Waste and landfill

Waste in the UK is big business: the UK services market for waste management is valued at about £5bn, with the potential to grow to at least £12bn over the next 10 years.[70] This market, which comprises approximately 0.5% of the UK GDP, involves an estimated 3500 firms.[71] Each year, over 400 Mt of waste is produced in the UK alone,[65, 70, 72] most of which ends up in landfill sites. By far the majority of this waste (~370 Mt) arises from agriculture, the mining and quarrying industry, and the construction and demolition industry[73, 74] (Figure 15). Landfill sites account for 22% of UK methane emissions (0.46 Mt).

In terms of methane production, the critical factor is the amount of *biodegradable* waste sent to landfill sites. Municipal waste (from households and small businesses), although only a small proportion of total waste production, comprises the most biodegradable matter and therefore generates the most methane. Both agricultural waste (Chapter 6) and sewage sludge can be highly biodegradable. Sewage sludge is not considered here since it represents less than 1% of total waste generated. The other waste streams contain only a minute fraction of biodegradable material. Therefore the main focus of this chapter is municipal waste.

The generation of methane from biodegradable waste in landfill is the most complex of all the sectors explored in this report. The quantities of methane arising depend on the qualities and quantities of waste and the waste disposal methods chosen. The proportion of methane captured, rather than emitted to the atmosphere, is dependent on the landfill cap technology employed. Furthermore, any methane captured may be burned to generate heat or electricity. In the latter case, the methane counts as a renewable energy resource and is eligible for valuable Renewable Obligation Certificates. The challenge is to find the optimum balance between environmentally benign waste disposal practices, renewable energy generation and minimising GHG emissions to the atmosphere. This poses a host of challenges at the waste-energy-climate change interface.

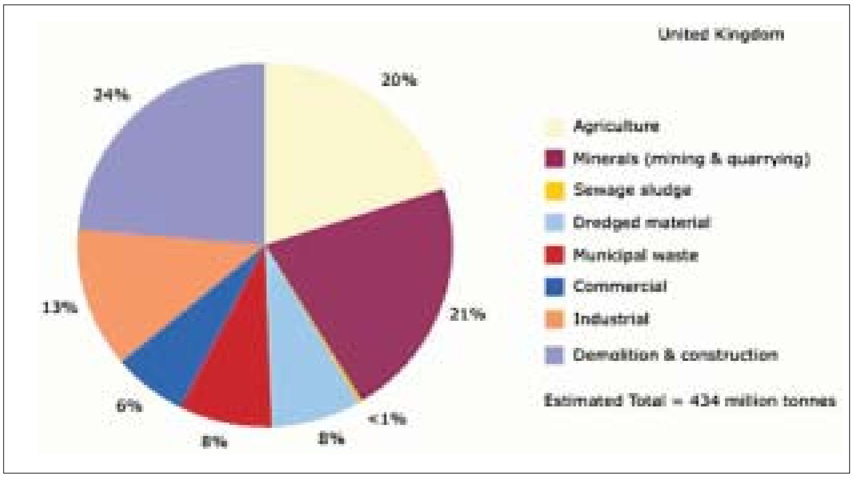

Figure 15: Estimated annual waste by sector (by mass)

Source: DEFRA, 2003[65]

5.1 Methane from landfill

The production of methane in landfill is a result of the restricted availability of oxygen during the decomposition of organic waste. Many modern landfill management practices aimed at improving safety and environmental control have paradoxically accentuated the generation of methane by restricting airflow to the site. Improving aeration can reduce methane production, as has been successfully practised in Japan, although this process is energy intensive. Also, the introduction of air into landfill creates an explosion hazard, if oxygen concentrations are too high, and a greater risk of fire due to the higher temperatures reached by aerobic decomposition processes.[75]

The amount of methane emitted to the atmosphere depends almost entirely on the design and management of the landfill and the quantity of biodegradable waste entering the landfill. Unchecked, the landfill gas will migrate through the site in response to gradients of pressure or gas concentration, or simply along paths of least resistance. The gas may migrate through the waste (depending on its permeability) or through cracks and fissures in the compacted waste or bedrock material. In the absence of obstacles, such as impermeable liners along the landfill perimeter, the gas can travel considerable distances from the boundary of a site, for example, along buried utility installation routeways (*i.e.* pipes for water, gas or sewage, or channels for electricity and telecommunications cables). Similarly, the propensity for migration to the atmosphere depends largely on the permeability of the landfill cover. Sand and gravel caps will do little to impede vertical migration of the gas, whilst more impermeable silts and clays can successfully restrict this movement. However, any weaknesses within the capping layer will be readily exploited.

In a modern, well-engineered landfill, deposited waste is mechanically compacted to eliminate voids and then sealed with a low-permeability capping layer, usually clay. This process restricts the availability of oxygen within the site, so that, once capped, the majority of waste decomposition is carried out anaerobically. The resultant landfill gas typically consists of between 40 to 60% methane (by volume) with the remainder being mainly carbon dioxide and a host of trace constituents. The actual composition of landfill gas is dependent upon a number of factors, most importantly the degradable organic carbon content of the waste and the speed at which the material degrades. The composition also changes over time as biochemical conditions alter during the process of decay.

