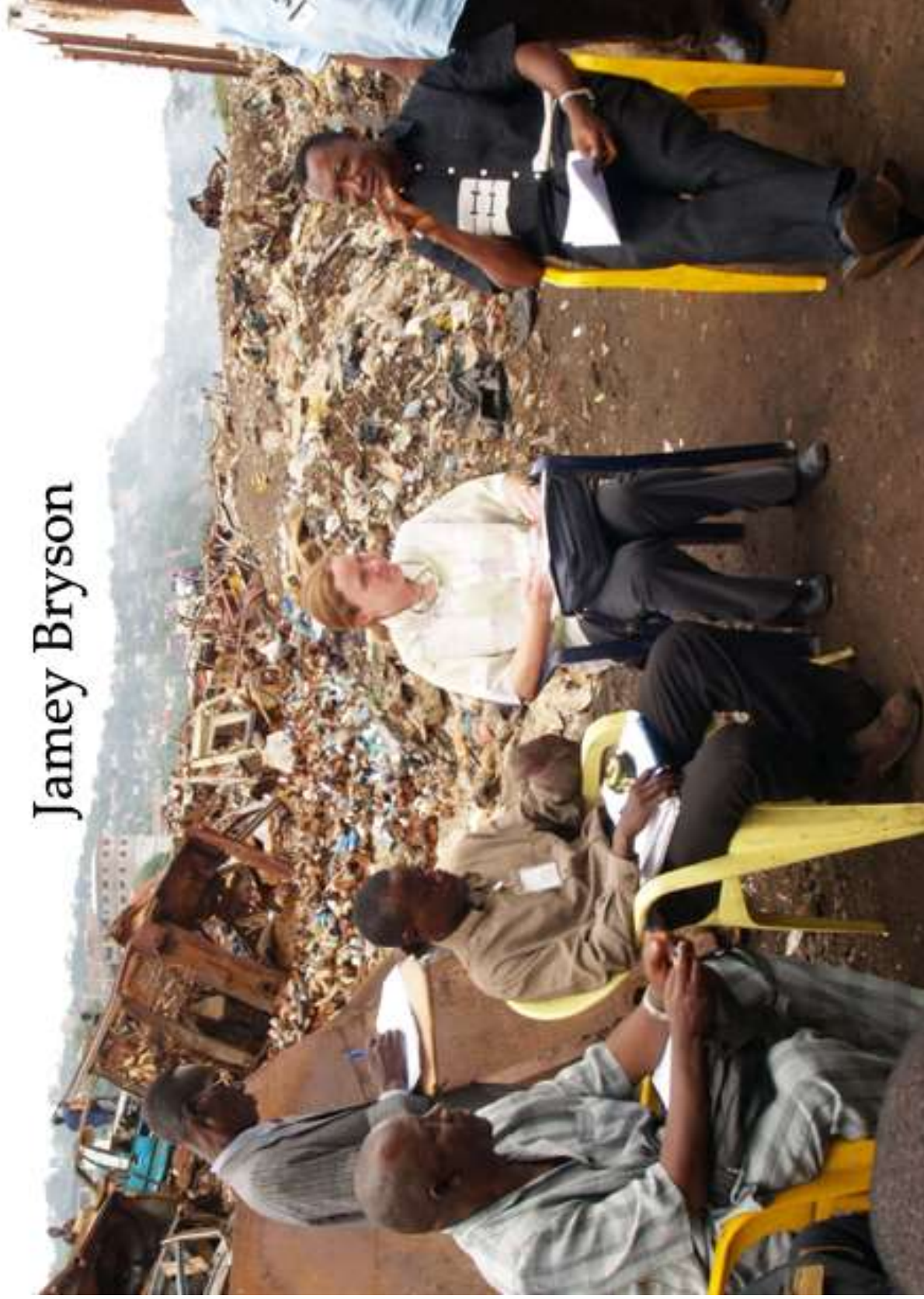


# Waste Management Handbook

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WORLD TECHNOLOGIES

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## Chapter- 1

# Introduction to Waste Management



A blue wheelie bin in Berkshire, England



Waste management in Kathmandu (Nepal)

**Waste management** is the collection, transport, processing, recycling or disposal, and monitoring of waste materials. The term usually relates to materials produced by human activity, and is generally undertaken to reduce their effect on health, the environment or aesthetics. Waste management is also carried out to recover resources from it. Waste management can involve solid, liquid, gaseous or radioactive substances, with different methods and fields of expertise for each.

Waste management practices differ for developed and developing nations, for urban and rural areas, and for residential and industrial producers. Management for non-hazardous waste residential and institutional waste in metropolitan areas is usually the responsibility of local government authorities, while management for non-hazardous commercial and industrial waste is usually the responsibility of the generator.

## **Methods of disposal**

### **Integrated waste management**

Integrated waste management using LCA (life cycle analysis) attempts to offer the most benign options for waste management. For mixed MSW (Municipal Solid Waste) a number of broad studies have indicated that waste administration, then source separation

and collection followed by reuse and recycling of the non-organic fraction and energy and compost/fertilizer production of the organic waste fraction via anaerobic digestion to be the favoured path. Non-metallic waste resources are not destroyed as with incineration, and can be reused/ recycled in a future resource depleted society.

### **Plasma gasification**

Plasma is a highly ionized or electrically charged gas. An example in nature is lightning, capable of producing temperatures exceeding 12,600 °F (6,980 °C). A gasifier vessel utilizes proprietary plasma torches operating at +10,000 °F (5,540 °C) (the surface temperature of the Sun) in order to create a gasification zone of up to 3,000 °F (1,650 °C) to convert solid or liquid wastes into a syngas. When municipal solid waste is subjected to this intense heat within the vessel, the waste's molecular bonds break down into elemental components. The process results in elemental destruction of waste and hazardous materials.

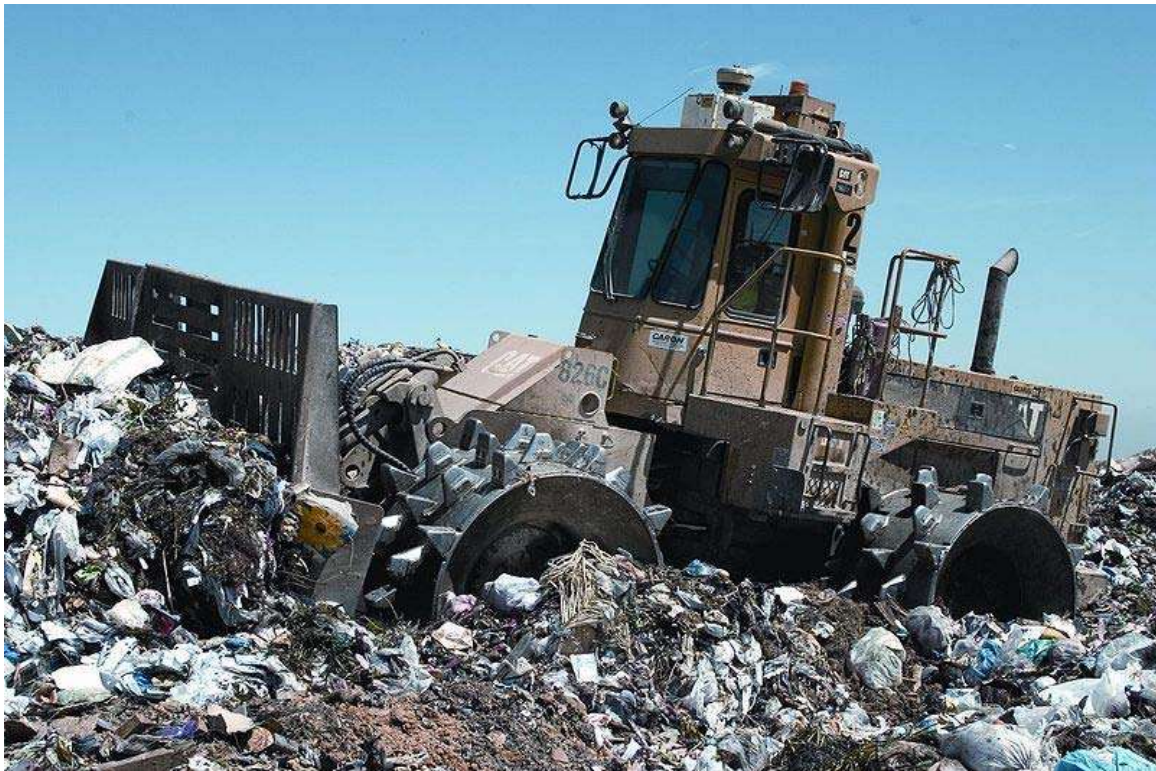
According to the U.S. Environmental Protection Agency, the U.S. generated 250 million tons of waste in 2008 alone, and this number continues to rise. About 54% of this trash (135,000,000 short tons (122,000,000 t)) ends up in landfills and is consuming land at a rate of nearly 3,500 acres (1,400 ha) per year. In fact, landfilling is currently the number one method of waste disposal in the US. Some states no longer have capacity at permitted landfills and export their waste to other states. Plasma gasification offers states new opportunities for waste disposal, and more importantly for renewable power generation in an environmentally sustainable manner.

### **Landfill**



Landfill operation in Hawaii.

Disposing of waste in a landfill involves burying the waste, and this remains a common practice in most countries. Landfills were often established in abandoned or unused quarries, mining voids or borrow pits. A properly designed and well-managed landfill can be a hygienic and relatively inexpensive method of disposing of waste materials. Older, poorly designed or poorly managed landfills can create a number of adverse environmental impacts such as wind-blown litter, attraction of vermin, and generation of liquid leachate. Another common byproduct of landfills is gas (mostly composed of methane and carbon dioxide), which is produced as organic waste breaks down anaerobically. This gas can create odour problems, kill surface vegetation, and is a greenhouse gas.



A landfill compaction vehicle in action.

Design characteristics of a modern landfill include methods to contain leachate such as clay or plastic lining material. Deposited waste is normally compacted to increase its density and stability, and covered to prevent attracting vermin (such as mice or rats). Many landfills also have landfill gas extraction systems installed to extract the landfill gas. Gas is pumped out of the landfill using perforated pipes and flared off or burnt in a gas engine to generate electricity.

## Incineration



Spittelau incineration plant in Vienna.

Incineration is a disposal method in which solid organic wastes are subjected to combustion so as to convert them into residue and gaseous products. This method is useful for disposal of residue of both solid waste management and solid residue from waste water management. This process reduces the volumes of solid waste to 20 to 30 percent of the original volume. Incineration and other high temperature waste treatment systems are sometimes described as "thermal treatment". Incinerators convert waste materials into heat, gas, steam and ash.

Incineration is carried out both on a small scale by individuals and on a large scale by industry. It is used to dispose of solid, liquid and gaseous waste. It is recognized as a practical method of disposing of certain hazardous waste materials (such as biological medical waste). Incineration is a controversial method of waste disposal, due to issues such as emission of gaseous pollutants.

Incineration is common in countries such as Japan where land is more scarce, as these facilities generally do not require as much area as landfills. Waste-to-energy (WtE) or energy-from-waste (EfW) are broad terms for facilities that burn waste in a furnace or boiler to generate heat, steam and/or electricity. Combustion in an incinerator is not always perfect and there have been concerns about micro-pollutants in gaseous emissions from incinerator stacks. Particular concern has focused on some very persistent organics such as dioxins, furans, PAHs,... which may be created within the incinerator and afterwards in the incinerator plume which may have serious environmental consequences in the area immediately around the incinerator. On the other hand this method or the more benign anaerobic digestion produces heat that can be used as energy.

## Recycling



Steel scrap, sorted and baled for recycling.

The popular meaning of 'recycling' in most developed countries refers to the widespread collection and reuse of everyday waste materials such as empty beverage containers. These are collected and sorted into common types so that the raw materials from which the items are made can be reprocessed into new products. Material for recycling may be collected separately from general waste using dedicated bins and collection vehicles, or sorted directly from mixed waste streams.

The most common consumer products recycled include aluminum beverage cans, steel food and aerosol cans, HDPE and PET bottles, glass bottles and jars, paperboard cartons, newspapers, magazines, and corrugated fiberboard boxes.

PVC, LDPE, PP, and PS are also recyclable, although these are not commonly collected. These items are usually composed of a single type of material, making them relatively easy to recycle into new products. The recycling of complex products (such as computers and electronic equipment) is more difficult, due to the additional dismantling and separation required.

### **Sustainability**

The management of waste is a key component in a business' ability to maintaining ISO14001 accreditations. Companies are encouraged to improve their environmental efficiencies each year. One way to do this is by improving a company's waste management with a new recycling service. (such as recycling: glass, food waste, paper and cardboard, plastic bottles etc.)

### **Biological reprocessing**



An active compost heap.

Waste materials that are organic in nature, such as plant material, food scraps, and paper products, can be recycled using biological composting and digestion processes to decompose the organic matter. The resulting organic material is then recycled as mulch or compost for agricultural or landscaping purposes. In addition, waste gas from the process (such as methane) can be captured and used for generating electricity and heat (CHP/cogeneration) maximising efficiencies. The intention of biological processing in waste management is to control and accelerate the natural process of decomposition of organic matter.

There are a large variety of composting and digestion methods and technologies varying in complexity from simple home compost heaps, to small town scale batch digesters,

industrial-scale enclosed-vessel digestion of mixed domestic waste. Methods of biological decomposition are differentiated as being aerobic or anaerobic methods, though hybrids of the two methods also exist.

Anaerobic digestion of the organic fraction of MSW Municipal Solid Waste has been found to be in a number of LCA analysis studies to be more environmentally effective, than landfill, incineration or pyrolysis. The resulting biogas (methane) though must be used for cogeneration (electricity and heat preferably on or close to the site of production) and can be used with a little upgrading in gas combustion engines or turbines. With further upgrading to synthetic natural gas it can be injected into the natural gas network or further refined to hydrogen for use in stationary cogeneration fuel cells. Its use in fuel cells eliminates the pollution from products of combustion (SO<sub>x</sub>, NO<sub>x</sub>, particulates, dioxin, furans, PAHs...).

An example of waste management through composting is the Green Bin Program in Toronto, Canada, where household organic waste (such as kitchen scraps and plant cuttings) are collected in a dedicated container and then composted.

### Energy recovery



Anaerobic digestion component of Lübeck mechanical biological treatment plant in Germany, 2007

The energy content of waste products can be harnessed directly by using them as a direct combustion fuel, or indirectly by processing them into another type of fuel. Recycling through thermal treatment ranges from using waste as a fuel source for cooking or heating, to anaerobic digestion and the use of the gas fuel (see above), to fuel for boilers to generate steam and electricity in a turbine. Pyrolysis and gasification are two related forms of thermal treatment where waste materials are heated to high temperatures with limited oxygen availability. The process usually occurs in a sealed vessel under high

pressure. Pyrolysis of solid waste converts the material into solid, liquid and gas products. The liquid and gas can be burnt to produce energy or refined into other chemical products (chemical refinery). The solid residue (char) can be further refined into products such as activated carbon. Gasification and advanced Plasma arc gasification are used to convert organic materials directly into a synthetic gas (syngas) composed of carbon monoxide and hydrogen. The gas is then burnt to produce electricity and steam. An alternative to pyrolysis is high temperature and pressure supercritical water decomposition (hydrothermal monophasic oxidation).

### **Avoidance and reduction methods**

An important method of waste management is the prevention of waste material being created, also known as waste reduction. Methods of avoidance include reuse of second-hand products, repairing broken items instead of buying new, designing products to be refillable or reusable (such as cotton instead of plastic shopping bags), encouraging consumers to avoid using disposable products (such as disposable cutlery), removing any food/liquid remains from cans, packaging, ... and designing products that use less material to achieve the same purpose (for example, lightweighting of beverage cans).

### **Waste handling and transport**



A front-loading garbage truck in North America.

Waste collection methods vary widely among different countries and regions. Domestic waste collection services are often provided by local government authorities, or by private companies in the industry. Some areas, especially those in less developed countries, do not have a formal waste-collection system. Examples of waste handling systems include:

- In Australia, curbside collection is the method of disposal of waste. Every urban domestic household is provided with three bins: one for recyclables, another for general waste and another for garden materials - this bin is provided by the municipality if requested. Also, many households have compost bins; but this is not provided by the municipality. To encourage recycling, municipalities provide large recycle bins, which are larger than general waste bins. Municipal, commercial and industrial, construction and demolition waste is dumped at landfills and some is recycled. Household waste is segregated: recyclables sorted and made into new products, and general waste is dumped in landfill areas. According to the ABS, the recycling rate is high and is 'increasing, with 99% of households reporting that they had recycled or reused some of their waste within the past year (2003 survey), up from 85% in 1992'. This suggests that Australians are in favour of reduced or no landfilling and the recycling of waste. Of the total waste produced in 2002–03, '30% of municipal waste, 45% of commercial and industrial waste and 57% of construction and demolition waste' was recycled. Energy is produced from waste as well: some landfill gas is captured for fuel or electricity generation. Households and industries are not charged for the volume of waste they produce.
- In Europe and a few other places around the world, a few communities use a proprietary collection system known as Envac, which conveys refuse via underground conduits using a vacuum system. Other vacuum-based solutions include the MetroTaifun single-line and ring-line systems.
- In Canadian urban centres curbside collection is the most common method of disposal, whereby the city collects waste and/or recyclables and/or organics on a scheduled basis. In rural areas people often dispose of their waste by hauling it to a transfer station. Waste collected is then transported to a regional landfill.
- In Taipei, the city government charges its households and industries for the volume of rubbish they produce. Waste will only be collected by the city council if waste is disposed in government issued rubbish bags. This policy has successfully reduced the amount of waste the city produces and increased the recycling rate.
- In Israel, the Arrow Ecology company has developed the ArrowBio system, which takes trash directly from collection trucks and separates organic and inorganic materials through gravitational settling, screening, and hydro-mechanical shredding. The system is capable of sorting huge volumes of solid waste, salvaging recyclables, and turning the rest into biogas and rich agricultural compost. The system is used in California, Australia, Greece, Mexico, the United Kingdom and in Israel. For example, an ArrowBio plant that has been operational

at the Hiriya landfill site since December 2003 serves the Tel Aviv area, and processes up to 150 tons of garbage a day.

## Technologies

Traditionally the waste management industry has been slow to adopt new technologies such as RFID (Radio Frequency Identification) tags, GPS and integrated software packages which enable better quality data to be collected without the use of estimation or manual data entry.

- Technologies like RFID tags are now being used to collect data on presentation rates for curb-side pick-ups which is useful when examining the usage of recycling bins or similar.
- Benefits of GPS tracking is particularly evident when considering the efficiency of ad hoc pick-ups (like skip bins or dumpsters) where the collection is done on a consumer request basis.
- Integrated software packages are useful in aggregating this data for use in optimisation of operations for waste collection operations.
- Rear vision cameras are commonly used for OH&S reasons and video recording devices are becoming more widely used, particularly concerning residential services and contaminations of the waste stream.

## Waste management concepts

There are a number of concepts about waste management which vary in their usage between countries or regions. Some of the most general, widely used concepts include:

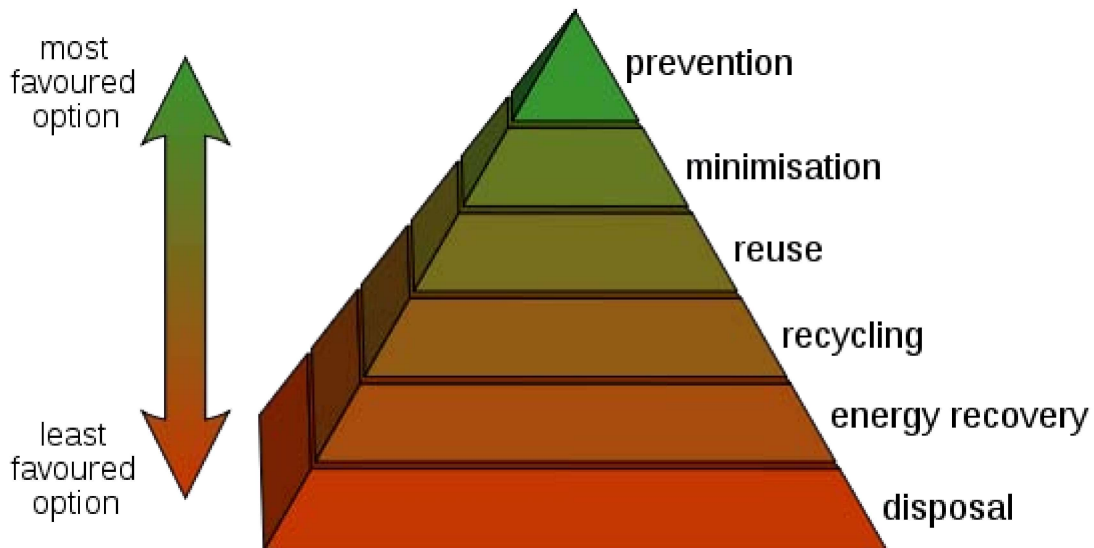


Diagram of the waste hierarchy.

