, providing no more than 10 to 15 percent of the heat input to the boiler. At this firing rate, variation in RDF moisture and heat content have only a small impact on boiler operations. The RDF used in suspension-fired boilers is usually a clean, double-shredded, fluff RDF with a small particle size to facilitate burning in suspension.

Fluidized Bed Combustors

Fluidized bed combustors for RDF are a relatively new approach involving the firing of the RDF into a bed of fluidized inert non-combustible, high melting-point material (sand) that substitutes for a grate. The RDF is combusted in the suspended sand bed. This improves the combustion reaction by bringing the waste in direct contact with the bed of material. waterwall boiler is located above the fluidized bed where the heat is transferred to produce steam. These types of combustor are less used to burn RDF than the dedicated stoker-fired combustors.

Fluidized bed combustion can be an attractive alternative because a wide variety of materials can be burned, including high-moisture content materials such as sludge. In addition, because the units should operate at lower excess air conditions, they can be relatively smaller in size when the emission control equipment is included.

Energy Recovery

In RDF systems generated heat energy may be recovered like as in mass-burn and modular systems.

Emissions Control

Emission control follows the same as discussed in the case of Field-Erected Mass-Burning Systems (FEMBS).

Advantages of RDF Systems

- RDF boilers can be smaller than those for mass burning since a considerable amount of non-combustible material is removed from raw MSW.
- The handling and storage characteristics of RDF are significantly better than MSW.
- RDF can be burned in existing fossil fuel boilers, which can greatly reduce capital costs.
- RDF burned in a dedicated boiler can displace more expensive fossil fuels (i.e., natural gas and oil).
- RDF can be produced at a remote site and transported to the conversion facility—an important advantage if land is scare or expensive, if truck traffic is undesirable near the intended energy user, or if the energy user is far from the source of MSW.
- The recovery and sale of reusable materials from MSW can reduce landfill requirements.

Limitations of RDF Systems

- Explosions
- Dust in the processing plant

- Storage/retrieval problems
- Materials handing problems
- Higher capital costs

Combustion Byproducts

In addition to heat recovery and exhaust gases, ash and residues are the main by-products of incineration. Incineration facility and its emission control system produce a variety of residues such as:

- Bottom Ash and Scrubber Product
- Fly Ash

Bottom Ash

Bottom ash is what remains in the combustion chamber after burn-out is complete and is by far the largest residue component. Scrubber product is the residue from gas scrubbing systems that consists of adsorbing material, usually a calcium or sodium based alkali, and neutralized acid gases. The use of bottom ash and slag as an aggregate in road construction or in the production of brick materials is more common in some countries like the Netherlands than in others.

Fly Ash

Fly ash consists primarily of particulate carried out of the combustion chamber with the combustion gases and is collected by air pollution control devices, such as electrostatic precipitators and baghouse. Fly ash can be used in bonded asphalt and other road products.

However, disposal of ash from incineration facilities has become a controversial issue. Often fly ash and occasionally bottom ash shows presence of high levels of heavy metals, particularly lead and cadmium, while heavy metals are present as insoluble salts.   Such presence of toxics raises concerns of contaminates groundwater by leaching from landfills.

Overview Of Incineration Chamber Technologies

Overview

Several kinds of incineration chambers are used in various incineration systems. The application of each type of incineration chamber is also a function of the physical form and ash content of the wastes being combusted. In each of these designs, waste material is combusted in the presence of a relatively large excess of oxygen (air) to maximize the conversion of the hydrocarbon–based wastes to carbon dioxide and water. In some configurations, excess fuel and oxygen must be added to increase incineration temperatures to improve destruction and removal efficiency. This also increases the production and emission of carbon dioxide. Sulphur and nitrogen in the feedstock are oxidized to form SOx and NOx. Halogens in the feedstock are primarily converted to acid halide gases such as HCl and HF and exit the combustion chamber with the combustion gases.

The major types of incineration chamber designs used in modern incineration systems are as follows:

Liquid Injection

Liquid injection combustion chambers are used primarily for pumpable liquid wastes that are injected into burners in the form of an atomized spray using spray nozzles.

