

# Landfill

Landfill is often regarded as the last resort waste management option. While this may be partly true, modern landfilling is an active treatment process.

An engineered landfill is designed to contain waste and its decomposition products until they present no significant risks to health or the environment. Materials and energy recovery or land reclamation are also among the potential benefits of properly designed facilities.

## Modern landfills

A common landfill classification system reflects the type of waste each receives. There are landfills for hazardous wastes, municipal wastes and inert wastes. In practice, these are not exclusive definitions. Other variants include mono-fills, in which single waste types are permitted, and co-disposal sites, in which municipal and hazardous wastes may be combined.

Landfills can also be classed by the management strategy employed:

### Total containment

Any migration of liquid between the landfill site and the environment is prevented. Total containment at sites accepting anything but inert wastes imposes a long-term responsibility for monitoring and supervision. This strategy must frequently be used with hazardous wastes, but applies less rigorously over time at sites accepting municipal solid waste (MSW).

### Containment and collection of leachate

Leakage of contaminated liquid containing soluble waste decomposition products (leachate) from the landfill is controlled using a low-permeability engineered liner beneath the wastes, and by collecting and treating leachate.

Risks of leachate migration from the site depend on the extent to which the containment barrier integrity is maintained, and on the efficiency of leachate management. This strategy demands active (and expensive) systems, and research is underway into accelerated leaching - the

flushing bio-reactor concept - to speed stabilisation by reducing waste decomposition periods, from perhaps centuries to a few decades.

### Controlled contaminant release

This approach uses a base liner made of natural, often local, materials. While sumps for collection and removal of leachate are sometimes provided, leachate levels are permitted to rise within the waste, permitting gradual migration into the ground.

Naturally, this approach is not suited to every location and geological setting, and full risk and environmental impact assessment approaches should be carried out before development is approved.

### Unrestricted contaminant release

Here, no control is used for water infiltration or leachate escape. This occurs, by default, in waste dumps, particularly in poorer countries.

### Landfill design and operation

Landfills often comprise several successive infilled phases (and/or cells within phases) of permitted waste which are spread, compacted and covered daily with soils.

Compaction is often carried out with large specialised steel-wheeled compactors. However, smaller bulldozers act equally well in small sites and especially in developing

countries where affordability is a primary concern. The largest machines can achieve final waste densities of more than one tonne per cubic metre ( $t/m^3$ ), but 0.7-0.8  $t/m^3$  is more typical.

At the end of each day, or more frequently where necessary, the waste is buried with a layer of cover material (usually soil) which is itself compacted. This controls nuisances, such as pests, litter and smells, and reduces the likelihood of fire.

Engineering methods used within state-of-the-art landfills are relatively sophisticated. Principle site liner containment components include natural and/or synthetic plastic materials, with soil protection layers above and beneath, a porous leachate drainage layer and a top cover.

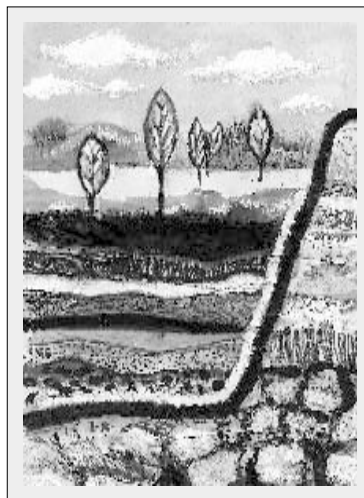
The most common liner materials are mineral liners (such as clay), polymeric flexible liners (eg high density polyethylene) or composite liners using both approaches. In some sites double liner systems are demanded (see Table 1, page 2). Liners are more robust than the name might suggest; composite liners can be as much as five metres deep.

Many complex reactions can occur between the extremely heterogeneous components of landfilled waste.