- Waste hierarchy - The waste hierarchy refers to the "3 Rs" reduce, reuse and recycle, which classify waste management strategies according to their desirability in terms of waste minimization. The waste hierarchy remains the cornerstone of most waste minimization strategies. The aim of the waste hierarchy is to extract the maximum practical benefits from products and to generate the minimum amount of waste.
- Extended producer responsibility - Extended Producer Responsibility (EPR) is a strategy designed to promote the integration of all costs associated with products throughout their life cycle (including end-of-life disposal costs) into the market price of the product. Extended producer responsibility is meant to impose accountability over the entire lifecycle of products and packaging introduced to the market. This means that firms which manufacture, import and/or sell products are required to be responsible for the products after their useful life as well as during manufacture.
- Polluter pays principle - the Polluter Pays Principle is a principle where the polluting party pays for the impact caused to the environment. With respect to waste management, this generally refers to the requirement for a waste generator to pay for appropriate disposal of the waste.

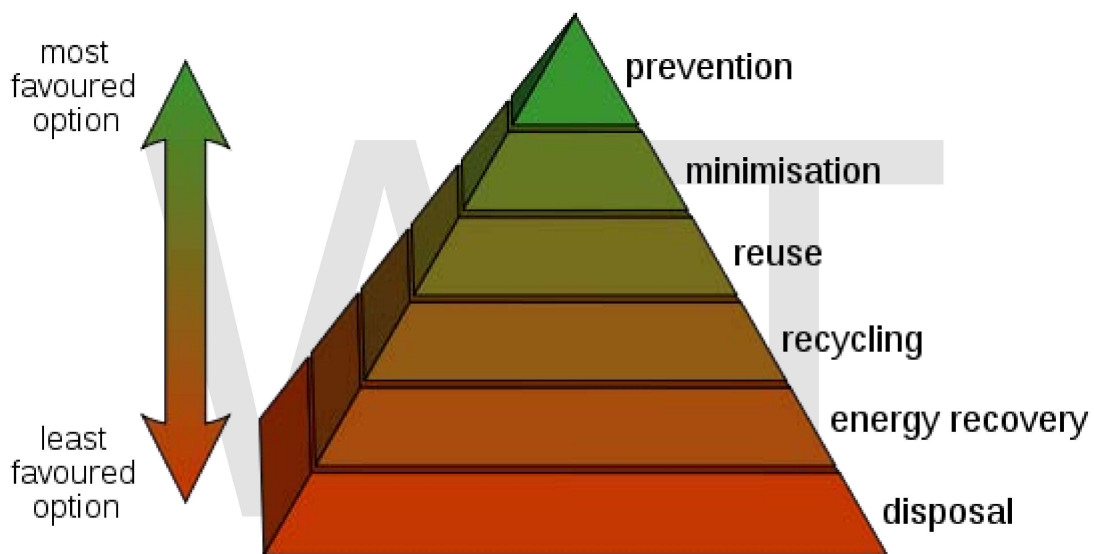
## Education and awareness

Education and awareness in the area of waste and waste management is increasingly important from a global perspective of resource management. The Talloires Declaration is a declaration for sustainability concerned about the unprecedented scale and speed of environmental pollution and degradation, and the depletion of natural resources. Local, regional, and global air pollution; accumulation and distribution of toxic wastes; destruction and depletion of forests, soil, and water; depletion of the ozone layer and emission of "green house" gases threaten the survival of humans and thousands of other living species, the integrity of the earth and its biodiversity, the security of nations, and the heritage of future generations. Several universities have implemented the Talloires Declaration by establishing environmental management and waste management programs, e.g. the waste management university project. University and vocational education are promoted by various organizations, e.g. WAMITAB and Chartered Institution of Wastes Management. Many supermarkets encourage customers to use their reverse vending machines to deposit used purchased containers and receive a refund from the recycling fees. Brands that manufacture such machines include Tomra and Envipco.

In 2010, CNBC aired the documentary *Trash Inc: The Secret Life of Garbage* about waste, what happens to it when it's "thrown away", and its impact on the world.

## Chapter- 2

# Waste Minimisation



Waste hierarchy

**Waste minimisation** is the process and the policy of reducing the amount of waste produced by a person or a society.

Waste minimisation involves efforts to minimise resource and energy use during manufacture. For the same commercial output, usually the fewer materials are used, the less waste is produced. Waste minimisation usually requires knowledge of the production process, cradle-to-grave analysis (the tracking of materials from their extraction to their return to earth) and detailed knowledge of the composition of the waste.

The main sources of waste vary from country to country. In the UK, most waste comes from the construction and demolition of buildings, followed by mining and quarrying, industry and commerce. Household waste constitutes a relatively small proportion of all waste. Reasons for the creation of waste sometimes include requirements in the supply

chain. For example, a company handling a product may insist that it should be packaged using particular packing because it fits its packaging equipment.

In the waste hierarchy, the most effective approaches to managing waste are at the top. In contrast to waste minimisation, waste management focuses on processing waste after it is created, concentrating on re-use, recycling, and waste-to-energy conversion.

## **In industries**

In industries, using more efficient manufacturing processes and better materials will generally reduce the production of waste. The application of waste minimisation techniques has led to the development of innovative and commercially successful replacement products. Waste minimisation has proven benefits to industry and the wider environment.

Waste minimisation often requires investment, which is usually compensated by the savings. However, waste reduction in one part of the production process may create waste production in another part.

There are government incentives for waste minimisation, which focus on the environmental benefits of adopting waste minimisation strategies. In the UK, several pilot schemes such as The Catalyst Project and the Dee Waste Minimisation Project, have shown the efficacy of such policies. Fourteen companies in Merseyside took part in the Catalyst Project; the project generated overall savings of £9 million and landfill waste was reduced by 12,000 tonnes per year.

The following is a list of waste minimisation processes:

### **Resource optimisation**

Minimising the amount of waste produced by organisations or individuals goes hand-in-hand with optimising their use of raw materials. For example, a dressmaker may arrange pattern pieces on a length of fabric in a particular way to enable the garment to be cut out from the smallest area of fabric.

### **Reuse of scrap material**

Scraps can be immediately re-incorporated at the beginning of the manufacturing line so that they do not become a waste product. Many industries routinely do this; for example, paper mills return any damaged rolls to the beginning of the production line, and in the manufacture of plastic items, off-cuts and scrap are re-incorporated into new products.

### **Improved quality control and process monitoring**

Steps can be taken to ensure that the number of reject batches is kept to a minimum. This is achieved by increasing the frequency of inspection and the number of points of inspection. For example, installing automated continuous monitoring equipment can help to identify production problems at an early stage.

### **Waste exchanges**

This is where the waste product of one process becomes the raw material for a second process. Waste exchanges represent another way of reducing waste disposal volumes for waste that cannot be eliminated.

#### Ship to point of use

This involves making deliveries of incoming raw materials or components direct to the point where they are assembled or used in the manufacturing process to minimise handling and the use of protective wrappings or enclosures.

### **Product design**

Waste minimisation and resource maximisation for manufactured products can most easily be done at the design stage. Reducing the number of components used in a product or making the product easier to take apart can make it easier to be repaired or recycled at the end of its useful life.

In some cases, it may be best not to minimise the volume of raw materials used to make a product, but instead reduce the volume or toxicity of the waste created at the end of a product's life, or the environmental impact of the product's use.

#### **Fitting the intended use**

In this strategy, products and packages are optimally designed to meet their intended use. This applies especially to packaging materials, which should only be as durable as necessary to serve their intended purpose. On the other hand, it could be more wasteful if food, which has consumed resources and energy in its production, is damaged and spoiled because of extreme measures to reduce the use of paper, metals, glass and plastics in its packaging.

#### **Durability**

Improving product durability, such as extending a vacuum cleaner's useful life to 15 years instead of 12, can reduce waste and usually much improves resource optimisation.

But in some cases it has a negative environmental impact. If a product is too durable, its replacement with more efficient technology is likely to be delayed. For example, a washing machine produced 10 years ago may use twice as much water, detergent and energy as one produced today. Therefore, extending an older machine's useful life may place a heavier burden on the environment than scrapping it, recycling its metal and buying a new model. Similarly, older vehicles consume more fuel and produce more emissions than their modern counterparts.

Most proponents of waste minimisation consider that the way forward may be to view any manufactured product at the end of its useful life as a resource for recycling and reuse rather than waste. Recycling a product is easier if it is constructed of fewer materials. Car manufacturers have recently reduced the number of plastics used in their cars from twenty or more to three or four, hence simplifying the recovery of plastics from

scrapped cars. However, exceptions (like having a combination of paper and plastic or plastic coating on glass) do exist, and might enable a product to fulfill its role with the minimum of resources.

Making refillable glass bottles strong enough to withstand several journeys between the consumer and the bottling plant requires making them thicker and so heavier, which increases the resources required to transport them. Since transport has a large environmental impact, careful evaluation is required of the number of return journeys bottles make. If a refillable bottle is thrown away after being refilled only several times, the resources wasted may be greater than if the bottle had been designed for a single journey.

Many choices involve trade-offs of environmental impact, and often there is insufficient information to make informed decisions.

## **In households**

Appropriate amounts and sizes can be chosen when purchasing goods; buying large containers of paint for a small decorating job or buying larger amounts of food than can be consumed create unnecessary waste. Also, if a pack or can is to be thrown away, any remaining contents must be removed before the container can be recycled .

Home composting, the practice of turning kitchen and garden waste into compost can be considered waste minimisation.

The resources that households use can be reduced considerably by using electricity thoughtfully (e.g. turning off lights and equipment when it is not needed) and by reducing the number of car journeys made. Individuals can reduce the amount of waste they create by buying fewer products and by buying products which last longer. Mending broken or worn items of clothing or equipment also contributes to minimising household waste. Individuals can minimise their water usage, and walk or cycle to their destination rather than using their car to save fuel and cut down emissions.

In a domestic situation, the potential for minimisation is often dictated by lifestyle. Some people may view it as wasteful to purchase new products solely to follow fashion trends when the older products are still usable. Adults working full-time have little free time, and so may have to purchase more convenient foods that require little preparation, or prefer disposable nappies if there is a baby in the family.

The amount of waste an individual produces is a small portion of all waste produced by society, and personal waste reduction can only make a small impact on overall waste volumes. Yet, influence on policy can be exerted in other areas. Increased consumer awareness of the impact and power of certain purchasing decisions allows industry and individuals to change the total resource consumption. Consumers can influence manufacturers and distributors by avoiding buying products that do not have eco-labelling, which is currently not mandatory, or choosing products that minimise the use

of packaging. In the UK, PullApart combines both environmental and consumer packaging surveys, in a curbside packaging recycling classification system to waste minimise. Where reuse schemes are available, consumers can be proactive and use them.

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## Chapter- 3

# Reuse



An interior bathroom wall that incorporates repurposed clear glass bottles into a bottle wall.

To **Reuse** is to use an item more than once. This includes conventional reuse where the item is used again for the same function, and new-life reuse where it is used for a new function. In contrast, recycling is the breaking down of the used item into raw materials which are used to make new items. By taking useful products and exchanging them, without reprocessing, reuse help save time, money, energy, and resources. In broader economic terms, reuse offers quality products to people and organizations with limited means, while generating jobs and business activity that contribute to the economy.

Historically, financial motivation was one of the main drivers of reuse. In the developing world this driver can lead to very high levels of reuse, however rising wages and consequent consumer demand for the convenience of disposable products has made the reuse of low value items such as packaging uneconomic in richer countries, leading to the demise of many reuse programs. Current environmental awareness is gradually changing attitudes and regulations, such as the new packaging regulations, are gradually beginning to reverse the situation.

The classic example of conventional reuse is the doorstep delivery of milk in refillable bottles; other examples include the retreading of tires and the use of reusable plastic boxes (transit packing) instead of single-use cardboard cartons.



Ants, being social insects, have been able to reuse rail tracks abandoned by humans for their own transportation. (Kadina, South Australia)

## **Advantages & disadvantages**

Reuse has certain potential advantages:

- Energy and raw materials savings as replacing many single use products with one reusable one reduces the number that need to be manufactured.

- Reduced disposal needs and costs.
- Refurbishment can bring sophisticated, sustainable, well paid jobs to underdeveloped economies.
- Cost savings for business and consumers as a reusable product is often cheaper than the many single use products it replaces.
- Some older items were better handcrafted and appreciate in value.

Disadvantages are also apparent:

- Reuse often requires cleaning or transport, which have environmental costs.
- Some items, such as freon appliances or infant auto seats, could be hazardous or less energy efficient as they continue to be used.
- Reusable products need to be more durable than single-use products, and hence require more material per item. This is particularly significant if only a small proportion of the reusable products are in fact reused.
- Sorting and preparing items for reuse takes time, which is inconvenient for consumers and costs money for businesses.

## Examples

### Reuse centers & virtual exchanges



An electric wire reel reused as a center table in a Rio de Janeiro decoration fair. The reuse of materials is a very sustainable practice that is rapidly growing among designers in Brazil

These services facilitate the transaction and redistribution of unwanted, yet perfectly usable, materials and equipment from one entity to another. The entities that benefit from either side of this service (as donors, sellers, recipients, or buyers) can be businesses, nonprofits, schools, community groups, and individuals. Some maintain a physical space (a reuse center), and others act as a matching service (a virtual exchange). Reuse centers generally maintain both warehouses and trucks. They take possession of the donated materials and make them available for redistribution or sale. Virtual exchanges do not have physical space or trucks, but instead allow users to post listings of materials available and wanted (for free or at low cost) on an online materials exchange website. Staff will help facilitate the exchange of these materials without ever taking possession of the materials.

Reuse centers include Goodwill Industries, Salvation Army, Second Harvest Food Bank, and Habitat for Humanity ReStores. Virtual exchanges include CalMax (California, US) or WasteMatch (New York, US). Lesser known organizations such as Alchemy Goods (Seattle, WA, US) and STAY VOCAL (Norwell, MA, US) have received increasing attention as reuse companies.

Helpful consumer resources exist for exchanging usable materials, such as the Freecycle network which is a grassroots and entirely nonprofit movement of people who are giving (and getting) stuff for free in their own towns. It's all about reuse and keeping good stuff out of landfills. Each local group is moderated by a local volunteer. Membership is free.

Teleplan Camera Repair has introduced a free camera recycling program through the reuse of cameras.

In Marrickville (a suburb of Sydney, Australia), Reverse Garbage is the largest reuse centre in the country, diverting more than 12,000 cubic metres of resources from landfills each year.

## **Remanufacturing**

The most involved reuse organizations are "repair and overhaul" industries which take valuable parts, such as engine blocks, office furniture, toner cartridges, single-use cameras, aircraft hulls, and cathode ray tubes (CRTs) and refurbish them in a factory environment in order to meet the same/similar specifications as new products. Xerox (copy machines), Video Display Corp. (CRTs), and Cummins Engine are examples of refurbishing factories in the USA. Rolls Royce has a very large aircraft remanufacturing factory in Singapore; Caterpillar recently announced the opening of a tractor refurbishing plant in China. Some factories operate in competition with the original equipment manufacturer (OEM). When the refurbished item is resold under a new label (used

monitor CRTs made into TVs, or cameras resold under a new label) this has been found legal by most courts.

When the item is resold under the same OEM name, it is informally considered a "gray market" item - if it is sold as used, it's legal, if it's represented as an OEM product eligible for rebates and warranties, it is considered "counterfeit" or "black market". The automobile parts industry in the USA is governed by laws on the disclosure of "used" parts and, in some states, mattresses which have been used are required to be sanitized or destroyed. Whether these laws are in place to protect consumers from black market items, or to protect manufacturers ("hindsight obsolescence"), is often an area of intense debate. Fuji Photo Film Co. v. Jazz Photo Corp. is a recent example of the war between patent holders and refurbishing factories. To quote the 2003 District Court of New Jersey: *"Thus, the key issue in the dispute between Fuji and Jazz is whether the cameras sold by Jazz are "refurbished" in such a way that they can be considered to have been permissibly "repaired" or impermissibly "reconstructed."* When the distinction requires court intervention in the USA, it is easy to imagine the difficulty in discerning between "remanufacturing" and "counterfeiting" in less developed or rapidly developing nations. Twinkle ki chood main mera lund.

## Deposit programs



Reusable glass bottles collected in Bishkek, Kyrgyzstan. Deposit values (0.5-2 Kyrgyz som) are posted next to the sample bottles on the rack

Deposit programs offer customers a financial incentive to return packaging for reuse. Although no longer common, international experience is showing that they can still be an effective way to encourage packaging reuse. However, financial incentive, unless great, may be less of an incentive than convenience: statistics show that, on average, a milk bottle is returned 12 times, whereas a lemonade bottle with a 15p deposit is returned, on average, only 3 times.

Refillable bottles are used extensively in many European countries; for example in Denmark, 98% of bottles are refillable, and 98% of those are returned by consumers. These systems are typically supported by deposit laws and other regulations.

Sainsbury Ltd have operated a plastic carrier bag cash refund scheme in 1991 - "the penny back scheme". The scheme is reported to save 970 tonnes of plastic per annum. The scheme has now been extended to a penny back on a voucher which can be contributed to schools registered on the scheme; it estimates this will raise the savings in plastic to 2500 tonnes per annum.



The 600 ml brown bottle is the "standard beer reused bottle" in Brazil.

In some developing nations like India and Pakistan, the cost of new bottles often forces manufacturers to collect and refill old glass bottles for selling cola and other drinks. India and Pakistan also have a way of reusing old newspapers: "Kabadiwalas" buy these from the readers for scrap value and reuse them as packaging or recycle them. Scrap intermediaries help consumer dispose of other materials including metals and plastics.

### **Closed-loop programs**

These apply primarily to items of packaging, for example, where a company is involved in the regular transportation of goods from a central manufacturing facility to warehouses or warehouses to retail outlets. In these cases there is considerable benefit to using reusable "transport packaging" such as plastic crates or pallets. Tesco have established a series of nine recycling service units which wash returnable plastic trays; it is estimated that this operations saves around 50,000 tonnes of packaging per annum. Marks and Spencer operate a similar scheme with 90% reuse or recycle of transit packaging. 65% of

their foods are transported on reusable plastic trays saving 25,000 tonnes of cardboard per year; they also have a 3 year plan to eliminate transit packaging on textiles and home furnishing product lines saving another 28,000 tonnes per annum. The same company started a coat hanger reuse scheme in 1993 and now reuse over 20 million of these annually saving 1,200 tonnes of plastic.

The benefits of closed-loop reuse are primarily due to virtually no additional transport costs being involved, the empty lorry returning with the empty crates. There have been some recent attempts to get the public to join in on closed loop reuse schemes with the so called "blue basket" schemes (green in the case of Safeway) where shoppers use reusable plastic baskets in place of carrier bags for transporting their goods home from the supermarket; these baskets fit on specially designed trolleys making shopping supposedly easier.

### **Refilling programs**

There have been some market-led initiatives to encourage packaging reuse by companies introducing refill packs of certain commodities (mainly soap powders and cleaning fluids), the contents being transferred before use into a reusable package kept by the customer, with the savings in packaging being passed onto the customer by lower shelf prices. The refill pack itself is not reused, but being a minimal package for carrying the product home, it requires less material than one with the durability and features (reclosable top, convenient shape, etc.) required for easy use of the product, while avoiding the transport cost and emissions of returning the reusable package to the factory.

### **Regiving/regifting**

Some items, such as clothes and children's toys, often become unwanted before they wear out due to changes in their owner's needs or preferences; these can be reused by selling or giving them to new owners. Regiving can take place informally between family, friends, or neighbours, through explicitly environmental organisations such as Freecycle, Scavenger and Freesharing Networks or through anti-poverty charities such as the Red Cross, United Way, Salvation Army, and Goodwill which give these items to those who could not afford them new. Other organizations such as iLoveSchools have websites where both new and used goods can be offered to any of America's school teachers so their life can be extended and help schoolchildren. The average American, for example, throws away 67.9 pounds of used clothing and rags. With the U.S. population at approximately 296 million people, that translates into 20 billion pounds of used clothing and textiles that are tossed into the landfills each year. This has partly motivated movements such as The Compact, whose members promise not to buy anything new for a year, and rely on reusing items that otherwise would be thrown away. Reuse not only reduces landfill inline with the waste minimization program but can help raise money for a good cause.

### **Printer cartridges & toners reuse**

Printer ink cartridges can be reused. They are sorted into different brands and models which may then be refilled, or resold back to the companies that created these cartridges. The companies then refill the ink reservoir which can be sold back to consumers. Toner cartridges are recycled the same way as ink cartridges, using toner instead of ink. This method is highly efficient as there is no energy spent on melting and recreating the cartridges.

## Repurposing



An iMac G4 that has been repurposed into a lamp (photographed next to a Mac Classic and a flip phone).

Repurposing is to use a tool for use as a another tool, usually for a purpose unintended by the original tool-maker. Typically, repurposing is done using items usually considered to be junk or garbage. A good example of this would be the Earthship style of house, that uses tires as insulating walls and bottles as glass walls. Reuse is not limited to repeated uses for the same purpose. Examples of repurposing include using tires as boat fenders and steel drums as feeding troughs. Incinerator and power plant exhaust stack fly-ash is used extensively as an additive to concrete, providing increased strength. This type of reuse can sometimes make use of items which are no longer usable for their original purpose, for example using worn-out clothes as rags.



The bottle, can and tire walls of 2 Earthships.

### **Waste exchanges**

A waste exchange, or virtual exchange (see above), facilitates the use of a waste product from one process as a raw material for another. As with new life reuse of finished items, this avoids the environmental costs of disposing of the waste and obtaining new raw material, and may still be possible if the nature of the process makes avoiding production of the waste or recycling it back into the original process impossible.