Fixed Earth

Fixed hearth incinerators also use a two–stage combustion process, much like rotary kiln systems. Unlike a rotary kiln system, however, the waste is combusted under starved air conditions in a primary stage where the volatile fraction is destroyed pyrolytically. The smoke and pyrolytic products then enter the secondary stage where the combustion process is completed using a large quantity of excess air.

Fluidized Bed

Fluidized bed incinerators are used primarily for incineration of sludge or shredded materials. These systems also offer the option for in–situ acid gas neutralization within the fluidized bed by adding lime or limestone solids.

Rotary Kiln

Rotary kiln incinerators are used for a wide variety of feedstocks, including solid wastes, slurries, liquids, and containerized wastes. The rotary kiln incinerator is said to be the most universal of thermal waste disposal systems. It can be used for the disposal of a wide variety of solid and sludge wastes and for the incineration of liquid and gaseous waste. The rotary kiln system is used in industrial waste incineration and municipal waste incineration, and more recently it has been applied to the clean-up of sites with organics-contaminated soils.

The rotary kiln includes provisions for waste feeding, air injection, the kiln itself, an afterburner, and an ash collection system. Rotary kilns use a turning cylinder, either refractory or waterwall design, to tumble the waste through the system. The kiln is declined, with waste entering at the high elevation end and ash and non-combustibles leaving at the lower end. A traveling or reciprocating grate may follow rotary combustors to further complete combustion. A typical industrial rotary kiln facility is shown in the **Figure 8**.

The rotary kiln combustion typically occurs in two stages:

- Rotary Kiln
- Afterburner

Both stages are briefly discussed below.

Rotary Kiln or Primary Combustion Chamber

The conventional rotary kiln is a horizontal cylinder, lined with refractory materials that turn about its horizontal axis. Waste is deposited in the kiln at one end, and the waste burns out to ash by the time it reaches the other end. Kiln rotational speed is variable, in the range of ¾ to 2-½ r/min. The ratio of length to diameter of a kiln used for waste disposal is normally in the range of 2:1 to 5:1.

A source of heat is required to bring the kiln up to the operating temperature and to maintain its temperature during incineration of the waste feed. Supplemental fuel is normally injected into the kiln through a conventional burner, or a ring burner when gas fuel is used.

Afterburner or Secondary Combustion Chamber

This is normally placed immediately downstream of the kiln. It is stationary, designed to maintain the temperature of the gas stream exiting the kiln at a pre-selected temperature level for a specific time.

There are kiln system designs in which the volatiles released from the kiln have a high enough heating value that they require no external source of supplementary fuel. The gas discharge from the afterburner is directed to an air emissions control system. An induced-draft or exhaust fan is provided within the emission control system to draw gases from the kiln through the equipment line, followed by discharge through a stack to the atmosphere. The design may include a waste heat boiler between the afterburner and the scrubber for energy recovery.

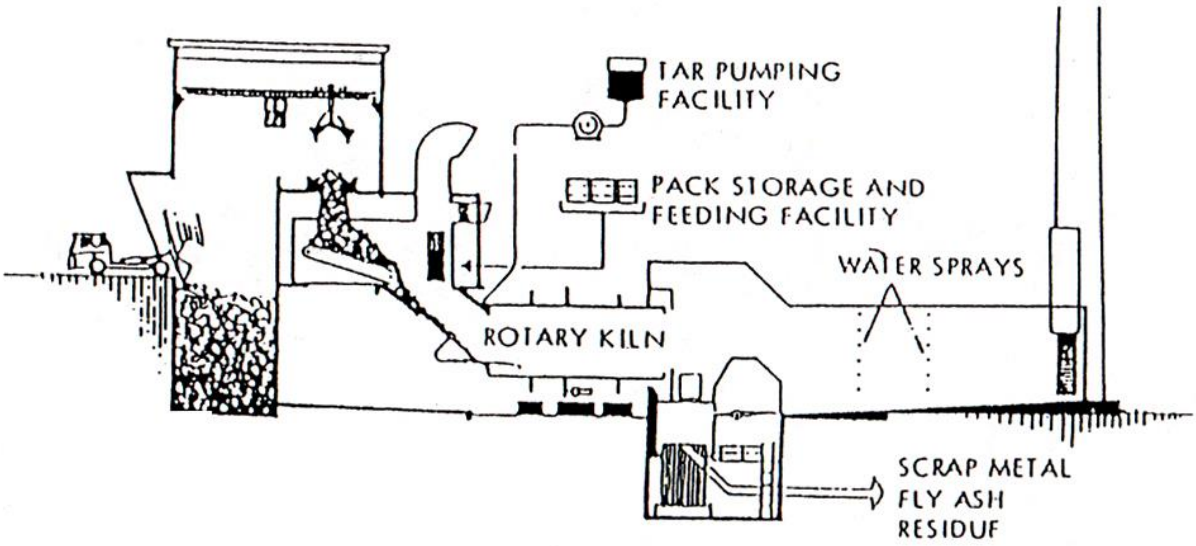
There are several variations in kiln design, such as:

- Parallel flow or counter flow
- Slagging or no slagging mode
- Refractory or bare wall

The more common used kiln design is a parallel-flow system, no slagging, lined with refractory and is generally referred as the conventional kiln.

The rotary kiln can incinerate a wide variety of wastes; however, its application has limitations.

Figure 8
Typical Major Industrial Rotary Kiln Facility



General Operation Considerations

The key to the success of an energy recovery system is controlling the combustion process so that the heat produced can be transferred most efficiently from the hot combustion gases to some other medium – almost always water in boiler. Waste-to-energy systems are designed to maximize waste combustion efficiencies and heat output while minimizing emissions by balancing the time, temperature, turbulence and oxygen (air). Many incinerators are designed to operate in the combustion zone at 1,800 °F to 2,000 °F (1,000 to 1,100 °C). This temperature is selected to ensure efficient combustion, which will have the bonus of fully combusting odorous gas molecules with the resulting elimination of odour emissions. However, a minimum temperature of 1,500 °F (800 °C) is required to eliminate odour. By selecting proper temperature can also provide incinerator wall protection from the deleterious effects of overheating.

The heterogeneous nature of municipal solid waste requires that waste-to-energy systems be carefully designed to operate efficiently over a wide range of waste input conditions. In some circumstances, prior sorting of input wastes may be necessary

Environmental Aspects

Environmental issues are recognized as critical to the viability of incineration facility. While air emissions often dominate the public and political assessments of a given process, problems with all effluents and environmental consequences must be resolved as part of the permitting process.

The major air pollutant produced by incineration facilities is particulate matter. Electrostatic precipitator is used, that generally remove particulates from incineration systems. Electrostatic precipitators can effectively reduce particulate emission to 0.2-0.3 gr/dsef. Electrified gravel filter beds and fabric filters (bag-houses) can be used for further emission control.

Other pollutants emitted by incineration facilities are sulphur dioxide (SO2), nitrogen oxides (NOx), carbon monoxide (CO), hydrogen chloride (HCl), metals, and various organic species such as dioxins, furans, and polynuclear aromatic hydrocarbons.

While ash is usually the major residue problem at incineration facilities, some plants also generate wastewater.

Wastewater in an incineration facility can be generated in various forms. These include tipping floor runoff system wash water, ash quench water, and water from pollution control systems. These systems also must deal with normal problems experienced by all large industrial facilities, including sanitary wastewater disposal and surface-water runoff. For most facilities, wastewater can be recycled in a closed-loop system.

For most facilities, the quantity of water used amounts to a few meters per ton of refuse burned. Usually this effluent can be discharged to a local sewer system.

Conclusions

Waste in the low-income economies is generally low in paper, plastic, and other combustibles as compared to high-or middle-income economies. Thus, large-scale incineration needs auxiliary fuel. Trained manpower is usually not available to operate and maintain a controlled combustion incinerator or waste-to-energy plant. High capital costs and stringent maintenance requirements promote further discouragement.