### Biological processes

Generally, more than half of household waste is organic. This degrades gradually through five stages within a landfill:

aerobic hydrolysis, in which microorganisms convert some carbohydrates to simple sugars (such as glucose), carbon dioxide ( $CO_2$ ) and water; hydrolysis and fermentation, when carbohydrates, lipids and proteins are broken down into volatile acids, acetate,  $CO_2$ , hydrogen ( $H_2$ ) and inorganic salts; acetogenesis, where bacteria turn soluble acids to  $CO_2$  and  $H_2$ . These, with carbohydrates are also transformed into acetic acid;



*methanogenesis*, in which bacteria convert acetic acid to methane and CO<sub>2</sub>. Finally, conditions may become aerobic again as the waste stabilises.

### Chemical processes

Two general types of chemical reactions take place within landfilled waste.

Firstly, oxidation, using trapped oxygen, which soon becomes depleted. Secondly, acid-metal reactions, due to the presence of organic acids and CO<sub>2</sub>. These processes mobilise metallic ions and salts which are potential pollutants. However, once methane generation is established the landfill becomes less acidic and metals are generally retained within the waste mass.

### Physical processes

Compaction of waste has a strong bearing on its behaviour. This process begins at the collection stage and continues within the landfill. High densities reduce future settlement and limit potential moisture up-take.

Processes of absorption and adsorption also affect the rate at which pollutants can reach the environment.

### Landraising

Recent years have seen a growth in landraising, or above ground landfills. Although more visually intrusive, landraising does offer some environmental benefits. Wastes are kept further from potential contact with groundwater, and leakages are easier to identify and control.

### Pollution from landfills

A waste disposal facility must guarantee adequate control over the two main types of pollution - leachate and landfill gas. When landfill gas is

collected some liquid (condensate), is also collected.

### Leachate

Leachate is generated as a result of moisture entry into a landfill, either as rain, snow melt, run-on or as moisture in the waste itself. A typical landfill design includes run-on control and a final cover to minimise moisture flow into the waste. The most significant components of leachate are organic chemicals, ammonia and heavy metals.

Organic chemicals are present as soluble decomposition products (eg

organic acids). They also exist as organic chemicals (eg toluene, dioxins, PCBs and organophosphates) discarded in the waste.

Heavy metals, such as mercury, chromium, nickel, lead, cadmium, copper and zinc, are often found in landfill leachate. Discharges depend mainly on the acidity and rates of flow of leachate. Many heavy metals come from the non-regulated hazardous waste fractions from households and businesses.

No engineering design can guarantee total containment, and some migration of leachate is inevitable. Leachate management systems tend to be one of the following:

- > on-site treatment (generally some form of aeration tank system)
- > disposal to sewerage systems
- > transport off-site for treatment elsewhere

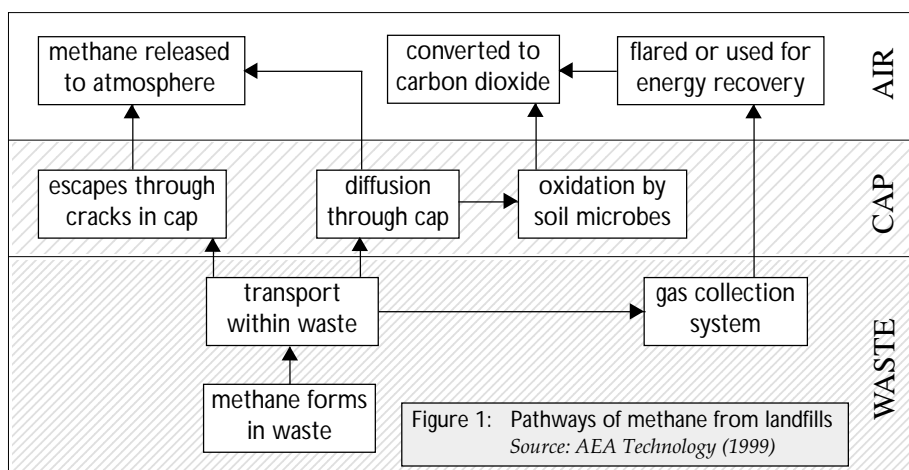
### Landfill gas

All landfills containing biodegradable materials will produce landfill gas (see Figure 1, page 3). Typically this gas contains methane and carbon dioxide as major components (see Table 2, left), with more than 100 other minor components also present. The major components will vary in concentration, related to the stage of degradation and any dilution by air in the waste. Typically, under stable anaerobic