This sort of scheme needs to have a far broader base than is currently the case, it requires organization and the setting up of waste brokerages where lists of currently available wastes are and the quantities available. One of the problems is once a demand for a waste is known or shown then the material is no longer a “waste” but a sellable commodity which often prices itself out of the market, c.f waste cement kiln dust and N-viro (lime conditioned sewage sludge fertilizer). In the former East Germany, organic household waste was collected and used as fodder for pigs. This integrated system was made possible by the state's control of agriculture; the complexities of continuing it in a market economy after German reunification meant the system had to be discontinued.

### **Measuring the impact of reuse, reuse metrics**

There are many ways of measuring the positive environmental, economic and social impact data reuse has on our communities.

These include, but are not limited, to:

- # of tons diverted from the landfill
- \$ avoided disposal costs (donor/seller)
- \$ avoided purchase costs (recipient/buyer)
- \$ value of materials donated (donor)
- \$ revenues earned (donor/seller)
- # of jobs created or retained
- # of families/individuals/organizations assisted

## **Internalized environmental costs**

This is an economist's way of saying introduce an environmental tax: a charge on items which reflects the environmental costs of their manufacture and disposal. This makes the environmental benefit of using one reusable item instead of many disposable ones into a financial incentive. Such charges have been introduced in some countries. Such schemes are said to encourage reuse.

## **Comparison to recycling**

Recycling differs from reuse in that it breaks down the item into raw materials which are then used to make new items, as opposed to reusing the intact item. As this extra processing requires energy, as a rule of thumb reuse is environmentally preferable to recycling ("reduce, reuse, recycle"), though recycling does have a significant part to play as it can often make use of items which are broken, worn out or otherwise unsuitable for reuse. However, as transport emissions are significant portion of the environmental impact of both reuse and recycling, in some cases recycling is the more prudent course as reuse can require long transport distances. A complex life cycle analysis may be required during a products design phase to determine the efficacy of reuse, recycling, or neither, and produce accordingly.

## **Reuse of information**

Besides the great amount of reuse of our physical resources, there is now a powerful argument for reuse of information, notably program code for the software that drives computers and the Internet, but also the documentation that explains how to use every modern device. And it is proposed as a way to improve education by assembling a great library of shareable learning objects that can be reused in learning management systems.

Software reuse grew out of the standard subroutine libraries of the 1960s. It is the main principle of today's object-oriented programming. Instead of constantly reinventing

software wheels, programming languages like C++, Java, Objective-C, and others are building vast collections of reusable software objects and components.

Reuse is closely related to the concept of single source publishing in which text written once is output to multiple publishing channels like print, the web, mobile devices, and online help. Reuse of information always has a single source, but not all single-sourced information is reused in multiple different contexts.

Reuse of information has a tremendous return on investment for organizations whose documentation is translated into many languages. Translation memory systems can store text that has already been translated into dozens of languages for retrieval and reuse.

WWT

## Chapter- 4

# Recycling of Waste Materials

**Recycling** involves processing used materials (waste) into new products to prevent waste of potentially useful materials, reduce the consumption of fresh raw materials, reduce energy usage, reduce air pollution (from incineration) and water pollution (from landfilling) by reducing the need for "conventional" waste disposal, and lower greenhouse gas emissions as compared to virgin production. Recycling is a key component of modern waste reduction and is the third component of the "Reduce, Reuse, Recycle" waste hierarchy.

Recyclable materials include many kinds of glass, paper, metal, plastic, textiles, and electronics. Although similar in effect, the composting or other reuse of biodegradable waste – such as food or garden waste – is not typically considered recycling. Materials to be recycled are either brought to a collection center or picked up from the curbside, then sorted, cleaned, and reprocessed into new materials bound for manufacturing.

In a strict sense, recycling of a material would produce a fresh supply of the same material—for example, used office paper would be converted into new office paper, or used foamed polystyrene into new polystyrene. However, this is often difficult or too expensive (compared with producing the same product from raw materials or other sources), so "recycling" of many products or materials involves their **reuse** in producing different materials (e.g., paperboard) instead. Another form of recycling is the **salvage** of certain materials from complex products, either due to their intrinsic value (e.g., lead from car batteries, or gold from computer components), or due to their hazardous nature (e.g., removal and reuse of mercury from various items). Critics dispute the net economic and environmental benefits of recycling over its costs, and suggest that proponents of recycling often make matters worse and suffer from confirmation bias. Specifically, critics argue that the costs and energy used in collection and transportation detract from (and outweigh) the costs and energy saved in the production process; also that the jobs produced by the recycling industry can be a poor trade for the jobs lost in logging, mining, and other industries associated with virgin production; and that materials such as paper pulp can only be recycled a few times before material degradation prevents further recycling. Proponents of recycling dispute each of these claims, and the validity of arguments from both sides has led to enduring controversy.

# History

## Early recycling

Recycling has been a common practice for most of human history, with recorded advocates as far back as Plato in 400 BC. During periods when resources were scarce, archaeological studies of ancient waste dumps show less household waste (such as ash, broken tools and pottery)—implying more waste was being recycled in the absence of new material.

In pre-industrial times, there is evidence of scrap bronze and other metals being collected in Europe and melted down for perpetual reuse. In Britain dust and ash from wood and coal fires was collected by 'dustmen' and downcycled as a base material used in brick making. The main driver for these types of recycling was the economic advantage of obtaining recycled feedstock instead of acquiring virgin material, as well as a lack of public waste removal in ever more densely populated areas. In 1813, Benjamin Law developed the process of turning rags into 'shoddy' and 'mungo' wool in Batley, Yorkshire. This material combined recycled fibres with virgin wool. The West Yorkshire shoddy industry in towns such as Batley and Dewsbury, lasted from the early 19th century to at least 1914.



Publicity photo for US aluminium salvage campaign in 1942

Industrialization spurred demand for affordable materials; aside from rags, ferrous scrap metals were coveted as they were cheaper to acquire than was virgin ore. Railroads both purchased and sold scrap metal in the 19th century, and the growing steel and automobile industries purchased scrap in the early 20th century. Many secondary goods were collected, processed, and sold by peddlers who combed dumps, city streets, and went door to door looking for discarded machinery, pots, pans, and other sources of metal. By World War I, thousands of such peddlers roamed the streets of American cities, taking advantage of market forces to recycle post-consumer materials back into industrial production.

### **Wartime recycling**

Resource shortages caused by the world wars, and other such world-changing occurrences greatly encouraged recycling. Massive government promotion campaigns were carried out in World War II in every country involved in the war, urging citizens to donate metals and conserve fibre, as a matter of significant patriotic importance. Resource conservation programs established during the war were continued in some countries without an abundance of natural resources, such as Japan, after the war ended.

### **Post-war recycling**

The next big investment in recycling occurred in the 1970s, due to rising energy costs. Recycling aluminium uses only 5% of the energy required by virgin production; glass, paper and metals have less dramatic but very significant energy savings when recycled feedstock is used.

## **Legislation**

### **Supply**

For a recycling program to work, having a large, stable supply of recyclable material is crucial. Three legislative options have been used to create such a supply: mandatory recycling collection, container deposit legislation, and refuse bans. Mandatory collection laws set recycling targets for cities to aim for, usually in the form that a certain percentage of a material must be diverted from the city's waste stream by a target date. The city is then responsible for working to meet this target.

Container deposit legislation involves offering a refund for the return of certain containers, typically glass, plastic, and metal. When a product in such a container is purchased, a small surcharge is added to the price. This surcharge can be reclaimed by the consumer if the container is returned to a collection point. These programs have been very successful, often resulting in an 80% recycling rate. Despite such good results, the

shift in collection costs from local government to industry and consumers has created strong opposition to the creation of such programs in some areas.

A third method of increase supply of recyclates is to ban the disposal of certain materials as waste, often including used oil, old batteries, tires and garden waste. One aim of this method is to create a viable economy for proper disposal of banned products. Care must be taken that enough of these recycling services exist, or such bans simply lead to increased illegal dumping.

## **Government-mandated demand**

Legislation has also been used to increase and maintain a demand for recycled materials. Four methods of such legislation exist: minimum recycled content mandates, utilization rates, procurement policies, recycled product labeling.

Both minimum recycled content mandates and utilization rates increase demand directly by forcing manufacturers to include recycling in their operations. Content mandates specify that a certain percentage of a new product must consist of recycled material. Utilization rates are a more flexible option: industries are permitted to meet the recycling targets at any point of their operation or even contract recycling out in exchange for tradeable credits. Opponents to both of these methods point to the large increase in reporting requirements they impose, and claim that they rob industry of necessary flexibility.

Governments have used their own purchasing power to increase recycling demand through what are called "procurement policies". These policies are either "set-asides", which earmark a certain amount of spending solely towards recycled products, or "price preference" programs which provide a larger budget when recycled items are purchased. Additional regulations can target specific cases: in the United States, for example, the Environmental Protection Agency mandates the purchase of oil, paper, tires and building insulation from recycled or re-refined sources whenever possible.

The final government regulation towards increased demand is recycled product labeling. When producers are required to label their packaging with amount of recycled material in the product (including the packaging), consumers are better able to make educated choices. Consumers with sufficient buying power can then choose more environmentally conscious options, prompt producers to increase the amount of recycled material in their products, and indirectly increase demand. Standardized recycling labeling can also have a positive effect on supply of recyclates if the labeling includes information on how and where the product can be recycled.

## **Process**

### **Collection**



Recycling and rubbish bin in a German railway station.

A number of different systems have been implemented to collect recyclates from the general waste stream. These systems lie along the spectrum of trade-off between public convenience and government ease and expense. The three main categories of collection are "drop-off centres", "buy-back centres" and "curbside collection".

Drop-off centres require the waste producer to carry the recyclates to a central location, either an installed or mobile collection station or the reprocessing plant itself. They are the easiest type of collection to establish, but suffer from low and unpredictable throughput. Buy-back centres differ in that the cleaned recyclates are purchased, thus providing a clear incentive for use and creating a stable supply. The post-processed material can then be sold on, hopefully creating a profit. Unfortunately government

subsidies are necessary to make buy-back centres a viable enterprise, as according to the United States Nation Solid Wastes Management Association it costs on average US\$50 to process a ton of material, which can only be resold for US\$30.

### **Curbside collection**

Curbside collection encompasses many subtly different systems, which differ mostly on where in the process the recyclates are sorted and cleaned. The main categories are mixed waste collection, commingled recyclables and source separation. A waste collection vehicle generally picks up the waste.



A recycling truck collecting the contents of a recycling bin in Canberra, Australia.

At one end of the spectrum is mixed waste collection, in which all recyclates are collected mixed in with the rest of the waste, and the desired material is then sorted out and cleaned at a central sorting facility. This results in a large amount of recyclable waste, paper especially, being too soiled to reprocess, but has advantages as well: the city need not pay for a separate collection of recyclates and no public education is needed. Any changes to which materials are recyclable is easy to accommodate as all sorting happens in a central location.

In a Commingled or single-stream system, all recyclables for collection are mixed but kept separate from other waste. This greatly reduces the need for post-collection cleaning but does require public education on what materials are recyclable.

Source separation is the other extreme, where each material is cleaned and sorted prior to collection. This method requires the least post-collection sorting and produces the purest recyclates, but incurs additional operating costs for collection of each separate material. An extensive public education program is also required, which must be successful if recyclate contamination is to be avoided.

Source separation used to be the preferred method due to the high sorting costs incurred by commingled collection. Advances in sorting technology, however, have lowered this overhead substantially—many areas which had developed source separation programs have since switched to comingled collection.

## Sorting



Early sorting of recyclable materials: glass and plastic bottles in Poland.

Once commingled recyclates are collected and delivered to a central collection facility, the different types of materials must be sorted. This is done in a series of stages, many of which involve automated processes such that a truck-load of material can be fully sorted in less than an hour. Some plants can now sort the materials automatically, known as

single-stream recycling. A 30 percent increase in recycling rates has been seen in the areas where these plants exist.

Initially, the commingled recyclates are removed from the collection vehicle and placed on a conveyor belt spread out in a single layer. Large pieces of corrugated fiberboard and plastic bags are removed by hand at this stage, as they can cause later machinery to jam.

Next, automated machinery separates the recyclates by weight, splitting lighter paper and plastic from heavier glass and metal. Cardboard is removed from the mixed paper, and the most common types of plastic, PET (#1) and HDPE (#2), are collected. This separation is usually done by hand, but has become automated in some sorting centers: a spectroscopic scanner is used to differentiate between different types of paper and plastic based on the absorbed wavelengths, and subsequently divert each material into the proper collection channel.

Strong magnets are used to separate out ferrous metals, such as iron, steel, and tin-plated steel cans ("tin cans"). Non-ferrous metals are ejected by magnetic eddy currents in which a rotating magnetic field induces an electric current around the aluminium cans, which in turn creates a magnetic eddy current inside the cans. This magnetic eddy current is repulsed by a large magnetic field, and the cans are ejected from the rest of the recycle stream.

Finally, glass must be sorted by hand based on its color: brown, amber, green or clear.

## Cost-benefit analysis

Environmental effects of recycling

Material	Energy savings	Air pollution savings
Aluminium	95%	95%
Cardboard	24%	—
Glass	5-30%	20%
Paper	40%	73%
Plastics	70%	—
Steel	60%	—

There is some debate over whether recycling is economically efficient. Municipalities often see fiscal benefits from implementing recycling programs, largely due to the reduced landfill costs. A study conducted by the Technical University of Denmark found that in 83% of cases, recycling is the most efficient method to dispose of household waste. However, a 2004 assessment by the Danish Environmental Assessment Institute concluded that incineration was the most effective method for disposing of drink containers, even aluminium ones.

Fiscal efficiency is separate from economic efficiency. Economic analysis of recycling includes what economists call externalities, which are unpriced costs and benefits that

accrue to individuals outside of private transactions. Examples include: decreased air pollution and greenhouse gases from incineration, reduced hazardous waste leaching from landfills, reduced energy consumption, and reduced waste and resource consumption, which leads to a reduction in environmentally damaging mining and timber activity. About 4,000 minerals have been identified, of these around 100 can be called common, another several hundred are relatively common, and the rest are rare. At current rates, current known reserves of phosphorus will be depleted in the next 50 to 100 years. Without mechanisms such as taxes or subsidies to internalize externalities, businesses will ignore them despite the costs imposed on society. To make such non-fiscal benefits economically relevant, advocates have pushed for legislative action to increase the demand for recycled materials. The United States Environmental Protection Agency (EPA) has concluded in favor of recycling, saying that recycling efforts reduced the country's carbon emissions by a net 49 million metric tonnes in 2005. In the United Kingdom, the Waste and Resources Action Programme stated that Great Britain's recycling efforts reduce CO<sub>2</sub> emissions by 10-15 million tonnes a year. Recycling is more efficient in densely populated areas, as there are economies of scale involved.

Certain requirements must be met for recycling to be economically feasible and environmentally effective. These include an adequate source of recyclates, a system to extract those recyclates from the waste stream, a nearby factory capable of reprocessing the recyclates, and a potential demand for the recycled products. These last two requirements are often overlooked—without both an industrial market for production using the collected materials and a consumer market for the manufactured goods, recycling is incomplete and in fact only "collection".

Many economists favor a moderate level of government intervention to provide recycling services. Economists of this mindset probably view product disposal as an externality of production and subsequently argue government is most capable of alleviating such a dilemma. However, those of the laissez faire approach to municipal recycling see product disposal as a service that consumers value. A free-market approach is more likely to suit the preferences of consumers since profit-seeking businesses have greater incentive to produce a quality product or service than does government. Moreover, economists most always advise against government intrusion in any market with little or no externalities.”

### **Trade in recyclates**



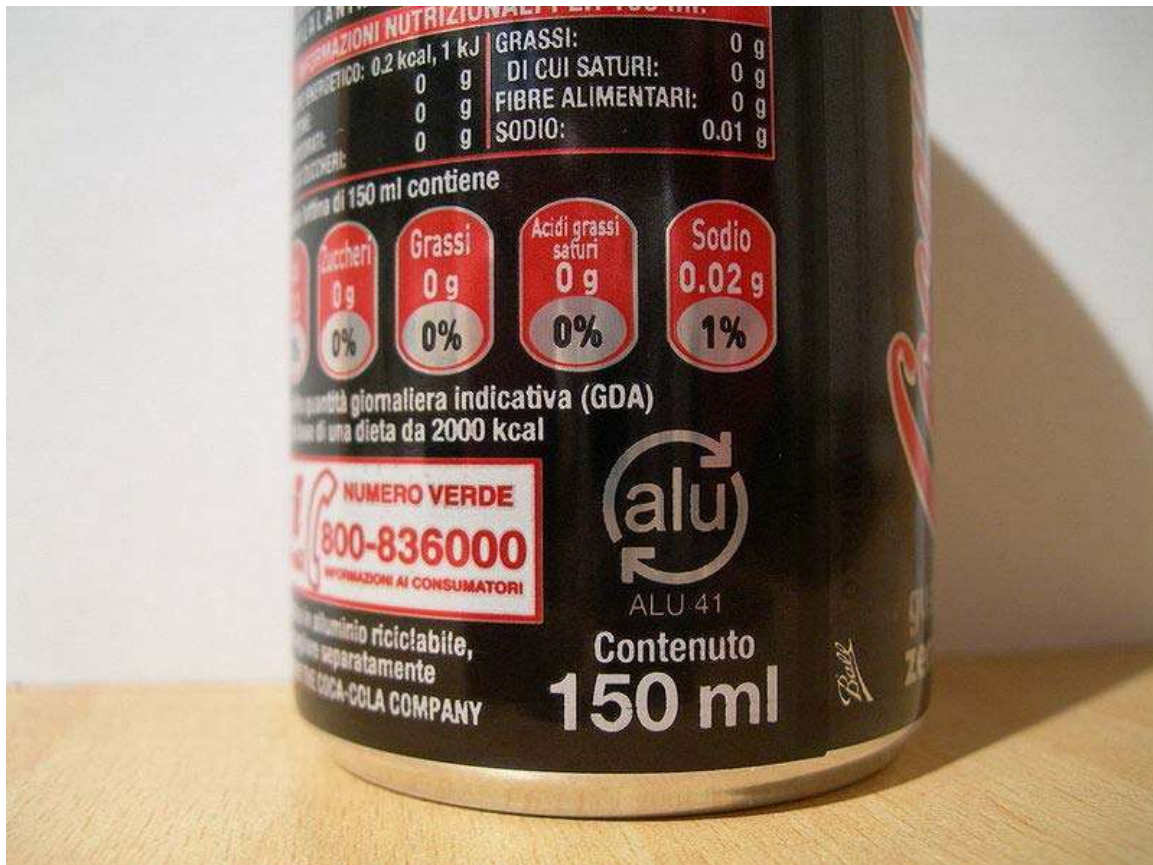
Computers being collected for recycling at a pick up event in Olympia, Washington, United States.

Certain countries trade in unprocessed recyclates. Some have complained that the ultimate fate of recyclates sold to another country is unknown and they may end up in landfills instead of reprocessed. According to one report, in America, 50-80% of computers destined for recycling are actually not recycled. There are reports of illegal-waste imports to China being dismantled and recycled solely for monetary gain, without consideration for workers' health or environmental damage. Though the Chinese government has banned these practices, it has not been able to eradicate them. In 2008, the prices of recyclable waste plummeted before rebounding in 2009. Cardboard averaged about £53/tonne from 2004–2008, dropped to £19/tonne, and then went up to £59/tonne in May 2009. PET plastic averaged about £156/tonne, dropped to £75/tonne and then moved up to £195/tonne in May 2009. Certain regions have difficulty using or exporting as much of a material as they recycle. This problem is most prevalent with glass: both Britain and the U.S. import large quantities of wine bottled in green glass. Though much of this glass is sent to be recycled, outside the American Midwest there is not enough wine production to use all of the reprocessed material. The extra must be downcycled into building materials or re-inserted into the regular waste stream.

Similarly, the northwestern United States has difficulty finding markets for recycled newspaper, given the large number of pulp mills in the region as well as the proximity to Asian markets. In other areas of the U.S., however, demand for used newsprint has seen wide fluctuation.

In some U.S. states, a program called RecycleBank pays people with coupons to recycle, receiving money from local municipalities for the reduction in landfill space which must be purchased. It uses a single stream process in which all material is automatically sorted.

## Criticism



An Italian aluminium can recycling logo. The USA, UK and Italy have several aluminium recycling schemes in operation.



A UK LDPE plastic bottle recycling logo. The UK openly encourages plastic recycling schemes and has many under way already.

Much of the difficulty inherent in recycling comes from the fact that most products are not designed with recycling in mind. The concept of sustainable design aims to solve this problem, and was laid out in the book *"Cradle to Cradle: Remaking the Way We Make Things"* by architect William McDonough and chemist Michael Braungart. They suggest that every product (and all packaging they require) should have a complete "closed-loop" cycle mapped out for each component—a way in which every component will either return to the natural ecosystem through biodegradation or be recycled indefinitely.

As with environmental economics, care must be taken to ensure a complete view of the costs and benefits involved. For example, cardboard packaging for food products is more easily recycled than plastic, but is heavier to ship and may result in more waste from spoilage.

The following are criticisms of many popular points used for recycling.