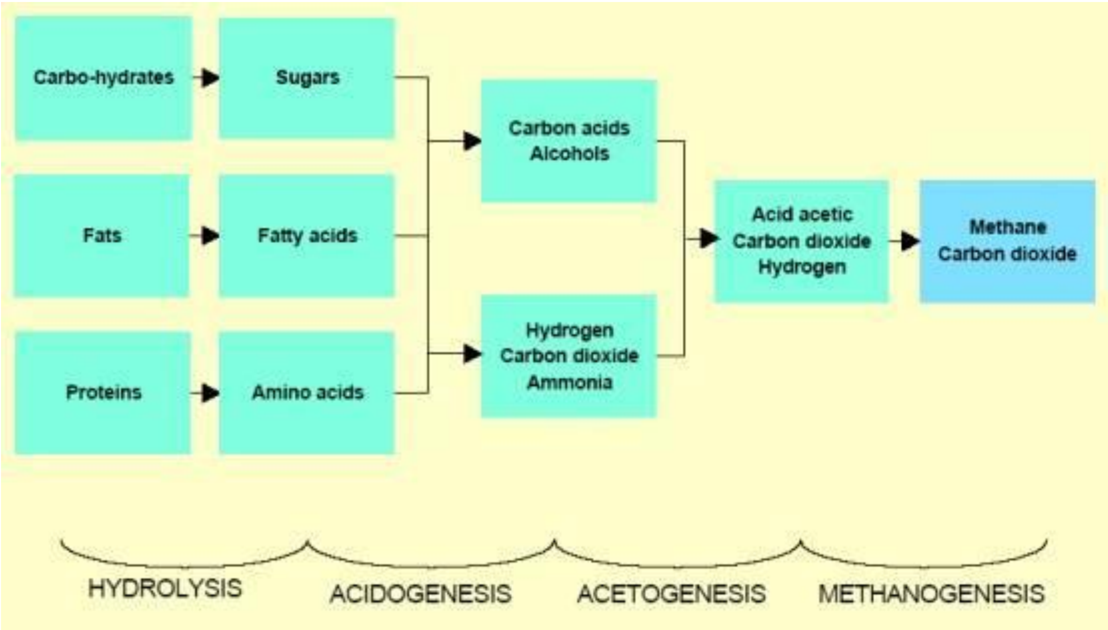
In developing countries, however, there have been many problems with imported incinerators. Some are not operated at a high enough temperature to destroy pathogens, and contribute to air pollution due to lack of environmental controls. The high moisture contents and low calorific content of MSW in these countries means that, at present, incineration is not an efficient process for waste disposal.

Anaerobic digestion of waste

Where communities have opted for the segregation of organic waste from businesses or households, the establishment of Anaerobic Digestion (AD) will normally be part of the waste management system. In recent years, organic waste has furthermore become a very important raw material for boosting biogas production from both manure and sewage sludge. Biogas can be used locally for the generation of electricity and heat or it can be upgraded for injection into the natural gas network and/or utilised as a transport fuel.

Anaerobic Digestion

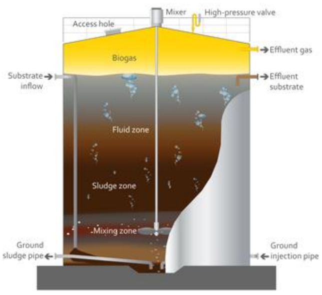
Anaerobic digestion (AD) is a natural process and is the microbiological conversion of organic matter to methane in the absence of oxygen. The decomposition is caused by natural bacterial action in various stages. It takes place in a variety of natural anaerobic environments, including water sediment, water-logged soils, natural hot springs, ocean thermal vents and the stomach of various animals (e.g. cows). The digested organic matter resulting from the anaerobic digestion process is usually called digestate.



Anaerobic Process Plants

Anaerobic process plants produce conditions that encourage the natural breakdown of organic matter by bacteria in the absence of air. The process generates three main products:

- Biogas - a mixture of carbon dioxide (CO_2) and methane (CH_4), which can be used to generate heat and/or electricity
- Fibre - can be used as a nutrient-rich soil conditioner, and
- Liquor - can be used as liquid fertiliser.