Liner type	Primary barrier	Secondary barrier	Tertiary barrier
<b>Single</b>	clay, or bentonite-enhanced soil, or hydraulic asphalt	not applicable	not applicable
<b>Composite</b>	flexible membrane liner	clay, or bentonite-enhanced soil, or geosynthetic clay liner	not applicable
<b>Double</b>	clay, or bentonite-enhanced soil, and geosynthetic clay liner, or flexible membrane liner	clay, or bentonite-enhanced soil, and geosynthetic clay liner, or flexible membrane liner	not applicable
<b>Multiple</b>	flexible membrane liner	clay, or bentonite-enhanced soil, or geosynthetic clay liner	clay, or bentonite-enhanced soil, or geosynthetic clay liner, or flexible membrane liner

Source: After UK Environment Ministry Waste Management Paper 26B (1995)

Compound	Typical concentration (per cent)
<b>Methane</b>	30 - 60
<b>Carbon dioxide</b>	20 - 50
<b>Oxygen</b>	<2
<b>Nitrogen</b>	<10
<b>Water</b>	Saturated



annual heating needs of 500,000 Canadian homes.

More than a quarter of this is captured at 27 landfill gas recovery schemes.

In Germany, two-thirds of MSW landfills recover energy from landfill gas.

conditions methane content will be 50-60 per cent (by volume), with CO<sub>2</sub> forming the bulk of the remainder. A significant minor component is hydrogen, a by-product of early fermentation.

Landfill gas has a distinctive and unpleasant odour, due to the presence of mercaptans and thiols. Low concentrations of hydrogen sulphide may also be present, especially where plaster board has been deposited (wrongly) alongside other wastes.

Landfills are the largest man-made source of methane, a potent greenhouse gas (GHG). Atmospheric methane levels have increased since the beginning of the 19th century. World-wide, emissions from landfills and open dumps have been estimated to contribute six per cent of total global methane emissions. In theory, one tonne of MSW will produce up to around 375 cubic metres (m<sup>3</sup>) of landfill gas, with a calorific value of up to 20 megajoules per m<sup>3</sup>.

However, collection is challenging, and even the most efficient landfill gas recovery systems capture no more than 70 per cent. As a general rule, a landfill containing one million tonnes (Mt) MSW disposed over ten years will generate a peak of 700 m<sup>3</sup>/hour methane.

It has been estimated that annual global production of methane from solid wastes will rise from around 55 Mt in 1995 to 90 Mt in 2025. In 1996, the European Commission published a study which concluded that

in 1990 around 22 Mt of methane were emitted from man-made sources in Europe, including 7.3 Mt from landfills.

Gas control systems are used to prevent hazardous sub-surface migration and surface emissions of landfill gas. These systems range from something simple like a gravel seam, which allows gas to flow to a particular zone, to sophisticated networks of vertical boreholes and horizontal inter-connectors. Full recovery schemes include collection, extraction and transportation elements, and are often installed progressively as the landfill is constructed.

Some landfill gas is sure to escape, partly because methane is less dense than air. Where the landfill is covered by an impermeable cap, generated gas will tend to move laterally beyond site boundaries, especially within deeper sites and where gas migration control systems are not in place.

Methane can be recovered and used, which may reduce costs. By the early 1990s, as many as 500 landfill gas recovery projects existed world-wide, often generating electricity (usually in the 1-5 megawatt range).