### **Saves energy**

There is controversy on just how much energy is saved through recycling. The Energy Information Administration (EIA) states on its website that "a paper mill uses 40 percent

less energy to make paper from recycled paper than it does to make paper from fresh lumber." Critics often argue that in the overall processes, it can take more energy to produce recycled products than it does to dispose of them in traditional landfill methods. This argument is followed from the curbside collection of recyclables, which critics note is often done by a second waste truck. Recycling proponents point out that a second timber or logging truck is eliminated when paper is collected for recycling.

It is difficult to determine the exact amount of energy consumed or produced in waste disposal processes. How much energy is used in recycling depends largely on the type of material being recycled and the process used to do so. Aluminium is generally agreed to use far less energy when recycled rather than being produced from scratch. The EPA states that "recycling aluminum cans, for example, saves 95 percent of the energy required to make the same amount of aluminum from its virgin source, bauxite."

Economist Steven Landsburg has suggested that the sole benefit of reducing landfill space is trumped by the energy needed and resulting pollution from the recycling process. Others, however, have calculated through life cycle assessment that producing recycled paper uses less energy and water than harvesting, pulping, processing, and transporting virgin trees. When less recycled paper is used, additional energy is needed to create and maintain farmed forests until these forests are as self-sustainable as virgin forests.

Other studies have shown that recycling in itself is inefficient to perform the "decoupling" of economic development from the depletion of non-renewable raw materials that is necessary for sustainable development. When global consumption of a natural resource grows by more than 1% per annum, its depletion is inevitable, and the best recycling can do is to delay it by a number of years. Nevertheless, if this decoupling can be achieved by other means, so that consumption of the resource is reduced below 1% per annum, then recycling becomes indispensable – indeed recycling rates above 80% are required for a significant slowdown of the resource depletion.

### **Saves money**



A man rummaging through a skip at the back of an office building in Central London in 2006. The wood could be used for urban lumberjacking and the cardboard could be recycled.

The amount of money actually saved through recycling depends on the efficiency of the recycling program used to do it. The Institute for Local Self-Reliance argues that the cost of recycling depends on various factors around a community that recycles, such as landfill fees and the amount of disposal that the community recycles. It states that communities start to save money when they treat recycling as a replacement for their traditional waste system rather than an add-on to it and by "redesigning their collection schedules and/or trucks."

In many cases, the cost of recyclable materials also exceeds the cost of raw materials. Virgin plastic resin costs 40% less than recycled resin. Additionally, a United States Environmental Protection Agency (EPA) study that tracked the price of clear glass from July 15 to August 2, 1991, found that the average cost per ton ranged from \$40 to \$60, while a USGS report shows that the cost per ton of raw silica sand from years 1993 to 1997 fell between \$17.33 and \$18.10.

In a 1996 article for *The New York Times*, John Tierney argued that it costs more money to recycle the trash of New York City than it does to dispose of it in a landfill. Tierney argued that the recycling process employs people to do the additional waste disposal,

sorting, inspecting, and many fees are often charged because the processing costs used to make the end product are often more than the profit from its sale. Tierney also referenced a study conducted by the Solid Waste Association of North America (SWANA) that found in the six communities involved in the study, "all but one of the curbside recycling programs, and all the composting operations and waste-to-energy incinerators, increased the cost of waste disposal."

Tierney also points out that "the prices paid for scrap materials are a measure of their environmental value as recyclables. Scrap aluminum fetches a high price because recycling it consumes so much less energy than manufacturing new aluminum."

### **Working conditions**

Critics often argue that while recycling may create jobs, they are often jobs with low wages and terrible working conditions. These jobs are sometimes considered to be make-work jobs that don't produce as much as the cost of wages to pay for those jobs. In areas without many environmental regulations and/or worker protections, jobs involved in recycling such as ship breaking can result in deplorable conditions for both workers and the surrounding communities.

Recycling proponents counter that the jobs involved in recovery of an equal amount of virgin material creates worse jobs. Timber harvesting and ore mining are more dangerous than paper recycling and metal recycling.

### **Saves trees**



Christmas trees gathered for recycling.

Economist Steven Landsburg, author of a paper entitled "Why I Am Not an Environmentalist," has claimed that paper recycling actually reduces tree populations. He argues that because paper companies have incentives to replenish the forests they own, large demands for paper lead to large forests. Conversely, reduced demand for paper leads to fewer "farmed" forests. Similar arguments were expressed in a 1995 article for The Free Market.

When foresting companies cut down trees, more are planted in their place. Most paper comes from pulp forests grown specifically for paper production. Many environmentalists point out, however, that "farmed" forests are inferior to virgin forests in several ways. Farmed forests are not able to fix the soil as quickly as virgin forests, causing widespread soil erosion and often requiring large amounts of fertilizer to maintain while containing little tree and wild-life biodiversity compared to virgin forests. Also, the new trees planted are not as big as the trees that were cut down, and the argument that there will be "more trees" is not compelling to forestry advocates when they are counting saplings.

The recycling of paper should not be confused with saving the tropical forest. Many people have the misconception that paper-making is what's causing deforestation of tropical rain forests but rarely any tropical wood is harvested for paper. Deforestation is

mainly caused by population pressure such as demand of more land for agriculture or construction use. Therefore, the recycling paper, although reduces demand of trees, doesn't greatly benefit the tropical rain forests.

### **Possible income loss and social costs**

In some prosperous and many less prosperous countries in the world, the traditional job of recycling is performed by the entrepreneurial poor such as the karung guni, Zabaleen, the rag and bone man, waste picker, and junk man. With the creation of large recycling organizations that may be profitable, either by law or economies of scale, the poor are more likely to be driven out of the recycling and the remanufacturing market. To compensate for this loss of income to the poor, a society may need to create additional forms of societal programs to help support the poor. Like the parable of the broken window, there is a net loss to the poor and possibly the whole of a society to make recycling artificially profitable through law. However, as seen in Brazil and Argentina, waste pickers/informal recyclers are able to work alongside governments, in (semi)funded cooperatives, allowing informal recycling to be legitimized as a paying government job.

Because the social support of a country is likely less than the loss of income to the poor doing recycling, there is a greater chance that the poor will come in conflict with the large recycling organizations. This means fewer people can decide if certain waste is more economically reusable in its current form rather than being reprocessed. Contrasted to the recycling poor, the efficiency of their recycling may actually be higher for some materials because individuals have greater control over what is considered "waste."

One labor-intensive underused waste is electronic and computer waste. Because this waste may still be functional and wanted mostly by the poor, the poor may sell or use it at a greater efficiency than large recyclers.

Many recycling advocates believe that this laissez-faire individual-based recycling does not cover all of society's recycling needs. Thus, it does not negate the need for an organized recycling program. Local government often consider the activities of the recycling poor as contributing to property blight.

### **Public participation in recycling programmes**

Many studies have addressed recycling behaviour and strategies to encourage community involvement in recycling programmes. It has been argued that recycling behaviour is not natural because it requires a focus and appreciation for long term planning, whereas humans have evolved to be sensitive to short term survival goals; and that to overcome this innate predisposition, the best solution would be to use social pressure to compel participation in recycling programmes. However, recent studies have concluded that social pressure is unviable in this context. One reason for this is that social pressure functions well in small group sizes of 50 to 150 individuals (common to nomadic hunter-gatherer peoples) but not in communities numbering in the millions, as we see today.

Another reason is that individual recycling does not take place in the public view. In a study done by social psychologist Shawn Burn , it was found that personal contact with individuals within a neighborhood is the most effective way to increase recycling within a community. In his study, he had 10 block leaders talk to their neighbors and convince them to recycle. A comparison group was sent fliers promoting recycling. It was found that the neighbors that were personally contacted by their block leaders recycled much more than the group without personal contact. As a result of this study, Shawn Burn believes that personal contact within a small group of people is an important factor in encouraging recycling. Another study done by Stuart Oskamp examines the effect of neighbors and friends on recycling. It was found in his studies that people who had friends and neighbors that recycled were much more likely to also recycle than those who didn't have friends and neighbors that recycled.

## **Social Psychology**

Psychology can be tied into the aspect of recycling based on the idea that it can explain why people do not recycle, as well as how to get people to recycle. Less than half of the paper used in the United States gets recycled. In order to make a change, it is important that the psychology behind recycling is understood. Psychological barriers need to be removed in order to change people's actions. Some of these barriers include social norms, habits, and a lack of knowledge. Often times recycling is not a social norm, and people do not feel the need to recycle if their peers are not recycling too. If recycling were turned into a social norm where everyone was doing it as a group effort, it would eliminate this barrier. Another barrier that needs to be addressed is habits. Old habits are hard to break, but if incentives can be created for people to change their behavior, the desired action is more likely to be carried out. In this case the habit that needs to be broken would be throwing all garbage into the same bin instead of putting paper, plastic, etc into a recycling bin. This incentive could be anything that will motivate people to change their actions, such as turning it into a competition to see who can recycle the most. According to the Mississippi Department of Environmental Quality, once recycling becomes a habit it becomes part of people's daily routine. Last, is the idea that people have a lack of knowledge. Though there are many reasons as to why people do not recycle, it has been shown by the Massachusetts Department of Environmental Protection that people tend to not recycle when they lack the knowledge of what can be recycled. One way to correct this issue is by using a technique called social marketing. Social marketing is "the application of commercial marketing technologies to the analysis, planning, execution, and evaluation of programs designed to influence voluntary behavior of target audiences in order to improve their personal welfare and that of society." This process targets the needs of individuals, and addresses how those needs should be met. It's ultimate goal is to influence people's behavior, and to help people become more inclined to carry out the action that is desired. These are only some of the psychological principles that can be applied to recycling. Eliminating the barriers could help to encourage more recycling in the future.

## Chapter- 5

# Anaerobic Digestion



Anaerobic digestion and regenerative thermal oxidiser component of Lübeck mechanical biological treatment plant in Germany, 2007

**Anaerobic digestion** is a series of processes in which microorganisms break down biodegradable material in the absence of oxygen, used for industrial or domestic purposes to manage waste and/or to release energy.

It is widely used as part of the process to treat wastewater. As part of an integrated waste management system, anaerobic digestion reduces the emission of landfill gas into the atmosphere.

Anaerobic digestion is widely used as a renewable energy source because the process produces a methane and carbon dioxide rich biogas suitable for energy production, helping to replace fossil fuels. The nutrient-rich digestate which is also produced can be used as fertilizer.

The digestion process begins with bacterial hydrolysis of the input materials in order to break down insoluble organic polymers such as carbohydrates and make them available for other bacteria. Acidogenic bacteria then convert the sugars and amino acids into carbon dioxide, hydrogen, ammonia, and organic acids. Acetogenic bacteria then convert these resulting organic acids into acetic acid, along with additional ammonia, hydrogen, and carbon dioxide. Finally, methanogens convert these products to methane and carbon dioxide.

The technical expertise required to maintain industrial scale anaerobic digesters coupled with high capital costs and low process efficiencies had limited the level of its industrial application as a waste treatment technology. Anaerobic digestion facilities have, however, been recognized by the United Nations Development Programme as one of the most useful decentralized sources of energy supply, as they are less capital intensive than large power plants.

## **History**





Gas street lamp

Scientific interest in the manufacturing of gas produced by the natural decomposition of organic matter, was first reported in the seventeenth century by Robert Boyle and Stephen Hale, who noted that flammable gas was released by disturbing the sediment of streams and lakes. In 1808, Sir Humphry Davy determined that methane was present in the gases produced by cattle manure. The first anaerobic digester was built by a leper colony in Bombay, India in 1859. In 1895 the technology was developed in Exeter, England, where a septic tank was used to generate gas for the sewer gas destructor lamp, a type of gas lighting. Also in England, in 1904, the first dual purpose tank for both sedimentation and sludge treatment was installed in Hampton. In 1907, in Germany, a patent was issued for the Imhoff tank, an early form of digester.

Through scientific research anaerobic digestion gained academic recognition in the 1930s. This research led to the discovery of anaerobic bacteria, the microorganisms that facilitate the process. Further research was carried out to investigate the conditions under which methanogenic bacteria were able to grow and reproduce. This work was developed during World War II where in both Germany and France there was an increase in the application of anaerobic digestion for the treatment of manure.

## Applications

Anaerobic digestion is particularly suited to organic material and is commonly used for effluent and sewage treatment. Anaerobic digestion is a simple process that can greatly reduce the amount of organic matter which might otherwise be destined to be dumped at sea, landfilled or burnt in an incinerator.

Almost any organic material can be processed with anaerobic digestion. This includes biodegradable waste materials such as waste paper, grass clippings, leftover food, sewage and animal waste. The exception to this is woody wastes that are largely unaffected by digestion as most anaerobes are unable to degrade lignin. The exception being xylophalgeous anaerobes (lignin consumers), as used in the process for organic breakdown of cellulosic material by a cellulosic ethanol start-up company in the U.S. Anaerobic digesters can also be fed with specially grown energy crops such as silage for dedicated biogas production. In Germany and continental Europe these facilities are referred to as *biogas plants*. A *co-digestion* or *co-fermentation* plant is typically an agricultural anaerobic digester that accepts two or more input materials for simultaneous digestion.

In developing countries simple home and farm-based anaerobic digestion systems offer the potential for cheap, low-cost energy for cooking and lighting. Anaerobic digestion facilities have been recognized by the United Nations Development Programme as one of the most useful decentralized sources of energy supply. From 1975, China and India have both had large government-backed schemes for adaptation of small biogas plants for use in the household for cooking and lighting. Presently, projects for anaerobic digestion in the developing world can gain financial support through the United Nations Clean Development Mechanism if they are able to show they provide reduced carbon emissions.

Pressure from environmentally related legislation on solid waste disposal methods in developed countries has increased the application of anaerobic digestion as a process for reducing waste volumes and generating useful by-products. Anaerobic digestion may either be used to process the source separated fraction of municipal waste, or alternatively combined with mechanical sorting systems, to process residual mixed municipal waste. These facilities are called mechanical biological treatment plants.

Utilising anaerobic digestion technologies can help to reduce the emission of greenhouse gasses in a number of key ways:

- Replacement of fossil fuels
- Reducing or eliminating the energy footprint of waste treatment plants
- Reducing methane emission from landfills
- Displacing industrially produced chemical fertilizers
- Reducing vehicle movements
- Reducing electrical grid transportation losses

Methane and power produced in anaerobic digestion facilities can be utilized to replace energy derived from fossil fuels, and hence reduce emissions of greenhouse gasses. This is due to the fact that the carbon in biodegradable material is part of a carbon cycle. The carbon released into the atmosphere from the combustion of biogas has been removed by plants in order for them to grow in the recent past. This can have occurred within the last decade, but more typically within the last growing season. If the plants are re-grown, taking the carbon out of the atmosphere once more, the system will be carbon neutral. This contrasts to carbon in fossil fuels that has been sequestered in the earth for many millions of years, the combustion of which increases the overall levels of carbon dioxide in the atmosphere.

If the putrescible waste processed in anaerobic digesters was disposed of in a landfill, it would break down naturally and often anaerobically. In this case the gas will eventually escape into the atmosphere. As methane is about twenty times more potent as a greenhouse gas than carbon dioxide this has significant negative environmental effects.

Digester liquor can be used as a fertiliser supplying vital nutrients to soils. The solid, fibrous component of the digested material can be used as a soil conditioner to increase the organic content of soils. The liquor can be used instead of chemical fertilisers which require large amounts of energy to produce and transport. The use of manufactured fertilisers is therefore more carbon intensive than the use of anaerobic digester liquor fertiliser. In countries, such as Spain where there are many organically depleted soils the markets for the digested solids can be equally as important as the biogas.

In countries that collect household waste, the utilization of local anaerobic digestion facilities can help to reduce the amount of waste that requires transportation to centralized landfill sites or incineration facilities. This reduced burden on transportation reduces carbon emissions from the collection vehicles. If localized anaerobic digestion facilities are embedded within an electrical distribution network, they can help reduce the electrical losses that are associated with transporting electricity over a national grid.

In Oakland, California at the East Bay Municipal Utility District's (EBMUD) Main Wastewater Treatment Plant(MWWTP), food waste is currently co-digested with primary and secondary municipal wastewater solids and other high-strength wastes. Compared to municipal wastewater solids digestion, food waste digestion has many benefits. Anaerobic digestion of food waste pulp from the EBMUD food waste process provides a higher normalized energy benefit, compared to municipal wastewater solids:

- 730 to 1,300 kWh per dry ton of food waste applied.

- 560 to 940 kWh per dry ton of municipal wastewater solids applied.

## **Power generation**

Biogas from sewage works is sometimes used to run a gas engine to produce electrical power; some or all of which can be used to run the sewage works. Some waste heat from the engine is then used to heat the digester. It turns out that the waste heat is generally enough to heat the digester to the required temperatures. The power potential from sewage works is limited – in the UK there are about 80 MW total of such generation, with potential to increase to 150 MW, which is insignificant compared to the average power demand in the UK of about 35,000 MW. The scope for biogas generation from non-sewage waste biological matter – energy crops, food waste, abattoir waste etc. is much higher, estimated to be capable of about 3,000 MW. Farm biogas plants using animal waste and energy crops are expected to contribute to reducing CO<sub>2</sub> emissions and strengthen the grid while providing UK farmers with additional revenues.

Some countries offer incentives in the form of, for example, Feed-in Tariffs for feeding electricity onto the power grid in order to subsidize green energy production.

## **Grid injection**

Biogas grid-injection is the injection of biogas into the natural gas grid. Until the breakthrough of micro combined heat and power, two-thirds of all the energy (the heat) produced by biogas power plants was lost, as a result of using the grid to transport the gas to customers. As an alternative, the electricity and the heat can be used for on-site generation, resulting in a reduction of losses in the transportation of energy. Typical energy losses in natural gas transmission systems range from 1–2%, whereas the current energy losses on a large electrical system range from 5–8%.

In October 2010, Didcot Sewage Works became the first in the UK to produce biomethane gas supplied to the national grid, for use in up to 200 homes in Oxfordshire.

## **The process**

There are a number of microorganisms that are involved in the process of anaerobic digestion including acetic acid-forming bacteria (acetogens) and methane-forming archaea (methanogens). These organisms feed upon the initial feedstock, which undergoes a number of different processes converting it to intermediate molecules including sugars, hydrogen, and acetic acid, before finally being converted to biogas.

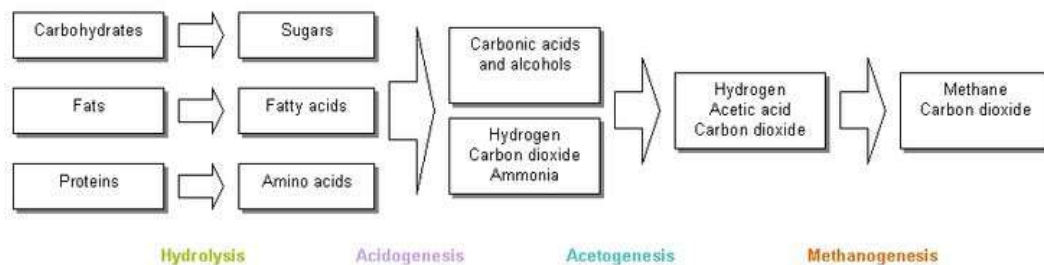
Different species of bacteria are able to survive at different temperature ranges. Ones living optimally at temperatures between 35–40 °C are called mesophiles or mesophilic bacteria. Some of the bacteria can survive at the hotter and more hostile conditions of 55–60 °C, these are called thermophiles or thermophilic bacteria. Methanogens come from the domain of archaea. This family includes species that can grow in the hostile

conditions of hydrothermal vents. These species are more resistant to heat and can therefore operate at high temperatures, a property that is unique to thermophiles.

As with aerobic systems the bacteria in anaerobic systems the growing and reproducing microorganisms within them require a source of elemental oxygen to survive. In an anaerobic system there is an absence of gaseous oxygen. Gaseous oxygen is prevented from entering the system through physical containment in sealed tanks. Anaerobes access oxygen from sources other than the surrounding air. The oxygen source for these microorganisms can be the organic material itself or alternatively may be supplied by inorganic oxides from within the input material. When the oxygen source in an anaerobic system is derived from the organic material itself, then the 'intermediate' end products are primarily alcohols, aldehydes, and organic acids plus carbon dioxide. In the presence of specialised methanogens, the intermediates are converted to the 'final' end products of methane, carbon dioxide with trace levels of hydrogen sulfide. In an anaerobic system the majority of the chemical energy contained within the starting material is released by methanogenic bacteria as methane.

Populations of anaerobic microorganisms typically take a significant period of time to establish themselves to be fully effective. It is therefore common practice to introduce anaerobic microorganisms from materials with existing populations, a process known as "seeding" the digesters, and typically takes place with the addition of sewage sludge or cattle slurry.

## Stages



The key process stages of anaerobic digestion

There are four key biological and chemical stages of anaerobic digestion:

1. Hydrolysis
2. Acidogenesis
3. Acetogenesis
4. Methanogenesis

In most cases biomass is made up of large organic polymers. In order for the bacteria in anaerobic digesters to access the energy potential of the material, these chains must first be broken down into their smaller constituent parts. These constituent parts or monomers

such as sugars are readily available by other bacteria. The process of breaking these chains and dissolving the smaller molecules into solution is called hydrolysis. Therefore hydrolysis of these high molecular weight polymeric components is the necessary first step in anaerobic digestion. Through hydrolysis the complex organic molecules are broken down into simple sugars, amino acids, and fatty acids.