The process takes place in a digester; a warmed, sealed airless container. The digestion tank is warmed and mixed thoroughly to create the ideal conditions for biogas conversion.

During the digestion process 30 - 60% of the organic material is converted into biogas. It can be then be burned in a conventional gas boiler for heat or it can be burned in a more efficient combined heat and power (CHP) system, where heat and electricity are generated.

The digestate is stored and can be applied straight to land or it can be separated to produce fibre and liquor.

Why Use Anaerobic Digestion?

Anaerobic Digestion projects have several benefits, depending on the priorities of the plant management. The main reasons for developing an AD project are summarised below.

Reduction of pollution through integrated waste management

- The products of AD produce less odour than farm slurry
- Can reduce pollution of water courses by reducing run-off. Run-off is the liquid slurry which is sprayed onto farmland, but then drains into surface water. It can carry sediments and pollutants into the receiving waters.
- AD can lessen the risks of the spread of disease and contamination by destroying bacteria, viruses and weed seeds.
- Well-managed AD can decrease methane (CH_4) release more effectively than conventional waste management, because the methane is converted into carbon dioxide (CO_2), a less potent greenhouse gas.
- The use of AD can aid industry to manage organic waste in a manner that is not detrimental to the surrounding area and will necessitate awareness of environmental regulations.

Commercial Benefits

- AD can generate income by charging gate fees, selling biogas (as electricity or heat), liquor and/or fibre products.
- AD can produce savings by avoiding the costs of synthetic fertilisers, soil conditioners and energy from other sources.

Legal and political objectives

- Public opinion is changing, and demands the farming community consider the environment and minimise pollution when farming.
- There are increased legislative and regulative measures being placed on farmers regarding local waste management.

Demand for alternative energy sources

- Heightened concern about global warming, and climate change, has influenced UK Government and EU policy.
- Government and EU policy is driving an increase in the proportion of energy derived from renewable sources.
- Competition within the energy industry has increased due to new emerging energy markets derived from alternative sources such as renewable energy.

Community issues

- Anaerobic digestion projects can directly boost rural economies by creating jobs and indirectly through increasing disposable incomes in rural areas.
- It can provide a waste management option with positive environmental and economic benefits.
- Anaerobic digestion can also offer an opportunity to realise potential in local communities working together,stimulating new developments that are community owned and operated.

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Process Types

In an anaerobic digestion plant, there are two types of AD process:

- Mesophilic digestion
- Thermophilic digestion.

Mesophilic Digestion

Mesophilic digestion is the most commonly used process for anaerobic digestion, in particular waste sludge treatment. Decomposition of the volatile suspended solids (VSS) is around 40% over a retention time of 15 to 40 days at a temperature of 30 to 40^{o}C, which requires larger digestion tanks.

It is usually more robust than the thermophilic process, but the biogas production tends to be less, and additional sanitisation is usually required.

Thermophilic Digestion

Thermophilic digestion is less common and not as mature a technology as mesophilic digestion. The digester is heated to 55^{o}C and held for a period of 12 to 14 days.

Thermophilic digestion systems provides higher biogas production, faster throughput and an improved pathogen and virus 'kill', but the technology is more expensive, more energy is needed and it is necessary to have more sophisticated control & instrumentation.