Most schemes are in America, where there are more than 200 projects, although Britain, Germany and Scandinavia also make extensive use of this effectively renewable resource. Canadian landfills annually generate one million tonnes of methane per year, equivalent to nine million barrels of oil. This would meet the

## Reclamation

When all parts of the landfill are complete, surfaces above waste deposits are (in phases) completely covered. Firstly, a sub-surface cap of low-permeability clay is provided (sometimes synthetic material too).

Above this surface liner, sub-surface soils and top-soils are placed to depths that depend on the ultimate intended use of the site. Ideally all soils should be stockpiled at the formation of the site, although if stored over many years, the surface soil layer will require additional management through cultivation and nutrient addition to return it to productive use.

The capping layer minimises the passage of water into the landfill, reducing leachate flow and slows the migration of gases. The final cover also provides a further barrier between the waste and the environment, while allowing plant growth and landscaping. Degradation processes will lead to settlement over time and the need for long-term aftercare of the surface cap (to maintain its integrity) and of surface soils (to re-level surface and/or repair any past erosion or areas with poor re-vegetation).

An increasing trend is for landfills to be converted into recreational areas, such as parks and golf courses. A good example of this is the Danehy Park site at Cambridge, Massachusetts, US. This has been open to the local community since 1990, and includes three softball fields, three soccer fields, and 50 acres of jogging, and cycle trails.

## Disincentives

Many governments have tried to reduce dependency on landfilling. For example, the British Government introduced a Landfill Tax in 1996, which reached £11 per tonne for active waste and £2 per tonne for inert waste in 2000.

## Landfill bans

Many countries ban certain materials, if untreated, from landfills. A US survey showed that virtually every state (or local authority) now operates bans, though not all are enforced. In California, bans cover latex paint, white goods, automobiles, recyclable metals, lead-acid batteries, adhesives, automotive products (eg anti-freeze, transmission fluid), cleaners, pesticides, mercury, solvents, used oil, whole tyres and household batteries.

A key policy development which builds on the concept of the landfill ban has been the European Union Landfill Directive (1999/31/EC). The main provision of this directive is the progressive banning of municipal biodegradable waste from landfills, to 35 per cent of 1995 levels by 2020. In the UK this means at least 6 Mtpa must be diverted (this could reach 33 Mtpa if arisings continue to grow).

Currently, more than 80 per cent of MSW in Britain is landfilled, which means that more than 60 composting facilities, up to 120 materials recovery facilities and perhaps 50 energy from waste plants will be needed. Some countries in the EU such as Denmark have traditionally depended less on landfill, and already comply with the EU directive's targets. In America, landfills currently manage 55 per cent of MSW generated (120 Mtpa).

Some municipalities in Australia and Canada have advanced the concept of regarding landfills as long term stores of material, for future use when economic changes have transformed a waste with no value to a resource. If long term environmental monitoring is required at

such a facility, then perhaps this is no more sustainable than the alternatives.

Overall costs of waste collection, treatment and disposal are rising, perhaps faster than personal income. This is acceptable in wealthy nations where a higher proportion of income tends to be spent on environmental protection measures. However, in much of the world such technological developments are not affordable, nor will they necessarily lead to major environmental benefits over and above low-cost landfills in suitable locations.

It is also wrong to claim that every environmental benefit attributed to other waste management options is, in fact, real and guaranteed. For example, some recycling involves considerable use of energy and emissions, in transportation and re-processing. Yet, direct disposal of inert materials such as glass has no short or long term adverse environmental impact.

Policy-makers need to be certain of the objectives of any requirements that are introduced, to ensure that environmental initiatives really deliver environmental benefits.

There is a need to monitor and reassess the waste management hierarchy, on the basis of sustainability: what is environmentally beneficial, technically feasible and socially acceptable.

## Conclusions

Landfills are unwelcome as neighbours, and regularly attract a hostile response from prospective host communities, yet these facilities will continue to be necessary. However much we try to reduce wastes, to increase re-use and recycling, to compost and to recover energy, the laws of nature mean that there will be some residual matter for which society can find no further use.

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