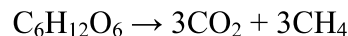
Acetate and hydrogen produced in the first stages can be used directly by methanogens. Other molecules such as volatile fatty acids (VFA's) with a chain length that is greater than acetate must first be catabolised into compounds that can be directly utilised by methanogens.

The biological process of acidogenesis is where there is further breakdown of the remaining components by acidogenic (fermentative) bacteria. Here VFAs are created along with ammonia, carbon dioxide and hydrogen sulfide as well as other by-products. The process of acidogenesis is similar to the way that milk sours.

The third stage anaerobic digestion is acetogenesis. Here simple molecules created through the acidogenesis phase are further digested by acetogens to produce largely acetic acid as well as carbon dioxide and hydrogen.

The terminal stage of anaerobic digestion is the biological process of methanogenesis. Here methanogens utilise the intermediate products of the preceding stages and convert them into methane, carbon dioxide and water. It is these components that makes up the majority of the biogas emitted from the system. Methanogenesis is sensitive to both high and low pHs and occurs between pH 6.5 and pH 8. The remaining, non-digestible material which the microbes cannot feed upon, along with any dead bacterial remains constitutes the digestate.

A simplified generic chemical equation for the overall processes outlined above is as follows:



## **Configuration**



Farm-based maize silage digester located near Neumünster in Germany, 2007. Green inflatable biogas holder is shown on top of the digester

Anaerobic digesters can be designed and engineered to operate using a number of different process configurations:

- Batch or continuous
- Temperature: Mesophilic or thermophilic
- Solids content: High solids or low solids
- Complexity: Single stage or multistage

### **Batch or continuous**

A batch system is the simplest form of digestion. Biomass is added to the reactor at the start of the process in a batch and is sealed for the duration of the process. Batch reactors suffer from odour issues that can be a severe problem when they are emptied. Typically biogas production will be formed with a normal distribution pattern over time. The operator can use this fact to determine when they believe the process of digestion of the organic matter has completed. As the batch digestion is simple and requires less equipment and lower levels of design work it is typically a cheaper form of digestion.

In continuous digestion processes organic matter is constantly added (continuous complete mixed) or added in stages to the reactor (continuous plug flow; first in – first

out). Here the end products are constantly or periodically removed, resulting in constant production of biogas. A single or multiple digesters in sequence may be used. Examples of this form of anaerobic digestion include continuous stirred-tank reactors (CSTRs), Upflow anaerobic sludge blanket (UASB), Expanded granular sludge bed (EGSB) and Internal circulation reactors (IC).

## Temperature

There are two conventional operational temperature levels for anaerobic digesters, which are determined by the species of methanogens in the digesters:

- *Mesophilic* which takes place optimally around 30-38 °C or at ambient temperatures between 20-45 °C where mesophiles are the primary microorganism present
- *Thermophilic* which takes place optimally around 49-57 °C at elevated temperatures up to 70 °C where thermophiles are the primary microorganisms present

A limit case has been reached in Bolivia, with anaerobic digestion in temperature working conditions less than 10 °C. The anaerobic process is very slow, taking more than three times the normal mesophilic time process.

There are a greater number of species of mesophiles than thermophiles. These bacteria are also more tolerant to changes in environmental conditions than thermophiles. Mesophilic systems are therefore considered to be more stable than thermophilic digestion systems.

As mentioned above, thermophilic digestion systems are considered to be less stable, the energy input is higher, and more energy is removed from the organic matter. However, the increased temperatures facilitate faster reaction rates and hence faster gas yields. Operation at higher temperatures facilitates greater sterilization of the end digestate. In countries where legislation, such as the Animal By-Products Regulations in the European Union, requires end products to meet certain levels of reduction in the amount of bacteria in the output material, this may be a benefit.

Certain processes shred the waste finely and use a short high temperature and pressure pre-treatment (pasteurization / hygienisation) stage that significantly enhances the gas output of the following standard mesophilic stage. The hygienisation process is also applied in order to reduce the pathogenic micro-organisms in the feedstock. Hygienisation / pasteurization may be achieved by using a Landia BioChop hygienisation unit or similar method of combined heat treatment and solids maceration.

A drawback of operating at thermophilic temperatures is that more heat energy input is required to achieve the correct operational temperatures. This increase in energy may not be outweighed by the increase in the outputs of biogas from the systems. It is therefore important to consider an energy balance for these systems.

## **Solids**

Typically there are three different operational parameters associated with the solids content of the feedstock to the digesters:

- High-solids (dry—stackable substrate)
- High-solids (wet—pumpable substrate)
- Low-solids (wet—pumpable substrate)

High-solids (dry) digesters are designed to process materials with a high-solids content between ~25-40%. Unlike wet digesters that process pumpable slurries, high solids (dry – stackable substrate) digesters are designed to process solid substrates deposited in tunnel-like chambers with a gas-tight door. They typically have few moving parts, require minimal or no pre-grinding or shredding, and do not use water addition.

Wet digesters can either be designed to operate in a high solids content, with a total suspended solids (TSS) concentration greater than ~20%, or a low solids concentration less than ~15%.

High-solids (wet) digesters process a thick slurry that requires more energy input to move and process the feedstock. The thickness of the material may also lead to associated problems with abrasion. High-solids digesters will typically have a lower land requirement due to the lower volumes associated with the moisture.

Low-solids (wet) digesters can transport material through the system using standard pumps that require significantly lower energy input. Low-solids digesters require a larger amount of land than high-solids due to the increase volumes associated with the increased liquid-to-feedstock ratio of the digesters. There are benefits associated with operation in a liquid environment as it enables more thorough circulation of materials and contact between the bacteria and their food. This enables the bacteria to more readily access the substances they are feeding off and increases the speed of gas yields.

## **Number of stages**



Two-stage, low-solids, UASB digestion component of a mechanical biological treatment system near Tel Aviv, process water is seen in balance tank and sequencing batch reactor, 2005

Digestion systems can be configured with different levels of complexity:

- One-stage or single-stage
- Two-stage or multistage

A single-stage digestion system is one in which all of the biological reactions occur within a single sealed reactor or holding tank. Utilising a single stage reduces construction costs, however facilitates less control of the reactions occurring within the system. Acidogenic bacteria, through the production of acids, reduce the pH of the tank. Methanogenic bacteria, as outlined earlier, operate in a strictly defined pH range. Therefore the biological reactions of the different species in a single stage reactor can be in direct competition with each other. Another one-stage reaction system is an anaerobic lagoon. These lagoons are pond-like earthen basins used for the treatment and long-term storage of manures. Here the anaerobic reactions are contained within the natural anaerobic sludge contained in the pool.

In a two-stage or multi-stage digestion system different digestion vessels are optimised to bring maximum control over the bacterial communities living within the digesters.

Acidogenic bacteria produce organic acids and more quickly grow and reproduce than methanogenic bacteria. Methanogenic bacteria require stable pH and temperature in order to optimise their performance.

Typically hydrolysis, acetogenesis and acidogenesis occur within the first reaction vessel. The organic material is then heated to the required operational temperature (either mesophilic or thermophilic) prior to being pumped into a methanogenic reactor. The initial hydrolysis or acidogenesis tanks prior to the methanogenic reactor can provide a buffer to the rate at which feedstock is added. Some European countries require a degree of elevated heat treatment in order to kill harmful bacteria in the input waste. In this instance there may be a pasteurisation or sterilisation stage prior to digestion or between the two digestion tanks. It should be noted that it is not possible to completely isolate the different reaction phases and often there is some biogas that is produced in the hydrolysis or acidogenesis tanks.

## **Residence**

The residence time in a digester varies with the amount and type of feed material, the configuration of the digestion system and whether it be one-stage or two-stage.

In the case of single-stage thermophilic digestion residence times may be in the region of 14 days, which comparatively to mesophilic digestion is relatively fast. The plug-flow nature of some of these systems will mean that the full degradation of the material may not have been realised in this timescale. In this event digestate exiting the system will be darker in colour and will typically have more odour.

In two-stage mesophilic digestion, residence time may vary between 15 and 40 days.

In the case of mesophilic UASB digestion hydraulic residence times can be (1hour-1day) and solid retention times can be up to 90 days. In this manner the UASB system is able to separate solid an hydraulic retention times with the utilisation of a sludge blanket.

Continuous digesters have mechanical or hydraulic devices, depending on the level of solids in the material, to mix the contents enabling the bacteria and the food to be in contact. They also allow excess material to be continuously extracted to maintain a reasonably constant volume within the digestion tanks.

## **Feedstocks**



Anaerobic lagoon & generators at the Cal Poly Dairy, United States 2003

The most important initial issue when considering the application of anaerobic digestion systems is the feedstock to the process. Digesters typically can accept any biodegradable material, however if biogas production is the aim, the level of putrescibility is the key factor in its successful application. The more putrescible the material the higher the gas yields possible from the system.

Substrate composition is a major factor in determining the methane yield and methane production rates from the digestion of biomass. Techniques are available to determine the compositional characteristics of the feedstock, whilst parameters such as solids, elemental and organic analyses are important for digester design and operation.

Anaerobes can breakdown material to varying degrees of success from readily in the case of short chain hydrocarbons such as sugars, to over longer periods of time in the case of cellulose and hemicellulose. Anaerobic microorganisms are unable to break down long chain woody molecules such as lignin. Anaerobic digesters were originally designed for operation using sewage sludge and manures. Sewage and manure are not, however, the material with the most potential for anaerobic digestion as the biodegradable material has already had much of the energy content taken out by the animal that produced it. Therefore, many digesters operate with *co-digestion* of two or more types of feedstock. For example, in a farm-based digester that uses dairy manure as the primary feedstock the

gas production may be significantly increased by adding a second feedstock; e.g. *grass* and *corn* (typical on-site feedstock), or various organic byproducts, such as *slaughterhouse waste, fats oils and grease* from restaurants, *organic household waste*, etc. (typical off-site feedstock).

A second consideration related to the feedstock is moisture content. Dryer, stackable substrates, such as food- and yard- waste, are suitable for digestion in tunnel-like chambers. Tunnel style systems typically have near zero wastewater discharge as well so this style system has advantages where the discharge of digester liquids are a liability. The wetter the material the more suitable it will be to handling with standard pumps instead of energy intensive concrete pumps and physical means of movement. Also the wetter the material, the more volume and area it takes up relative to the levels of gas that are produced. The moisture content of the target feedstock will also affect what type of system is applied to its treatment. In order to use a high solids anaerobic digester for dilute feedstocks, bulking agents such as compost should be applied to increase the solid content of the input material. Another key consideration is the carbon:nitrogen ratio of the input material. This ratio is the balance of food a microbe requires in order to grow. The optimal C:N ratio for the 'food' a microbe is 20–30:1. Excess N can lead to ammonia inhibition of digestion.

The level of contamination of the feedstock material is a key consideration. If the feedstock to the digesters has significant levels of physical contaminants such as plastic, glass or metals then pre-processing will be required in order for the material to be used. If it is not removed then the digesters can be blocked and will not function efficiently. It is with this that mechanical biological treatment plants are designed. The higher the level of pre-treatment a feedstock requires, the more processing machinery will be required and hence the project will have higher capital costs.

After sorting or screening to remove any physical contaminants, such as metals and plastics, from the feedstock the material is often shredded, minced and mechanically or hydraulically pulped to increase the surface area available to microbes in the digesters and hence increase the speed of digestion. The maceration of solids can be achieved by using a chopper pump to transfer the feedstock material into the airtight digester where anaerobic treatment takes place.

## **Products**

There are three principal products of anaerobic digestion: biogas, digestate and water.

### **Biogas**



Biogas holder with lightning protection rods and back-up gas flare

**Typical composition of biogas**

<b>Matter</b>	<b>%</b>
<b>Methane, CH<sub>4</sub></b>	50–75
<b>Carbon dioxide, CO<sub>2</sub></b>	25–50
<b>Nitrogen, N<sub>2</sub></b>	0–10
<b>Hydrogen, H<sub>2</sub></b>	0–1
<b>Hydrogen sulfide, H<sub>2</sub>S</b>	0–3
<b>Oxygen, O<sub>2</sub></b>	0–2



Biogas carrying pipes

Biogas is the ultimate waste product of the bacteria feeding off the input biodegradable feedstock, and is mostly methane and carbon dioxide, with a small amount hydrogen and trace hydrogen sulfide. (As-produced, biogas also contains water vapor, with the fractional water vapor volume a function of biogas temperature). Most of the biogas is produced during the middle of the digestion, after the bacterial population has grown, and tapers off as the putrescible material is exhausted. The gas is normally stored on top of the digester in an inflatable gas bubble or extracted and stored next to the facility in a gas holder.

The methane in biogas can be burned to produce both heat and electricity, usually with a reciprocating engine or microturbine often in a cogeneration arrangement where the

electricity and waste heat generated are used to warm the digesters or to heat buildings. Excess electricity can be sold to suppliers or put into the local grid. Electricity produced by anaerobic digesters is considered to be renewable energy and may attract subsidies. Biogas does not contribute to increasing atmospheric carbon dioxide concentrations because the gas is not released directly into the atmosphere and the carbon dioxide comes from an organic source with a short carbon cycle.

Biogas may require treatment or 'scrubbing' to refine it for use as a fuel. Hydrogen sulfide is a toxic product formed from sulfates in the feedstock and is released as a trace component of the biogas. National environmental enforcement agencies such as the U.S. Environmental Protection Agency or the English and Welsh Environment Agency put strict limits on the levels of gasses containing hydrogen sulfide, and if the levels of hydrogen sulfide in the gas are high, gas scrubbing and cleaning equipment (such as amine gas treating) will be needed to process the biogas to within regionally accepted levels. An alternative method to this is by the addition of ferrous chloride  $\text{FeCl}_2$  to the digestion tanks in order to inhibit hydrogen sulfide production.

Volatile siloxanes can also contaminate the biogas; such compounds are frequently found in household waste and wastewater. In digestion facilities accepting these materials as a component of the feedstock, low molecular weight siloxanes volatilise into biogas. When this gas is combusted in a gas engine, turbine or boiler, siloxanes are converted into silicon dioxide ( $\text{SiO}_2$ ) which deposits internally in the machine, increasing wear and tear. Practical and cost-effective technologies to remove siloxanes and other biogas contaminants are available at the present time. In certain applications, *in situ* treatment can be used to increase the methane purity by reducing the carbon dioxide content.

In countries such as Switzerland, Germany and Sweden the methane in the biogas may be concentrated in order for it to be used as a vehicle transportation fuel or alternatively input directly into the gas mains. In countries where the driver for the utilisation of anaerobic digestion are renewable electricity subsidies, this route of treatment is less likely as energy is required in this processing stage and reduces the over all levels available to sell.

## **Digestate**

Digestate is the solid remnants of the original input material to the digesters that the microbes cannot use. It also consists of the mineralised remains of the dead bacteria from within the digesters. Digestate can come in three forms; fibrous, liquor or a sludge-based combination of the two fractions. In two-stage systems the different forms of digestate come from different digestion tanks. In single stage digestion systems the two fractions will be combined and if desired separated by further processing.



#### Acidogenic anaerobic digestate

The second by-product (acidogenic digestate) is a stable organic material consisting largely of lignin and cellulose, but also of a variety of mineral components in a matrix of dead bacterial cells; some plastic may be present. The material resembles domestic compost and can be used as compost or to make low grade building products such as fibreboard. The solid digestate can also be utilized as feedstock for ethanol production.

The third by-product is a liquid (methanogenic digestate) that is rich in nutrients and can be used as a fertiliser dependent on the quality of the material being digested. Levels of potentially toxic elements (PTEs) should be chemically assessed. This will be dependent upon the quality of the original feedstock. In the case of most clean and source-separated biodegradable waste streams the levels of PTEs will be low. In the case of wastes originating from industry the levels of PTEs may be higher and will need to be taken into consideration when determining a suitable end use for the material.

Digestate typically contains elements such as lignin that cannot be broken down by the anaerobic microorganisms. Also the digestate may contain ammonia that is phytotoxic and will hamper the growth of plants if it is used as a soil improving material. For these two reasons a maturation or composting stage may be employed after digestion. Lignin and other materials are available for degradation by aerobic microorganisms such as fungi helping reduce the overall volume of the material for transport. During this maturation the ammonia will be broken down into nitrates, improving the fertility of the material and making it more suitable as a soil improver. Large composting stages are typically used by dry anaerobic digestion technologies.

## **Wastewater**

The final output from anaerobic digestion systems is water. This water originates both from the moisture content of the original waste that was treated but also includes water produced during the microbial reactions in the digestion systems. This water may be released from the dewatering of the digestate or may be implicitly separate from the digestate.

The wastewater exiting the anaerobic digestion facility will typically have elevated levels of biochemical oxygen demand (BOD) and chemical oxygen demand (COD), these are measures of the reactivity of the effluent and show an ability to pollute. Some of this material is termed 'hard COD' meaning it cannot be accessed by the anaerobic bacteria for conversion into biogas. If this effluent was put directly into watercourses it would negatively affect them by causing eutrophication. As such further treatment of the wastewater is often required. This treatment will typically be an oxidation stage where air is passed through the water in a sequencing batch reactors or reverse osmosis unit.

WWT

## Chapter- 6

# Waste-to-Energy



Spittelau incineration plant is one of several plants that provides district heating in Vienna.

**Waste-to-energy (WtE)** or **energy-from-waste (EfW)** is the process of creating energy in the form of electricity or heat from the incineration of waste source. WtE is a form of energy recovery. Most WtE processes produce electricity directly through combustion, or produce a combustible fuel commodity, such as methane, methanol, ethanol or synthetic fuels.

## Incineration

Incineration, the combustion of organic material such as waste with energy recovery is the most common WtE implementation. Incineration may also be implemented without energy and materials recovery; however, this is increasingly being banned in OECD (Organisation for Economic Co-operation and Development) countries. Furthermore, all new WtE plants in OECD countries must meet strict emission standards. Hence, modern incineration plants are vastly different from the old types, some of which neither recovered energy nor materials. Modern incinerators reduce the volume of the original waste by 95-96 %, depending upon composition and degree of recovery of materials such as metals from the ash for recycling.

Concerns regarding the operation of incinerators include fine particulate, heavy metals, trace dioxin and acid gas emissions, even though these emissions are relatively low from modern incinerators. Other concerns include toxic fly ash and incinerator bottom ash (IBA) management. Discussions regarding waste resource ethics include the opinion that incinerators destroy valuable resources and the fear that they may reduce the incentives for recycling and waste minimization activities. Incinerators have electric efficiencies on the order of 14-28%. The rest of the energy can be utilized for e.g. district heating, but is otherwise lost as waste heat.

The method of using incineration to convert municipal solid waste (MSW) to energy is a relatively old method of waste-to-energy production. Incineration generally entails burning garbage to boil water which powers steam generators that make electric energy to be used in our homes and businesses. One serious problem associated with incinerating MSW to make electrical energy, is the pollutants that are put into the atmosphere when burning the garbage that power the generators. These pollutants are extremely acidic and have been reported to cause serious environmental damage by turning rain into acid rain. One way that this problem has been significantly reduced is through the use of lime scrubbers on smokestacks. The limestone mineral used in these scrubbers has a pH of approximately 8 which means it is a base. By passing the smoke through the lime scrubbers, any acids that may be in the smoke are neutralized which prevents the acid from reaching the atmosphere and hurting our environment. (Field) According to the New York Times, modern incineration plants are so clean that "many times more dioxin is now released from home fireplaces and backyard barbecues than from incineration."

## WtE technologies other than incineration

There are a number of other new and emerging technologies that are able to produce energy from waste and other fuels without direct combustion. Many of these technologies have the potential to produce more electric power from the same amount of fuel than would be possible by direct combustion. This is mainly due to the separation of corrosive components (ash) from the converted fuel, thereby allowing higher combustion temperatures in e.g. boilers, gas turbines, internal combustion engines, fuel cells. Some are able to efficiently convert the energy into liquid or gaseous fuels:

Thermal technologies:

- Gasification (produces combustible gas, hydrogen, synthetic fuels)
- Thermal depolymerization (produces synthetic crude oil, which can be further refined)
- Pyrolysis (produces combustible tar/biooil and chars)
- Plasma arc gasification PGP or plasma gasification process (produces rich syngas including hydrogen and carbon monoxide usable for fuel cells or generating electricity to drive the plasma arch, usable vitrified silicate and metal ingots, salt and sulphur)

Non-thermal technologies:

- Anaerobic digestion (Biogas rich in methane)
- Fermentation production (examples are ethanol, lactic acid, hydrogen)
- Mechanical biological treatment (MBT)
  - MBT + Anaerobic digestion
  - MBT to Refuse derived fuel

## Global WTE developments

During the 2001-2007 period, the WTE capacity increased by about four million metric tons per annum. Japan and China built several plants that were based on direct smelting or on fluid bed combustion of solid waste. In China there are about 50 WTE plants. Japan is the largest user in thermal treatment of MSW in the world with 40 million tons. Some of the newest plants use stoker technology and others use the advanced oxygen enrichment technology. There are also over one hundred thermal treatment plants using relatively novel processes such as direct smelting, the Ebara fluidization process and the Thermo-select -JFE gasification and melting technology process. In Patras, Greece, a Greek company just finished testing a system that shows potential. It generates 25kwatts of electricity and 25kwatts of heat from waste water. In India its first energy bio-science center was developed to reduce the country's green house gases and its dependency on fossil fuel.