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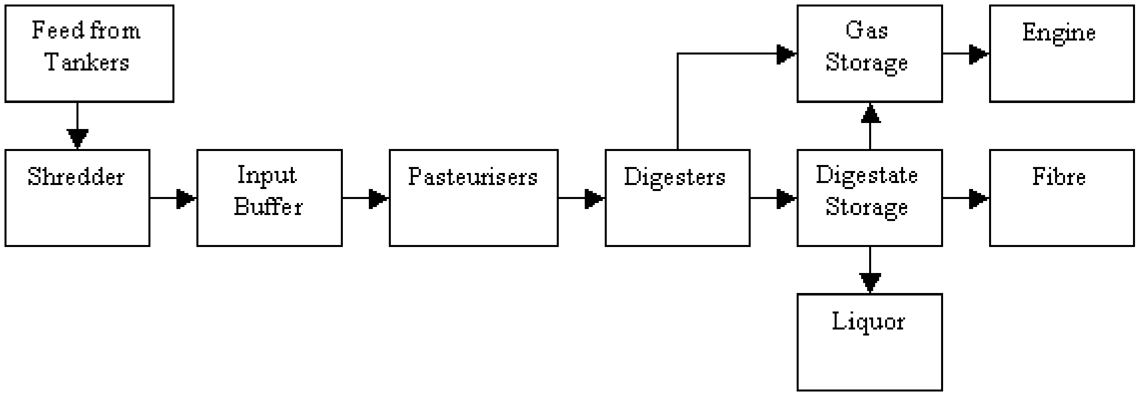
Project Plant Design

Because of the relative simplicity and it's established technology, it was decided that the plant design would be mesophilic. Below is a diagram of the main stages:



Flow Diagram of Mesophilic Process

Shredder

This is the initial stage of the mesophilic process, where the feed streams are pumped from the transport vehicles into the shredder, where the particles are shred to 12mm in size. This process is necessary for two reason; EU & UK regulations, but also small particle sizes are also digested more easily in the process.

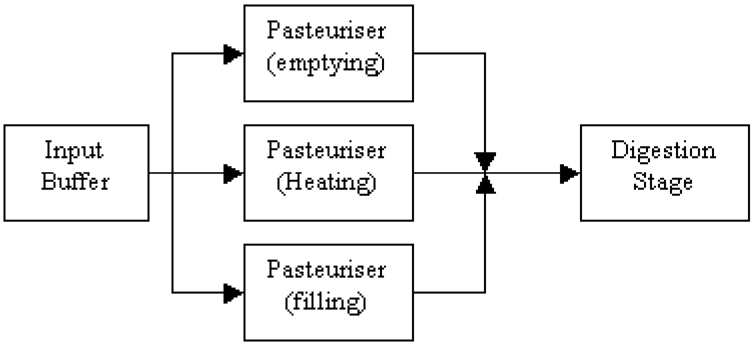
Input Buffer

The input buffer is simply a sealed tank which holds the shredded material. This allows a controlled flow of material in the pasteurisation stage. It also allows for any excess storage if there is an unforeseen amount of feed stream delivered.

Pasteurisers

Under current regulations, there must be a pasteurisation stage where the feed has to be heated to 70oC for at least one hour. This is to ensure a sufficient percentage of pathogens in the feedstock are destroyed. This also prevents any bacterial competition in the digestion stage.

To allow a constant supply of feed to the digestion stage, this process uses three pasteurisers. At any one time, a pasteuriser is emptying into the digester, one is sealed & heating, and one is being filled from the input buffer.



Pasteurisation Stage

Digesters

This is the process tank where the majority of the biogas is produced. Because of the previous three-pasteurisation stage, the feed into the digester is a consistent flow-rate.

In this stage, the anaerobic bacteria convert a quantity of the organic matter into biogas in a sealed container. This is continuously stirred and heated to around 35^{o}C.

Although there is a constant inflow and out flow of material, the average retention time is 18 days. This allows a significant percentage of the organic solids to be converted to biogas.

The outflows of the digesters are in two forms; the biogas and the liquor/fibre mixture, known as digestate.

Gas Storage

The gas from the digesters is stored here to control the flow into the engine. This engine is used to generate heat and electricity, for on-site or off-site use.

Digestate Storage

From the digesters flows a mixture of fibre and liquor (with trace amounts of biogas) into the digestate storage. In this stage, the digestate can be separated to allow appropriate use, or disposal, of the liquor and fibre.

Pre-treatment and material recovery facilities

Countries, communities and companies strive to use resources in the best possible way. Sorting at source and/or in Material Recovery Facilities (MRF) are means to achieving this goal through increased recycling. The key challenges are to generate products which are truly valuable and to be able to deal with the variations in the received input stream and health and safety issues.