Biofuel Energy Corporation of Denver, CO, opened two new biofuel plants in Wood River, NE, and Fairmont, MN, in July 2008. These plants use distillation to make ethanol for use in motor vehicles and other engines. Both plants are currently reported to be working at over 90% capacity. Fulcrum BioEnergy incorporated located in Pleasanton, CA, is currently building a WTE plant near Reno, NV. The plant is scheduled to open in early 2010 under the name of Sierra BioFuels plant. BioEnergy incorporated predicts that the plant will produce approximately 10.5 million gallons per year of ethanol from nearly 90,000 tons per year of MSW.(Biofuels News)

Waste to energy technology includes fermentation, which can take biomass and create ethanol, using waste cellulosic or organic material. In the fermentation process, the sugar in the waste is changed to carbon dioxide and alcohol, in the same general process that is used to make wine. Normally fermentation occurs with no air present. Esterification can also be done using waste to energy technologies, and the result of this process is biodiesel. The cost effectiveness of esterification will depend on the feedstock being used, and all the other relevant factors such as transportation distance, amount of oil present in the feedstock, and others. Gasification and pyrolysis by now can reach thermal conversion efficiencies from of up to 75%, however a complete combustion is superior in terms of fuel conversion efficiency. Some pyrolysis processes need an outside heat source which may be supplied by the gasification process, making the combined process self sustaining.

## **Carbon dioxide emissions**

In thermal WtE technologies, nearly all of the carbon content in the waste is emitted as carbon dioxide(CO<sub>2</sub>) to the atmosphere (when including final combustion of the products from pyrolysis and gasification). Municipal solid waste (MSW) contain approximately the same mass fraction of carbon as CO<sub>2</sub> itself (27%), so treatment of 1 metric ton (1.1 short tons) of MSW produce approximately 1 metric ton (1.1 short tons) of CO<sub>2</sub>.

In the event that the waste was landfilled, 1 metric ton (1.1 short tons) of MSW would produce approximately 62 cubic metres (2,200 cu ft) methane via the anaerobic decomposition of the biodegradable part of the waste. This amount of methane has more than twice the global warming potential than the 1 metric ton (1.1 short tons) of CO<sub>2</sub>, which would have been produced by combustion. In some countries, large amounts of landfill gas are collected, but still the global warming potential of the landfill gas emitted to atmosphere in e.g. the US in 1999 was approximately 32 % higher than the amount of CO<sub>2</sub> that would have been emitted by combustion.

In addition, nearly all biodegradable waste is biomass. That is, it has biological origin. This material has been formed by plants using atmospheric CO<sub>2</sub> typically within the last growing season. If these plants are regrown the CO<sub>2</sub> emitted from their combustion will be taken out from the atmosphere once more.

Such considerations are the main reason why several countries administrate WtE of the biomass part of waste as renewable energy. The rest - mainly plastics and other oil and gas derived products - is generally treated as non-renewables.

## **Determination of the biomass fraction**

Several methods have been developed by the European CEN 343 working group to determine the biomass fraction of waste fuels, such as Refuse Derived Fuel/Solid Recovered Fuel. The initial two methods developed (CEN/TS 15440) were the **manual sorting method** and the **selective dissolution method**. A detailed systematic comparison of these two methods has been recently published. Since each method suffered from limitations in properly characterizing the biomass fraction, two alternative methods have been developed.

The first method uses the principles of radiocarbon dating. A technical review (CEN/TR 15591:2007) outlining the carbon 14 method was published in 2007. A technical standard of the carbon dating method (CEN/TS 15747:2008) will be published in 2008. In the United States, there is already an equivalent carbon 14 method under the standard method ASTM D6866.

The second method (so called **balance method**) employs existing data on materials composition and operating conditions of the WtE plant and calculates the most probable result based on a mathematical-statistical model. Currently the balance method is installed at three Austrian incinerators.

A comparison between both methods carried out at three full-scale incinerators in Switzerland showed that both methods came to the same results.

Although carbon 14 dating can determine with some precision the biomass fraction of waste, it cannot determine directly the biomass calorific value. Determining the calorific value is important for green certificate programs such as the Renewable Obligation Certificate program in the United Kingdom. These programs award certificates based on the energy produced from biomass. Several research papers, including the one commissioned by the Renewable Energy Association in the UK, have been published that demonstrate how the carbon 14 result can be used to calculate the biomass calorific value. By contrast the balance method delivers all required information, namely, the ratio between biogenic and fossil energy production, as well as relative and total biogenic and fossil mass and carbon fractions. Moreover it requires no additional measurements and is therefore easy to install at low costs.

## **Examples of waste-to-energy plants**

According to ISWA there are 431 WtE plants in Europe (2005) and 89 in the United States (2004). Below is a list of a few examples of WtE plants.

- Edmonton Municipal Waste-to-Ethanol gasification Plant fueled by RDF scheduled for start of construction by the end of 2009

The following are examples of waste incineration WtE plants:

- Montgomery County Resource Recovery Facility in Dickerson, Maryland, USA (1995)
- Spittelau (1971), and Flötzersteig (1963), Vienna, Austria (Wien Energie)
- SYSAV in Malmö (2003 and 2008), Sweden (Flash presentation)
- Algonquin Power, Brampton, Ontario, Canada
- Teesside EfW plant near Middlesbrough, North East England (1998)
- Edmonton Incinerator in Greater London, England (1974)

WWT

## Chapter- 7

# Zero Waste

**Zero waste** is a philosophy that encourages the redesign of resource life cycles so that all products are reused. Any trash sent to landfills is minimal. The process recommended is one similar to the way that resources are reused in nature.

In industry this process involves creating commodities out of traditional waste products, essentially making old outputs new inputs for similar or different industrial sectors. An example might be the cycle of a glass milk bottle. The primary input (or resource) is silica-sand, which is formed into glass and then into a bottle. The bottle is filled with milk and distributed to the consumer. At this point, normal waste methods would see the bottle disposed in a landfill or similar. But with a zero-waste method, the bottle can be saddled at the time of sale with a deposit, which is returned to the bearer upon redemption. The bottle is then washed, refilled, and resold. The only material waste is the wash water, and energy loss has been minimized.

Zero waste can represent an economical alternative to waste systems, where new resources are continually required to replenish wasted raw materials. It can also represent an environmental alternative to waste since waste represents a significant amount of pollution in the world.

## History

### 1960s: Zero Waste Systems Inc

The term *zero waste* was first used publicly in the name of a company, Zero Waste Systems Inc (ZWS), which was founded by PhD chemist Paul Palmer in the mid 1970s in Oakland, California. The mission of ZWS was to find new homes for most of the chemicals being excessed by the nascent electronics industry. They soon expanded their services in many other directions. For example, they accepted free of charge, large quantities of new and usable laboratory chemicals which they resold to experimenters, scientists, companies and tinkerers of every description during the 1970s. ZWS arguably had the largest inventory of laboratory chemicals in all of California, which were sold for half price. They also collected all of the solvent produced by the electronics industry called developer/rinse (a mixture of xylene and butyl acetate). This was put into small

cans and sold as a lacquer thinner. ZWS collected all the "reflow oil" created by the printed circuit industry, which was filtered and resold into the "downhole" (oil well) industry. ZWS pioneered many other projects.

Because they were the only ones in the world in this business, they achieved an international reputation. Many magazine articles were written about them and several television shows featured them. The California Integrated Waste Management Board produced a slide show featuring ZWS's business and the EPA published a number of studies of their business, calling them an "active waste exchange".

Building on the lessons learned from ZWS, the ZWI considers recycling to be no more than an appendage to garbage creation and the garbage industry. ZWI likewise rejects all attempts to reuse garbage or any kind of waste product. Instead, ZWI calls for the redesign of all of the products of industry and commerce, and the processes that produce, sell and make use of them, so that discard never takes place and there is no waste generated needing to be reused or recycled. Discard is seen as the critical step, a commercial and psychological transfer of responsibility which breaks the chain of custody of a product, removes its owner and subjects it to the degradation of garbage management.

The website offers numerous specific examples of ways in which products can be designed so that discard is unnecessary since the lifetime of the product is extended to at least a threshold value of approximately a human lifetime of 100 years. A fully worked out set of principles and analysis is presented, revolving, among other changes, around standardization, modularization and robust design. A theory of Design Efficiency leading to Design Effectiveness is presented, which means that once a product is designed to be used in perpetuity, it can be fitted out with robust features, strong materials and special conveniences that could not be afforded in a product designed to be discarded after a single use. That theory is applied to packages as an example.

The ZWI rejects all association with the world of recycling, pointing out that there is no theory of recycling in existence; only a trusting hope that it can be useful.

### **1998-2003: peak**

The movement gained publicity and reached a peak in 1998+2002, and since then has been moving from "theory into action" by focusing on how a "zero waste community" is structured and behaves. The website of the Zero Waste International Alliance has a listing of communities across the globe that have created public policy to promote zero-waste practices. Finally, there is a USA zero-waste organization named the GrassRoots Recycling Network that puts on workshops and conferences about zero-waste activities.

### **Present day**

The tension between zero waste, viewed as post-discard total recycling of materials only, and zero waste as the reuse of all high level function remains a serious one today. It is

probably the defining difference between established recyclers and emerging zero-wasters. A signature example is the difference between smashing a glass bottle (recovering cheap glass) and refilling the bottle (recovering the entire function of the container).

The tension between the literal application of natural processes and the creation of industry-specific more efficient reuse modalities is another tension. Many observers look to nature as an ultimate model for production and innovative materials. Others point out that industrial products are inherently non-natural (such as chemicals and plastics that are mono-molecular) and benefit greatly from industrial methods of reuse, while natural methods requiring degradation and reconstitution are wasteful in that context.

biodegradable plastic is the most prominent example. One side argues that biodegradation of plastic is wasteful because plastic is expensive and environmentally damaging to make. Whether made of starch or petroleum, the manufacturing process expends all the same materials and energy costs. Factories are built, raw materials are procured, investments are made, machinery is built and used, humans labor and make use of all normal human inputs for education, housing, food etc. Even if the plastic is biodegraded after a single use, all of those costs are lost so it is much more important to design plastic parts for multiple reuse or perpetual lives. The other side argues that keeping plastic out of a dump or the sea is the sole benefit of interest.

## **Recycling**

It is important to distinguish recycling from Zero Waste. Some claim that the key component to zero waste is recycling while others reject that notion in favor of reusing high function. The common understanding of recycling is simply that of placing bottles and cans in a recycle bin. The modern version of recycling is more complicated and involves many more elements of financing and government support. For example, a 2007 report by the U.S. Environmental Protection Agency states that the US recycles at a national rate of 33.4% and includes in this figure composted materials . In addition many worldwide commodity industries have been created to handle the materials that are recycled. At the same time, claims of recycling rates have sometimes been exaggerated, for example by the inclusion of soil and organic matter used to cover garbage dumps daily, in the "recycled" column. In states with recycling incentives, there is constant local pressure to pump up the recycling rate figures.

The movement toward recycling has separated itself from the concept of zero waste. . One example of this is the computer industry where worldwide millions of PC's are disposed of each year (160 million in 2007). Those computers that enter the recycling stream are broken down into a small amount of raw materials while most merely enter dumps through export to third world countries. Companies are then able to purchase some raw materials, notably steel, copper and glass, reducing the use of new materials. On the other hand, there is an industry, more aligned with the Zero Waste principle of design for long term reuse, that actually repairs computers. It is called the Computer Refurbishing industry and it predates the current campaign to just collect and ship

electronics. They have organizations and conferences and have for many years donated computers to schools, clinics and non-profits. Zero Waste planning demands that components be redesigned for effective reuse over long lives leading to even more refurbishing and repair.

There is one seminal example that brings out the difference between Zero Waste and recycling in stark relief. That example, quoted in *Getting To Zero Waste*, is the software business. Zero Waste is sensitive to the waste of intellectual effort that would be caused by the need to recreate certain basic inventions of software (called objects in software design) as opposed to copying them over and over whenever needed. The waste would occur as the software developers consume resources while solving problems already solved earlier. The application of Zero Waste analysis is straightforward as it recommends conserving human effort. On the other hand, the usual approach of recycling would be to look for some materials that could be found to reuse. The materials on which software is saved (such as paper or diskettes) is of little significance compared to the saving of human effort and if software is saved electronically, there is no media at all. Thus Zero Waste correctly identifies a wasteful behavior to avoid while recycling has no application.

The recycling movement has been embraced by the garbage industry because it serves so well as greenwashing i.e a way to show that design for garbage creation is acceptable because materials will be kept out of a dump by recycling them. Zero Waste, on the other hand, offers the garbage industry no such screen against public condemnation of waste, and therefore actually threatens the continued need for garbage disposal. For example, in Alameda County California, garbage dumping is charged a surcharge of \$8/ton (as of 2009) which goes entirely for a recycling subsidy but none of which goes for any kind of Zero Waste style designing. Zero Waste has received no support from the garbage industry or politicians under their control except in those cases where it can be claimed to consist solely of more recycling.

## **Reduce and reuse**

Zero waste is poorly supported by the enactment of government laws to enforce the waste hierarchy of reduce, reuse, and recycle. In practice, these laws invariably emphasize destruction and recycling, while the reuse component is marginalized.

A special feature of Zero Waste as a design principle is that it can be applied to any product or process, in any situation or at any level. Thus it applies equally to toxic chemicals as to benign plant matter. It applies to the waste of atmospheric purity by coal burning or the waste of radioactive resources by attempting to designate the excesses of nuclear power plants as "nuclear waste". All processes can be designed to minimize the need for discard, both in their own operations and in the usage or consumption patterns which the design of their products leads to. Recycling, on the other hand, deals only with simple materials.

Zero Waste can even be applied to the waste of human potential by enforced poverty and the denial of educational opportunity. It encompasses redesign for reduced energy wasting in industry or transportation and the wasting of the earth's rainforests. It is a general principle of designing for the efficient use of all resources, however defined.

The recycling movement may be slowly branching out from its solid waste management base to include issues that are similar to the community sustainability movement. Zero waste on the other hand, is not based in waste management limitations to begin with but requires that we maximize our existing reuse efforts while creating and applying new methods that minimize and eliminate destructive methods like incineration and recycling. Zero Waste strives to ensure that products are designed to be repaired, refurbished, remanufactured and generally reused.. (“What is Zero Waste?”, para 2).

## **The significance of dump capacity**

Many dumps are currently exceeding carrying capacity. This is often, mistakenly used as a justification for moving to Zero Waste. Others counter by pointing out that there are huge tracts of land available throughout the USA and other countries which could be used for dumps. This is no more of an argument against the need for Zero Waste than is the former an argument for Zero Waste. The underlying need to move to a society designed along Zero Waste principles arises from the huge waste of resources that is inherent in poorly made, short-lived articles and production processes. The locus of the most egregious wasting takes place as articles are built and processes are run wastefully. The actual placing of a now useless item in a dump is barely the icing on the cake, in terms of the waste it represents. Poorly conceived proposals, that appear with a dismaying regularity on the Internet, to blithely destroy all garbage as a way to solve the garbage problem, make use of the common delusion that it is the garbage itself which is the problem. These proposals typically claim to convert all or a large portion of existing garbage into oil and sometimes claim to produce so much oil that the world will henceforth have abundant liquid fuels. One such plan, called Anything Into Oil was promoted by Discover Magazine and Fortune Magazine in 2004, even though it absurdly claimed to be able to convert a refrigerator into "light Texas crude" by the application of high pressure steam. Zero Waste analysis, which is long on scientific results and short on spectacular claims, receives no such promotion by the media.

## **Corporate initiatives**

An example of a company that has demonstrated a change in landfill waste policy is General Motors (GM). GM has confirmed their plans to make approximately half of its 181 plants worldwide "landfill-free" by the end of 2010. Companies like Subaru, Toyota, and Xerox are also producing landfill-free plants. GM is supposed to have about eighty producing plants twenty months. Furthermore, The United States Environmental Protection Agency (EPA) has worked with GM and other companies for decades to minimize the waste through its WasteWise program. The goal for General Motors is finding ways to recycle or reuse more than 90% of materials by: selling scrap materials, adopting reusable parts boxes to replace cardboard, and even recycling used work gloves.

The remainder of the scraps might be incinerated to create energy for the plants. Besides being nature friendly, it also saves money by cutting out waste and producing a more efficient production. All these organizations all push forth to make our world clean and producing zero waste.

### **Re-use of waste**

The waste sent to landfills may be harvested as useful materials, such as in the production of solar energy or fertiliser for crops.

It may also be reused and recycled for something that we can actually use. "The success of General Motors in creating zero-landfill facilities shows that zero-waste goals can be a powerful impetus for manufacturers to reduce their waste and carbon footprint," says Latisha Petteway, a spokesperson for the EPA.

## **Construction and deconstruction**

Zero Waste is a goal, a process, a way of thinking that profoundly changes our approach to resources and production. Zero Waste is not about recycling and diversion from landfills but about restructuring production and distribution systems to prevent waste from being manufactured in the first place. The materials that are still required in these re-designed, resource-efficient systems will be reused many times as the products that incorporate them are reused. Deconstruction can be described as construction in reverse. It involves carefully taking apart a building to maximize the reuse of materials, thereby reducing waste and conserving resources. Deconstruction can capture materials and some components from the millions of buildings that are existing and that were poorly designed for high level reuse but it is not a favored approach from a Zero Waste point of view. Zero Waste favors the design of buildings as assemblages of high level components, not their creation from rough materials such as lumber, cement or plaster. The details are not worked out yet but to the extent that entire rooms, entire walls, roofs or floors or entire utility systems can be pre-built and installed as completed components, that will be the goal of Zero Waste design. Until buildings are built as components capable of later dismantling, deconstruction is a stop-gap process that the United States can use to minimize the waste of building materials. For now, the largest parts that we are able to save tend to be architectural elements, windows, doors, and metals, many of which are being saved and resold by reuse yards such as Urban Ore in Berkeley California. The main parts that still need to be crushed are wood flooring, brick walls, and structural timbers. The demolition of traditional buildings has been long done by wrecking ball or bulldozer. Social and political artifacts, such as demolition contractor licenses and required permits that can only be satisfied by destruction and discard (with partial recycling of rubble and steel), render the destruction and disposal costs cheaper than deconstruction. Approximately seventy pounds of the waste is generated for about every square foot of the residential building demolition. It is arguable that this is artificial economics, based on the cultural preference for wastefulness and that Zero Waste designs of dismantlable components will ultimately be the cheapest as well as the most

conservative way to reuse buildings. Further discussions of this topic may be found on the ZWI website.

## **Market-based campaigns**

Market-based, legislation-mediated campaigns like Extended Producer Responsibility (EPR) and the Precautionary Principle are among numerous campaigns that have a Zero Waste slogan hung on them by means of claims they will ineluctably lead to policies of Zero Waste. At the moment, there is no evidence that EPR will increase reuse, rather than merely moving discard and disposal into private-sector dumping contracts. The Precautionary Principle is put forward to shift liability for proving new chemicals are safe from the public (acting as guinea pig) to the company introducing them. As such, its relation to Zero Waste is dubious. Likewise, many organizations, cities and counties have embraced a Zero Waste slogan while pressing for none of the key Zero Waste changes. In fact, it is common for many such to simply state that recycling is their entire goal. Many commercial or industrial companies claim to embrace Zero Waste but usually mean no more than a major materials recycling effort, having no bearing on product redesign. Examples include Staples, Home Depot, Toyota, General Motors and computer take-back campaigns. Earlier social justice campaigns have successfully pressured McDonald's to change their meat purchasing practices and Nike to change its labor practices in Southeast Asia. Those were both based on the idea that organized consumers can be active participants in the economy and not just passive subjects. However, the announced and enforced goal of the public campaign is critical. A goal to reduce waste generation or dumping through greater recycling will not achieve a goal of product redesign and so cannot reasonably be called a Zero Waste campaign.

## Chapter- 8

# Plasma Arc Waste Disposal

**Plasma arc gasification** is a waste treatment technology that uses electrical energy and the high temperatures created by an electric arc gasifier. This arc breaks down waste primarily into elemental gas and solid waste (slag), in a device called a **plasma converter**. The process has been intended to be a net generator of electricity, depending upon the composition of input wastes, and to reduce the volumes of waste being sent to landfill sites.

## Principle of Operation

Relatively high voltage, high current electricity is passed between two electrodes, spaced apart, creating an electrical arc. Inert gas under pressure is passed through the arc into a sealed container of waste material, reaching temperatures as high as 25,000 °F (13,900 °C) in the arc column. The temperature a few feet from the torch can be as high as 5,000–8,000 °F (2,760–4,427 °C). At these temperatures, most types of waste are broken into basic elemental components in a gaseous form, and complex molecules are separated into individual atoms.

The reactor operates at a slightly negative pressure, meaning that the feed system is complemented by a gaseous removal system, and later a solid removal system. Depending on the input waste (plastics tend to be high in hydrogen and carbon), gas from the plasma containment can be removed as syngas, and may be refined into various fuels at a later stage or fired on site to provide power.

Syngas is produced exclusively from organic materials with a conversion rate of greater than 99% using plasma gasification. Other inorganic materials in the waste stream that are not broken down but only go through a phase change (solid to liquid) add to the volume of slag with minimal energy recovery and increased cost for refining. For efficient operation of the plant, a portion of the syngas may be used to run on site turbines to power the plasma torches and feed system.

The latest independent review of plasma technology providers was undertaken by Juniper Consulting in 2008, as well as a separate independent review on Alter NRG /Westinghouse technology.

## **Existing facilities**

### **National Cheng Kung University - Tainan City, Taiwan (PEAT International)**

PEAT International constructed a plasma arc waste disposal facility at National Cheng Kung University (NCKU) in Tainan City, Taiwan, which uses its proprietary Plasma Thermal Destruction Recovery method. The facility is able to handle 3–5 metric tons (3.3–5.5 short tons) of waste per day from a variety of waste streams, including incinerator fly ash, medical waste, organic industrial process waste and inorganic sludges. It can also process waste consumer batteries and other materials, including heavy metal sludges, and refinery catalysts (waste streams that would generate valuable metal alloys). The facility was constructed as part of a comprehensive resource recovery facility funded by the Taiwanese government, marking the first time the Government of Taiwan committed financial and technical resources to the utilization of plasma technology. It was commissioned in November 2004 and received its operating permit in January, 2005. PEAT has been an active participant in the operations and maintenance of the facility on behalf of NCKU for its research purposes.

### **Yoshii, Utashinai, and Mihama-Mikata, Japan (Hitachi Metals Ltd.)**

Three similar small plants are in operation in Japan — a 166-short-ton (151,000 kg) per day "pilot" plant in Yoshii, co-developed by **Hitachi Metals Ltd.** and **Westinghouse Plasma**, which was certified after a demonstration period in 1999–2000; a 165-short-ton (150,000 kg) per day plant in Utashinai City, completed in 2002; and a 28-short-ton (25,000 kg) per day plant commissioned by the twin cities of Mihama and Mikata in 2002. Two similar facilities run by different companies in Australia and Germany closed after changes in senior management.

### **Ottawa, Ontario, Canada (Plasco Energy Group Inc.)**

A new and different type of plasma arc waste conversion that uses plasma to refine gases produced during waste conversion, rather than to destroy waste by brute force as do other plasma systems, has yet to show itself to be successful on a full commercial scale. Plasco Energy Group completed a plasma-arc waste demonstration plant in Ottawa, Canada at the Trail Road Landfill, to process 85 metric tons (94 short tons) per day of municipal solid waste. Unlike other plasma waste processing facilities, Plasco Energy Group's process does not use plasma to destroy waste, but rather to refine gases produced during waste conversion, in order to allow them to be used to run an internal combustion gas engine. On 24 October 2007, the Plasco Trail Road facility began delivering power to the grid.

The Plasco conversion system, which uses plasma to refine gases rather than expose them to extremely high temperatures, and whose liner is composed of refractory brick rather than metal, is not susceptible to premature attack of vessel liners. Plasco's internal studies claim that its emissions are also much lower than any other thermal waste processing system. By converting waste to CO<sub>2</sub> and water, rather than to methane, the greenhouse gas emissions of the process might be much less than competing technologies such as landfills. Plasco Energy is proposing a scaled up residual waste plasma gasification facility for Los Angeles, California.

In an update to local area residents on 6 December 2008, Plasco president Rod Bryden said delays at its facility were caused by malfunctioning machinery, not problems with the waste-to-energy technology.

### **Swindon, Wiltshire APP**

The heart of this technology, the Gasplasma process, forms the basis of APP's Swindon Plant, the first Gasplasma facility in the world. Gasplasma is the sequential use of gasification, plasma gas treatment, syngas polishing and gas engine power generation.

A full scale plant will treat 100,000 short tons (91,000 t) per annum of municipal waste and produce:

- Enough power for 10,000 homes
- Enough heat for around 700 homes
- over 99% landfill diversion of feedstock with minimal residues and emissions
- Increase recycling rates by over 20%
- High performance, high-value aggregate glass (trademark Plasmarok)
- Novel combination of three existing and proven technologies (termed Gasplasma)
- Negative carbon footprint and lowest environmental impact plant and building

A full scale plant will be 150 metres (490 ft) long, 50 metres (160 ft) wide, and along most of its length only 11 metres (36 ft) high. Above the thermal plant, the roof height is about 14 metres (46 ft), and the single exhaust for the engines 10 metres (33 ft) higher, at only 34 metres (112 ft). The building is approximately the size of a supermarket store and operates under a light vacuum, meaning it contains all odors. The entire process occurs within the building.

## **Planned Facilities**

### **Energy Park Peterborough (Tetronics)**

Energy Park Peterborough - the UK's First Green Energy Park, which is being managed by Peterborough Renewable Energy was granted consent by the Government Department for Energy and Climate Change (DECC) in November 2009. It will take in mixed waste and – through a combination of recycling, gasification and plasma-enhanced waste recovery – recycle and remanufacture it, producing reusable products and renewable

energy in the process. Energy Park Peterborough alone will save 600,000 tonnes of CO<sub>2</sub> per year, create over 100 green collar jobs in the local community and produce enough renewable energy to power 60,000 homes. Tetronics will Supply Plasma Hazardous Waste Treatment Technology. The technology will turn the Air Pollution Control (APC) residue generated from the Biomass Power Plant into bricks and tiles for the building industry, thereby; ensuring close to zero residues to be landfilled.

### **St. Lucie County, Florida (GeoPlasma)**

The first plasma-based waste disposal system in the USA was announced in 2006 in St. Lucie County, Florida. The county stated that it hopes to not only avoid further landfill, but completely empty its existing landfill — 4,300,000 short tons (3,900,000 t) of waste collected since 1978 — within 18 years. The plant was scheduled to come into operation in 2009. However, no permits as yet have been submitted for construction. Backers have announced that the facility would produce 600 short tons (540,000 kg) of solid rubble from around 3,000 short tons (2,700,000 kg) of waste per day at 5,500 °C (9,900 °F). Uncertainties have arisen however regarding the safety of such a facility. The public and environmental threats from incinerators coupled with the uncertainty of the community's ability to produce such large quantities of waste consistently have led GeoPlasma to submit a new proposal for a much smaller facility that would convert 200 short tons (180 t) of waste per day.

### **Vancouver, British Columbia, Canada (Plasco Energy Group Inc.)**

A proposed Plasma arc gasifier has been planned for the Metro Vancouver area. However residents of the area have protested. Metro Vancouver is currently conducting an RFP process to determine a long-term solution for waste management. Plasco is not proposing that Metro Vancouver discontinue the RFP process, but rather to establish an interim solution that can quickly address the shortfall in landfill capacity, while also providing a facility that will allow Metro Vancouver to closely scrutinize and evaluate this new technology as part of its long-term decision making process.

### **Port Hope, Ontario, Canada (Sunbay Energy Corporation)**

Utilizing technology licensed from Europlasma, the plasma arc facility proposed for lands in the vicinity of Wesleyville in Port Hope, Ontario (approximately 45 minutes east of Toronto) will handle 400 short tons (360 t) per day of Municipal Solid Waste (MSW) and Tire Derived Fuel (TDF). Sunbay Energy is currently obtaining the required approvals from Provincial authorities and intends to have the facility operational during the 4th Quarter of 2009.

### **Tallahassee, Florida (Green Power Systems)**

The city of Tallahassee, Florida has signed the largest plasma arc waste to energy contract (35 MW) to date with Green Power Systems to process 1,000 short tons (910 t)

daily from the city and several surrounding counties. Completion of the project is scheduled for October 2010.

### **Hirwaun, Wales (EnviroParks Limited)**

**EnviroParks Limited** plan (31/9/07) a consortium to build an Organic Park in Tower Colliery at Hirwaun, South Wales. This includes a plasma gasification plant combined with advanced anaerobic digestion to divert municipal solid waste from the landfill. EnviroParks are currently collaborating with partner Europlasma of Bordeaux to provide the plasma gasification unit to the park.

As much as £60 million is being put into the project by EnviroParks Ltd and its partners, to establish organic waste and mixed waste treatment facilities next to the Tower Colliery at Hirwaun. The Hirwaun site itself is large enough for the processing of over 250,000 metric tons (280,000 short tons) of non-hazardous waste a year. Initially, though, an anaerobic digestion plant will be designed to handle 50,000 metric tons (55,000 short tons) of organic wastes a year.

### **Jackson, Georgia (PR Power Company)**

PR Power Co. plans to open a plant south of Atlanta, near Jackson, Georgia, that will use a "plasma torch" to vaporize tires down to their natural elements — mainly hydrocarbons and scrap steel. The gases will be converted to electricity for sale to electric utilities and the scrap steel will be sold at an estimated \$50 a ton.

### **Red Deer, Alberta (Plasco Energy Group Inc.)**

Plasco is preparing to start construction on a commercial-scale facility in Red Deer, Alberta in the Summer of 2009. This facility, the company's first commercial plant, is expected to be completed by the end of 2010.

### **Maharashtra Enviro Power Limited, SMSIL Pune, Maharashtra India**

SMS Infrastructures Limited (SMSIL), Central India's largest civil engineering and infrastructure development company, constructed 68 tonne-per-day hazardous waste-to-energy plants, located in Pune, India, that will use Westinghouse Plasma Corporation's (WPC) plasma technology and reactor vessel design. Each plant will provide comprehensive disposal services for a wide variety of hazardous waste, and will produce up to 1.6 MW (net) of electricity

- The facilities will be the largest plasma gasification WTE plants in the world processing hazardous waste.

### **Beijing, China (Plasco Energy Group Inc.)**

Plasco announced in April 2010 that it is planning a joint venture with Beijing Environmental Sanitation Engineering Group Co. to construct a 200 tonne per day demonstration facility in Beijing. If successful, it is intended to construct a larger 1,000 tonne per day facility to help dispose of the city's 18,000 tonnes of municipal waste generated per day.

## **Concerns**

No municipal-scale waste disposal plasma arc facilities have as yet been constructed, so considerable technological and budgetary uncertainties remain.

Numerous municipal plasma arc gas plants (see above) are currently in development, including one for the city of Los Angeles. Practical (limited use of land space for landfills), technological (large-scale use of technology versus small-scale, e.g. plasma arc is currently favored as a means to destroy medical and hazardous waste), logistical (transportation infrastructure requirements) and budgetary considerations can affect the viability of individual projects.

## **Liners**

An issue regarding plasma systems that rely on high temperatures for processing is in the life of their liners. The liner is an important aspect of separating the high interior temperatures of the plasma system from the [metal] shell of the plasma container. Liners are highly susceptible to both chlorine attack and to local variabilities in [high] temperatures, both of which would be found with typical municipal waste systems, and are not likely to last more than a year in service. This concern can be addressed by using the method demonstrated at the Trail Road Plant in Ottawa, Canada, which requires lower temperatures and a more robust material (fire brick) for a liner instead of the expensive and fragile metal.

## **Waste stream consistency**

The content and the consistency of the waste has a direct impact on performance of a plasma facility. Pre-sorting and recycling useful material before gasification provides a more consistent waste stream. A waste stream that is high in inorganic (metals and construction waste) materials increase slag production and decrease the more valuable syngas production. Secondly, shredding the waste before entering the main chamber creates an efficient transfer of energy ensuring all materials are broken down.

## Chapter- 9

# Incineration



The Spittelau incineration plant in Vienna, designed by Friedensreich Hundertwasser.



SYSAV incineration plant in Malmö, Sweden capable of handling 25 metric tons (28 short tons) per hour household waste. To the left of the main stack, a new identical oven line is under construction (March 2007).

**Incineration** is a waste treatment process that involves the combustion of organic substances contained in waste materials. Incineration and other high temperature waste treatment systems are described as "thermal treatment". Incineration of waste materials converts the waste into ash, flue gas, and heat. The ash is mostly formed by the inorganic constituents of the waste, and may take the form of solid lumps or particulates carried by the flue gas. The flue gases must be cleaned of gaseous and particulate pollutants before they are dispersed into the atmosphere. In some cases, the heat generated by incineration can be used to generate electric power.

Incineration with energy recovery is one of several waste-to-energy (WtE) technologies such as gasification, Plasma arc gasification, pyrolysis and anaerobic digestion. Incineration may also be implemented without energy and materials recovery.

In several countries, there are still concerns from experts and local communities about the environmental impact of incinerators.

In some countries, incinerators built just a few decades ago often did not include a materials separation to remove hazardous, bulky or recyclable materials before combustion. These facilities tended to risk the health of the plant workers and the local environment due to inadequate levels of gas cleaning and combustion process control. Most of these facilities did not generate electricity.

Incinerators reduce the solid mass of the original waste by 80–85% and the volume (already compressed somewhat in garbage trucks) by 95-96 %, depending on composition and degree of recovery of materials such as metals from the ash for recycling. This means that while incineration does not completely replace landfilling, it significantly reduces the necessary volume for disposal. Garbage trucks often reduce the volume of waste in a built-in compressor before delivery to the incinerator. Alternatively, at landfills, the volume of the uncompressed garbage can be reduced by approximately 70% by using a stationary steel compressor, albeit with a significant energy cost. In many countries, simpler waste compaction is a common practice for compaction at landfills.

Incineration has particularly strong benefits for the treatment of certain waste types in niche areas such as clinical wastes and certain hazardous wastes where pathogens and toxins can be destroyed by high temperatures. Examples include chemical multi-product plants with diverse toxic or very toxic wastewater streams, which cannot be routed to a conventional wastewater treatment plant.

Waste combustion is particularly popular in countries such as Japan where land is a scarce resource. Denmark and Sweden have been leaders in using the energy generated from incineration for more than a century, in localised combined heat and power facilities supporting district heating schemes. In 2005, waste incineration produced 4.8 % of the electricity consumption and 13.7 % of the total domestic heat consumption in Denmark. A number of other European countries rely heavily on incineration for handling municipal waste, in particular Luxembourg, the Netherlands, Germany and France.

## **History**

The first incinerators for waste disposal were built in Nottingham by Manlove, Alliott & Co. Ltd. in 1874 to a design patented by Albert Fryer. They were originally known as destructors.

## **Technology**

An incinerator is a furnace for burning waste. Modern incinerators include pollution mitigation equipment such as flue gas cleaning. There are various types of incinerator plant design: moving grate, fixed grate, rotary-kiln, and fluidised bed.

### **Burn pile**

The burn pile, or burn pit is one of the simplest and earliest forms of waste disposal, essentially consisting of a mound of combustible materials piled on bare ground and set on fire. Indiscriminate piles of household waste are strongly discouraged and may be illegal in urban areas, but are permitted in certain rural situations such as clearing forested land for farming, where the stumps are uprooted and burned. Rural burn piles of organic yard waste are also sometimes permitted, though not asphalt shingles, plastics, or other petroleum products.

Burn piles can and have spread uncontrolled fires, for example if wind blows burning material off the pile into surrounding combustible grasses or onto buildings. As interior structures of the pile are consumed, the pile can shift and collapse, spreading the burn area. Even in a situation of no wind, small lightweight ignited embers can lift off the pile via convection, and waft through the air into grasses or onto buildings, igniting them.

### **Burn barrel**

The burn barrel is a somewhat more controlled form of private waste incineration, containing the burning material inside a metal barrel, with a metal grating over the exhaust. The barrel prevents the spread of burning material in windy conditions, and as the combustibles are reduced they can only settle down into the barrel. The exhaust grating helps to prevent the spread of burning embers. Typically steel 55-gallon drums are used as burn barrels, with air vent holes cut or drilled around the base for air intake. Over time the very high heat of incineration causes the metal to oxidize and rust, and eventually the barrel itself is consumed by the heat and must be replaced.

Private burning of dry cellulosic/paper products is generally clean-burning, producing no visible smoke, but the large amount of plastics in household waste can cause private burning to create a public nuisance and health hazard, generating acrid odors and fumes that make eyes burn and water. The temperatures in a burn barrel are not regulated, and usually do not reach high enough or for enough time to completely break down chemicals such as dioxin in plastics and other waste chemicals. Therefore plastics and other petroleum products must be separated and sent to commercial waste disposal facilities.

Private rural incineration is typically only permitted so long as it is not a nuisance to others, does not pose a risk of fire such as in dry conditions, and the fire is clean-burning, producing no visible smoke. People intending to burn waste may be required to contact a state agency in advance to check current fire risk and conditions, and to alert officials of the controlled fire that will occur.



Control room of a typical moving grate incinerator overseeing two boiler lines

### **Moving grate**

The typical incineration plant for municipal solid waste is a moving grate incinerator. The moving grate enables the movement of waste through the combustion chamber to be optimised to allow a more efficient and complete combustion. A single moving grate boiler can handle up to 35 metric tons (39 short tons) of waste per hour, and can operate 8,000 hours per year with only one scheduled stop for inspection and maintenance of about one month's duration. Moving grate incinerators are sometimes referred to as Municipal Solid Waste Incinerators (MSWIs).

The waste is introduced by a waste crane through the "throat" at one end of the grate, from where it moves down over the descending grate to the ash pit in the other end. Here the ash is removed through a water lock.



Municipal solid waste in the furnace of a moving grate incinerator capable of handling 15 metric tons (17 short tons) of waste per hour. The holes in the grate elements supplying the primary combustion air are visible.

Part of the combustion air (primary combustion air) is supplied through the grate from below. This air flow also has the purpose of cooling the grate itself. Cooling is important for the mechanical strength of the grate, and many moving grates are also water cooled internally.

Secondary combustion air is supplied into the boiler at high speed through nozzles over the grate. It facilitates complete combustion of the flue gases by introducing turbulence for better mixing and by ensuring a surplus of oxygen. In multiple/stepped hearth incinerators, the secondary combustion air is introduced in a separate chamber downstream the primary combustion chamber.

According to the European Waste Incineration Directive, incineration plants must be designed to ensure that the flue gases reach a temperature of at least 850 °C (1,560 °F) for 2 seconds in order to ensure proper breakdown of toxic organic substances. In order to comply with this at all times, it is required to install backup auxiliary burners (often fueled by oil), which are fired into the boiler in case the heating value of the waste becomes too low to reach this temperature alone.

The flue gases are then cooled in the superheaters, where the heat is transferred to steam, heating the steam to typically 400 °C (752 °F) at a pressure of 40 bars (580 psi) for the electricity generation in the turbine. At this point, the flue gas has a temperature of around 200 °C (392 °F), and is passed to the flue gas cleaning system.

In Scandinavia scheduled maintenance is always performed during summer, where the demand for district heating is low. Often incineration plants consist of several separate 'boiler lines' (boilers and flue gas treatment plants), so that waste can continue to be received at one boiler line while the others are subject to revision.

### **Fixed grate**

The older and simpler kind of incinerator was a brick-lined cell with a fixed metal grate over a lower ash pit, with one opening in the top or side for loading and another opening in the side for removing incombustible solids called clinkers. Many small incinerators formerly found in apartment houses have now been replaced by waste compactors.

### **Rotary-kiln**

The rotary-kiln incinerator is used by municipalities and by large industrial plants. This design of incinerator has 2 chambers: a primary chamber and secondary chamber. The primary chamber in a rotary kiln incinerator consist of an inclined refractory lined cylindrical tube. Movement of the cylinder on its axis facilitates movement of waste. In the primary chamber, there is conversion of solid fraction to gases, through volatilization, destructive distillation and partial combustion reactions. The secondary chamber is necessary to complete gas phase combustion reactions.

The clinkers spill out at the end of the cylinder. A tall flue gas stack, fan, or steam jet supplies the needed draft. Ash drops through the grate, but many particles are carried along with the hot gases. The particles and any combustible gases may be combusted in an "afterburner".

### **Fluidized bed**

A strong airflow is forced through a sandbed. The air seeps through the sand until a point is reached where the sand particles separate to let the air through and mixing and churning occurs, thus a fluidised bed is created and fuel and waste can now be introduced.

The sand with the pre-treated waste and/or fuel is kept suspended on pumped air currents and takes on a fluid-like character. The bed is thereby violently mixed and agitated keeping small inert particles and air in a fluid-like state. This allows all of the mass of waste, fuel and sand to be fully circulated through the furnace.

### **Specialized incineration**

Furniture factory sawdust incinerators need much attention as these have to handle resin powder and many flammable substances. Controlled combustion, burn back prevention systems are essential as dust when suspended resembles the fire catch phenomenon of any liquid petroleum gas.

## **Use of heat**

The heat produced by an incinerator can be used to generate steam which may then be used to drive a turbine in order to produce electricity. The typical amount of net energy that can be produced per tonne municipal waste is about 2/3 MWh of electricity and 2 MWh of district heating. Thus, incinerating about 600 metric tons (660 short tons) per day of waste will produce about 400 MWh of electrical energy per day (17 MW of electrical power continuously for 24 hours) and 1200 MWh of district heating energy each day.

## **Pollution**

Incineration has a number of outputs such as the ash and the emission to the atmosphere of flue gas. Before the flue gas cleaning system, the flue gases may contain significant amounts of particulate matter, heavy metals, dioxins, furans, sulfur dioxide, and hydrochloric acid.

In a study from 1994, Delaware Solid Waste Authority found that, for same amount of produced energy, incineration plants emitted fewer particles, hydrocarbons and less SO<sub>2</sub>, HCl, CO and NO<sub>x</sub> than coal-fired power plants, but more than natural gas fired power plants. According to Germany's Ministry of the Environment, waste incinerators reduce the amount of some atmospheric pollutants by substituting power produced by coal-fired plants with power from waste-fired plants.

## **Gaseous emissions**

### **Dioxin and furans**

The most publicized concerns from environmentalists about the incineration of municipal solid wastes (MSW) involve the fear that it produces significant amounts of dioxin and furan emissions. Dioxins and furans are considered by many to be serious health hazards.

In 2005, The Ministry of the Environment of Germany, where there were 66 incinerators at that time, estimated that "...whereas in 1990 one third of all dioxin emissions in Germany came from incineration plants, for the year 2000 the figure was less than 1 %. Chimneys and tiled stoves in private households alone discharge approximately 20 times more dioxin into the environment than incineration plants."

According to the United States Environmental Protection Agency, incineration plants are no longer significant sources of dioxins and furans. In 1987, before the governmental regulations required the use of emission controls, there was a total of 10,000 grams (350 oz) of dioxin emissions from US incinerators. Today, the total emissions from the 87 plants are 10 grams (0.35 oz) annually, a reduction of 99.9 %.

Backyard barrel burning of household and garden wastes, still allowed in some rural areas, generates 580 grams (20 oz) of dioxins annually. Studies conducted by the US-

EPA demonstrate that the emissions from just one family using a burn barrel produces more emissions than an incineration plant disposing of 200 metric tons (220 short tons) of waste per day.

### ***Dioxin cracking methods and limitations***

Generally, the breakdown of dioxin requires exposure of the molecular ring to a sufficiently high temperature so as to trigger thermal breakdown of the strong molecular bonds holding it together. Small pieces of fly ash may be somewhat thick, and too brief an exposure to high temperature may only degrade dioxin on the surface of the ash. For a large volume air chamber, too brief an exposure may also result in only some of the exhaust gases reaching the full breakdown temperature. For this reason there is also a time element to the temperature exposure to ensure heating completely through the thickness of the fly ash and the volume of waste gases.

There are trade-offs between increasing either the temperature or exposure time. Generally where the molecular breakdown temperature is higher, the exposure time for heating can be shorter, but excessively high temperatures can also cause wear and damage to other parts of the incineration equipment. Likewise the breakdown temperature can be lowered to some degree but then the exhaust gases would require a greater lingering period of perhaps several minutes, which would require large/long treatment chambers that take up a great deal of treatment plant space.

A side effect of breaking the strong molecular bonds of dioxin is the potential for breaking the bonds of nitrogen gas ( $N_2$ ) and oxygen gas ( $O_2$ ) in the supply air. As the exhaust flow cools, these highly reactive detached atoms spontaneously reform bonds into reactive oxides such as  $NO_x$  in the flue gas, which can result in smog formation and acid rain if they were released directly into the local environment. These reactive oxides must be further neutralized with selective catalytic reduction (SCR) or selective non-catalytic reduction (see below).

### ***Dioxin cracking in practice***

The temperatures needed to break down dioxin are typically not reached when burning of plastics outdoors in a burn barrel or garbage pit, causing high dioxin emissions as mentioned above. While plastic does usually burn in an open-air fire, the dioxins remain after combustion and either float off into the atmosphere, or may remain in the ash where it can be leached down into groundwater when rain falls on the ash pile.

Modern municipal incinerator designs include a high temperature zone, where the flue gas is ensured to sustain a temperature above  $850\text{ }^{\circ}\text{C}$  ( $1,560\text{ }^{\circ}\text{F}$ ) for at least 2 seconds before it is cooled down. They are equipped with auxiliary heaters to ensure this at all times. These are often fueled by oil, and normally only active for a very small fraction of the time.

For very small municipal incinerators, the required temperature for thermal breakdown of dioxin may be reached using a high-temperature electrical heating element, plus a selective catalytic reduction stage.

## **CO<sub>2</sub>**

As for other complete combustion processes, nearly all of the carbon content in the waste is emitted as CO<sub>2</sub> to the atmosphere. MSW contains approximately the same mass fraction of carbon as CO<sub>2</sub> itself (27%), so incineration of 1 ton of MSW produces approximately 1 ton of CO<sub>2</sub>.

If the waste was landfilled, 1 ton of MSW would produce approximately 62 cubic metres (2,200 cu ft) methane via the anaerobic decomposition of the biodegradable part of the waste. This much methane has more than twice the global warming potential than the 1 ton of CO<sub>2</sub>, which would have been produced by incineration. In some countries, large amounts of landfill gas are collected, but still the global warming potential of the landfill gas emitted to atmosphere in the US in 1999 was approximately 32 % higher than the amount of CO<sub>2</sub> that would have been emitted by incineration.

In addition, nearly all biodegradable waste has biological origin. This material has been formed by plants using atmospheric CO<sub>2</sub> typically within the last growing season. If these plants are regrown the CO<sub>2</sub> emitted from their combustion will be taken out from the atmosphere once more.

Such considerations are the main reason why several countries administrate incineration of the biodegradable part of waste as renewable energy. The rest – mainly plastics and other oil and gas derived products – is generally treated as non-renewables.

Different results for the CO<sub>2</sub> footprint of incineration can be reached with different assumptions. Local conditions (such as limited local district heating demand, no fossil fuel generated electricity to replace or high levels of aluminum in the waste stream) can decrease the CO<sub>2</sub> benefits of incineration. The methodology and other assumptions may also influence the results significantly. For example the methane emissions from landfills occurring at a later date may be neglected or given less weight, or biodegradable waste may not be considered CO<sub>2</sub> neutral. A study by Eunomia Research and Consulting in 2008 on potential waste treatment technologies in London demonstrated that by applying several of these (according to the authors) unusual assumptions the average existing incineration plants performed poorly for CO<sub>2</sub> balance compared to the theoretical potential of other emerging waste treatment technologies.

## **Other emissions**

Other gaseous emissions in the flue gas from incinerator furnaces include sulfur dioxide, hydrochloric acid, heavy metals and fine particles.

The steam content in the flue may produce visible fume from the stack, which can be perceived as a visual pollution. It may be avoided by decreasing the steam content by flue gas condensation and reheating, or by increasing the flue gas exit temperature well above its dew point. Flue gas condensation allows the latent heat of vaporization of the water to be recovered, subsequently increasing the thermal efficiency of the plant.

### **Flue gas cleaning**

The quantity of pollutants in the flue gas from incineration plants is reduced by several processes.

Particulate is collected by particle filtration, most often electrostatic precipitators (ESP) and/or baghouse filters. The latter are generally very efficient for collecting fine particles. In an investigation by the Ministry of the Environment of Denmark in 2006, the average particulate emissions per energy content of incinerated waste from 16 Danish incinerators were below 2.02 g/GJ (grams per energy content of the incinerated waste). Detailed measurements of fine particles with sizes below 2.5 micrometres ( $PM_{2.5}$ ) were performed on three of the incinerators: One incinerator equipped with an ESP for particle filtration emitted 5.3 g/GJ fine particles, while two incinerators equipped with baghouse filters emitted 0.002 and 0.013 g/GJ  $PM_{2.5}$ . For ultra fine particles ( $PM_{1.0}$ ), the numbers were 4.889 g/GJ  $PM_{1.0}$  from the ESP plant, while emissions of 0.000 and 0.008 g/GJ  $PM_{1.0}$  were measured from the plants equipped with baghouse filters.

Acid gas scrubbers are used to remove hydrochloric acid, nitric acid, hydrofluoric acid, mercury, lead and other heavy metals. Basic scrubbers remove sulfur dioxide, forming gypsum by reaction with lime.

Waste water from scrubbers must subsequently pass through a waste water treatment plant.

Sulfur dioxide may also be removed by dry desulfurisation by injection limestone slurry into the flue gas before the particle filtration.

$NO_x$  is either reduced by catalytic reduction with ammonia in a catalytic converter (selective catalytic reduction, SCR) or by a high temperature reaction with ammonia in the furnace (selective non-catalytic reduction, SNCR). Urea may be substituted for ammonia as the reducing reagent but must be supplied earlier in the process so that it can hydrolyze into ammonia. Substitution of urea can reduce costs and potential hazards associated with storage of anhydrous ammonia.

Heavy metals are often adsorbed on injected active carbon powder, which is collected by the particle filtration.

### **Solid outputs**



Operation of an incinerator aboard an aircraft carrier

Incineration produces fly ash and bottom ash just as is the case when coal is combusted. The total amount of ash produced by municipal solid waste incineration ranges from 4 to 10 % by volume and 15-20 % by weight of the original quantity of waste, and the fly ash amounts to about 10-20 % of the total ash. The fly ash, by far, constitutes more of a potential health hazard than does the bottom ash because the fly ash often contain high concentrations of heavy metals such as lead, cadmium, copper and zinc as well as small amounts of dioxins and furans. The bottom ash seldom contain significant levels of heavy metals. In testing over the past decade, no ash from an incineration plant in the USA has ever been determined to be a hazardous waste. At present although some historic samples tested by the incinerator operators' group would meet the being ecotoxic criteria at present the EA say "we have agreed" to regard incinerator bottom ash as "non-hazardous" until the testing programme is complete.

### **Other pollution issues**

Odor pollution can be a problem with old-style incinerators, but odors and dust are extremely well controlled in newer incineration plants. They receive and store the waste in an enclosed area with a negative pressure with the airflow being routed through the boiler which prevents unpleasant odors from escaping into the atmosphere. However, not all plants are implemented this way, resulting in inconveniences in the locality.

An issue that affects community relationships is the increased road traffic of waste collection vehicles to transport municipal waste to the incinerator. Due to this reason, most incinerators are located in industrial areas. This problem can be avoided to an extent through the transport of waste by rail from transfer stations.

## Debate

Use of incinerators for waste management is controversial. The debate over incinerators typically involves business interests (representing both waste generators and incinerator firms), government regulators, environmental activists and local citizens who must weigh the economic appeal of local industrial activity with their concerns over health and environmental risk.

People and organizations professionally involved in this issue include the U.S. Environmental Protection Agency and a great many local and national air quality regulatory agencies worldwide.

## Arguments for incineration



*Kehrichtverbrennungsanlage Zürcher Oberland (KEZO) in Hinwil, Switzerland*

- The concerns over the health effects of dioxin and furan emissions have been significantly lessened by advances in emission control designs and very stringent

new governmental regulations that have resulted in large reductions in the amount of dioxins and furans emissions.

- The U.K. Health Protection Agency concluded in 2009 that "Modern, well managed incinerators make only a small contribution to local concentrations of air pollutants. It is possible that such small additions could have an impact on health but such effects, if they exist, are likely to be very small and not detectable."
- Incineration plants can generate electricity and heat that can substitute power plants powered by other fuels at the regional electric and district heating grid, and steam supply for industrial customers. Incinerators and other waste-to-energy plants generate at least partially biomass-based renewable energy that offsets greenhouse gas pollution from coal-, oil- and gas-fired power plants. The E.U. considers energy generated from biogenic waste (waste with biological origin) by incinerators as non-fossil renewable energy under its emissions caps. These greenhouse gas reductions are in addition to those generated by the avoidance of landfill methane.
- The bottom ash residue remaining after combustion has been shown to be a non-hazardous solid waste that can be safely put into landfills or recycled as construction aggregate. Samples are tested for ecotoxic metals.
- In densely populated areas, finding space for additional landfills is becoming increasingly difficult.



• The Maishima waste treatment center in Osaka, designed by Friedensreich Hundertwasser, uses heat for power generation.

Fine particles can be efficiently removed from the flue gases with baghouse filters. Even though approximately 40 % of the incinerated waste in Denmark was incinerated at plants with no baghouse filters, estimates based on measurements by the Danish Environmental Research Institute showed that incinerators were only responsible for approximately 0.3 % of the total domestic emissions of particulate smaller than 2.5 micrometres ( $PM_{2.5}$ ) to the atmosphere in 2006.

- Incineration of municipal solid waste avoids the release of methane. Every ton of MSW incinerated, prevents about one ton of carbon dioxide equivalents from being released to the atmosphere.
- Incineration of medical waste and sewage sludge produces an end product ash that is sterile and non-hazardous.
- Most municipalities that operate incineration facilities have higher recycling rates than neighboring cities and counties that do not send their waste to incinerators.

This is in part due to enhanced recovery of ceramic materials reused in construction, as well as ferrous and in some cases non-ferrous metals that can be recovered from combustion residue. Metals recovered from ash would typically be difficult or impossible to recycle through conventional means, as the removal of attached combustible material through incineration provides an alternative to labor- or energy-intensive mechanical separation methods.

- Volume of combusted waste is reduced by approximately 90%, increasing the life of landfills. Ash from modern incinerators is vitrified at temperatures of 1,000 °C (1,830 °F) to 1,100 °C (2,010 °F), reducing the leachability and toxicity of residue. As a result, special landfills are generally no longer required for incinerator ash from municipal waste streams, and existing landfills can see their life dramatically increased by combusting waste, reducing the need for municipalities to site and construct new landfills.

### **Arguments against incineration**

WWT



Decommissioned Kwai Chung Incineration Plant from 1978. As of late February 2009, it has been demolished.

- The Scottish Protection Agency's (SEPA) comprehensive health effects research concluded "inconclusively" on health effects in Oct. 2009. The authors stress, that even though no conclusive evidence of non-occupational health effects from incinerators were found in the existing literature, "small but important effects might be virtually impossible to detect". The report highlights epidemiological deficiencies in previous UK health studies and suggests areas for future studies. The U.K. Health Protection Agency produced a lesser summary in September 2009. Many toxicologists criticise and dispute this report as not being comprehensive epidemiologically, thin on peer review and the effects of fine particle effects on health.

- The highly toxic fly ash must be safely disposed of. This usually involves additional waste miles and the need for specialist toxic waste landfill elsewhere. If not done properly, it may cause concerns for local residents.
- Some people are still concerned about the health effects of dioxin and furan emissions into the atmosphere from old incinerators; especially during start up and shut down, or where filter bypass is required.
- Incinerators emit varying levels of heavy metals such as vanadium, manganese, chromium, nickel, arsenic, mercury, lead, and cadmium, which can be toxic at very minute levels.
- Incinerator Bottom Ash (IBA) has elevated levels of heavy metals with ecotoxicity concerns if not reused properly. Some people have the opinion that IBA reuse is still in its infancy and is still not considered to be a mature or desirable product, despite additional engineering treatments. Concerns of IBA use in foam concrete have been expressed by the UK Health and Safety Executive in 2010 following several construction and demolition explosions. In its guidance document, IBA is currently banned from use by the UK Highway Authority in concrete work until these incidents have been investigated.
- Alternative technologies are available or in development such as Mechanical Biological Treatment, Anaerobic Digestion (MBT/AD), Autoclaving or Mechanical Heat Treatment (MHT) using steam or plasma arc gasification PGP, or combinations of these treatments. Erection of incinerators compete with the development and introduction of other emerging technologies. A UK government WRAP report, August 2008 found that in the UK median incinerator costs per ton were generally higher than those for MBT treatments by £18 per metric ton; and £27 per metric ton most for modern (post 2000) incinerators.
- Building and operating waste processing plants such as incinerators requires long contract periods to recover initial investment costs, causing a long term lock-in. Incinerator lifetimes normally range 25–30 years. This was highlighted by Peter Jones, OBE, the Mayor of London's waste representative in April 2009.
- Incinerators produce fine particles in the furnace. Even with modern particle filtering of the flue gases, a small part of these is emitted to the atmosphere.  $PM_{2.5}$  is not separately regulated in the European Waste Incineration Directive, even though they are repeatedly correlated spatially to infant mortality in the UK (M.Ryan's ONS data based maps around the EfW/CHP waste incinerators at Edmonton, Coventry, Chineham, Kirklees and Sheffield). Under WID there is no requirement to monitor stack top or downwind incinerator  $PM_{2.5}$  levels. Several European doctors associations (including cross discipline experts such as physicians, environmental chemists and toxicologists) in June 2008 representing over 33,000 doctors wrote a keynote statement directly to the European Parliament citing widespread concerns on incinerator particle emissions and the absence of specific fine and ultrafine particle size monitoring or in depth industry/government epidemiological studies of these minute and invisible incinerator particle size emissions.
- Local communities are often opposed to the idea of locating waste processing plants such as incinerators in their vicinity (the Not In My Back Yard

- phenomenon). Studies in Andover, Massachusetts strongly correlated 10% property devaluations with close incinerator proximity.
- Prevention, waste minimisation, reuse and recycling of waste should all be preferred to incineration according to the waste hierarchy. Supporters of zero waste consider incinerators and other waste treatment technologies as barriers to recycling and separation beyond particular levels, and that waste resources are sacrificed for energy production.
  - A 2008 Eunomia report found that under some circumstances and assumptions, incineration causes less CO<sub>2</sub> reduction than other emerging EfW and CHP technology combinations for treating residual mixed waste. The authors found that CHP incinerator technology without waste recycling ranked 19 out of 24 combinations (where all alternatives to incineration were combined with advanced waste recycling plants); being 228% less efficient than the ranked 1 Advanced MBT maturation technology; or 211% less efficient than plasma gasification/autoclaving combination ranked 2.
  - Some incinerators are visually undesirable. In many countries they require a visually intrusive chimney stack.
  - If reusable waste fractions are handled in waste processing plants such as incinerators in developing nations, it would cut out viable work for local economies. It is estimated that there are 1 million people making a livelihood off collecting waste.

## **Trends in incinerator use**

The history of municipal solid waste (MSW) incineration is linked intimately to the history of landfills and other waste treatment technology. The merits of incineration are inevitably judged in relation to the alternatives available. Since the 1970s, recycling and other prevention measures have changed the context for such judgements. Since the 1990s alternative waste treatment technologies have been maturing and becoming viable.

Incineration is a key process in the treatment of hazardous wastes and clinical wastes. It is often imperative that medical waste be subjected to the high temperatures of incineration to destroy pathogens and toxic contamination it contains.

### **Incineration in North America**

The first incinerator in the U.S. was built in 1885 on Governors Island in New York. In 1949, Robert C. Ross founded one of the first hazardous waste management companies in the U.S. He began Robert Ross Industrial Disposal because he saw an opportunity to meet the hazardous waste management needs of companies in northern Ohio. In 1958, the company built one of the first hazardous waste incinerators in the U.S. The first full-scale, municipally operated incineration facility in the U.S. was the Arnold O. Chantland Resource Recovery Plant, built in 1975 and located in Ames, Iowa. This plant is still in operation and produces refuse-derived fuel that is sent to local power plants for fuel. The first commercially successful incineration plant in the U.S. was built in Saugus,

Massachusetts in October 1975 by Wheelabrator Technologies, and is still in operation today.

There are several environmental or waste management corporations that transport ultimately to an incinerator or cement kiln treatment center. Currently (2009), there are three main businesses that incinerate waste: Clean Harbours, WTI-Heritage, and Ross Incineration Services. Clean Harbours has acquired many of the smaller, independently run facilities, accumulating 5–7 incinerators in the process across the U.S. WTI-Heritage has one incinerator, located in the southeastern corner of Ohio (across the Ohio River from West Virginia).

Several old generation incinerators have been closed; of the 186 MSW incinerators in 1990, only 89 remained by 2007, and of the 6200 medical waste incinerators in 1988, only 115 remained in 2003. No new incinerators were built between 1996 and 2007. The main reasons for lack of activity have been:

- Economics. With the increase in the number of large inexpensive regional landfills and, up until recently, the relatively low price of electricity, incinerators were not able to compete for the 'fuel', i.e., waste in the U.S.
- Tax policies. Tax credits for plants producing electricity from waste were rescinded in the U.S. between 1990 and 2004.

There has been renewed interest in incineration and other waste-to-energy technologies in the U.S. and Canada. In the U.S., incineration was granted qualification for renewable energy production tax credits in 2004. Projects to add capacity to existing plants are underway, and municipalities are once again evaluating the option of building incineration plants rather than continue landfilling municipal wastes. However, many of these projects have faced continued political opposition in spite of renewed arguments for the greenhouse gas benefits of incineration and improved air pollution control and ash recycling.

## **Incineration in Europe**

In Europe, with the ban on landfilling untreated waste, scores of incinerators have been built in the last decade, with more under construction. Recently, a number of municipal governments have begun the process of contracting for the construction and operation of incinerators. In Europe, some of the electricity generated from waste is deemed to be from a 'Renewable Energy Source (RES)' and is thus eligible for tax credits if privately operated. Also, some incinerators in Europe are equipped with waste recovery, allowing the reuse of ferrous and non-ferrous materials found in landfills. A prominent example is the AEB Waste Fired Power Plant.

## **Incineration in the United Kingdom**

The technology employed in the UK waste management industry has been greatly lagging behind that of Europe due to the wide availability of landfills. The Landfill

Directive set down by the European Union led to the Government of the United Kingdom imposing waste legislation including the landfill tax and Landfill Allowance Trading Scheme. This legislation is designed to reduce the release of greenhouse gases produced by landfills through the use of alternative methods of waste treatment. It is the UK Government's position that incineration will play an increasingly large role in the treatment of municipal waste and supply of energy in the UK.

In the UK in 2008, plans for potential incinerator locations exists for approximately 100 sites. These have been interactively mapped by UK NGO's.

### **Small incinerator units**



An example of a low capacity, mobile incinerator

Small scale incinerators exist for special purposes. For example, the small scale incinerators are aimed for hygienically safe destruction of medical waste in developing countries. Small incinerators can be quickly deployed to remote areas where an outbreak has occurred to dispose of infected animals quickly and without the risk of cross contamination.