Laboratory studies have identified five main stages in the process of waste decomposition and the process is relatively well understood[76] (Table 11). Methane production is variable over these five phases and, even within the methanogenic phase, production of methane depends upon the mix of easily digestible biodegradable material versus harder to digest materials such as wood. Some carbon based materials will not decompose and will remain in the landfill. It has been estimated that 6.6 Mt of the 18.6 Mt of carbon going to landfill remains and is sequestered there.[32]

Because the emissions of methane are so

Table 11: Methane formation in landfill

Phases	*Description*	*Time*	*Gases*
Phase 1 Initial adjustment	Aerobic phase where easily degradable organic matter is decomposed in the presence of oxygen (from air trapped in landfill), resulting in CO_2 generation.	Days to a month	CO_2 increases O_2 & N_2 decrease
Phase 2 Transition phase	Oxygen is depleted and anaerobic conditions begin to develop. CO_2 is produced as complex organic compounds undergo hydrolysis and acid fermentation.	2 weeks or more	N_2 & O_2 decrease CO_2, H_2 & H_2S increase
Phase 3 Acid phase	Hydrolysis converts organic matter to intermediate compounds, including acetic acid and volatile fatty acids. Acids accumulate in leachate. Methanogenesis begins.	3 months or more	CH_4 produced. H_2 & CO_2 reach maximum concentration
Phase 4 Methanogenesis	Hydrolysis continues and methanogens proliferate. Methanogens convert acids, H2 and CO2 into methane. For slowly biodegradable organic compounds (e.g. cellulose from paper and wood) this process continues for many years.	May be as long as 30 years	CH_4 production increases H_2 & CO_2 decrease
Phase 5 Maturation phase	Readily available biodegradable material has been converted to methane and carbon dioxide, and emissions decrease. Air diffuses back into landfill.	Decades	CH_4 & CO_2 decrease N_2 & O_2 increase

Source: Ong, 2003[76]

variable over time, it is exceptionally difficult to predict how much methane is produced by landfill. Whilst it is easy to measure the quantity of gas captured, estimating the amount of methane lost to the atmosphere through the cap is much more difficult, as it is impossible to predict accurately how much methane is generated. Furthermore, the quantity of methane escaping to the atmosphere is not simply the difference between production and capture; some methane may be oxidised in the capping layer through contact with low-affinity methanotrophic bacteria, particularly close to the surface of the site. Such contact can reduce methane content through oxidation to form carbon dioxide, although the importance of this in reducing overall emissions is unclear.[77]

5.2 Landfill in the UK

The current dominance of landfill in the UK is a result of economics, geography and advances in construction and maintenance. Due to the hydrology and geology of England and Wales, this option is more economically favoured as a waste disposal option compared to elsewhere in Northern Europe.[78-80]

Over the last six years, the amount of waste sent to landfill has stayed roughly constant, whilst recycling or composting has more than doubled (Figure 16). Around 75% (34 Mt) of municipal waste is sent to landfill each year by the devolved administrations, with the remainder incinerated, recycled or composted. This is estimated to contain more than 21 Mt of biodegradable matter, based on the assumption that between 60 to 70% of municipal waste is biodegradable.[81-85]

There is uncertainty around the exact number of landfill sites in the UK, estimated to be around 1500[156]. In England and Wales there were 2,300 working landfill sites in 2003, a fall from about 3,400 in 1994, although newer sites are larger. It is estimated that the total area of land taken for landfill sites is about 28,000 hectares – almost 0.2% of the land area of England and Wales.

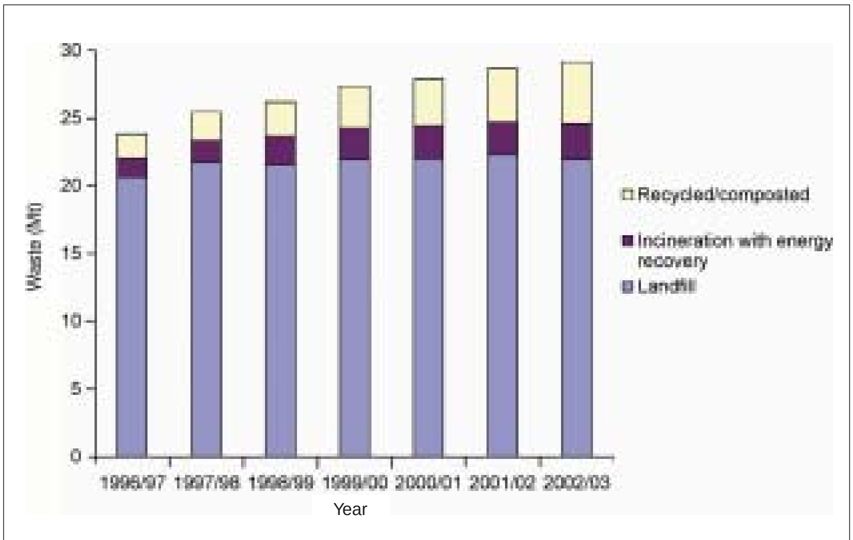

Figure 16: Disposal methods of municipal waste, England, 1996-2003

Source: DEFRA, 2004[86]

Landfill policy

The primary focus of waste policy in both the UK and EU has been on waste reduction rather than specifically targeted at methane. The main policy in the UK to date with regards to landfill has been the Landfill Tax, which centred on diverting waste away from landfill. Whilst such policy has influenced methane emissions to a certain extent, a more coherent and focused approach addressing methane emissions abatement directly is likely to be more effective in this area. The EU Landfill Directive represents a move in this direction, supported by the IPPC Directive (see below).

The waste management hierarchy (Table 12) is a central feature of European waste policy and, as such, has been adopted by the UK. This approach prioritises elimination and prevention of waste over minimisation, re-use, recycling, recovery, treatment and disposal. Moving up the hierarchy leads to more sustainable methods of waste management and increases the possibilities for reducing methane production. The hierarchy has, however, been criticised for not necessarily

Table 12: The waste hierarchy and options for dealing with biodegradable matter

Level	*What this means for biodegradable waste*	*Responsibility*
Reduce	Home composting	
	Less packaging	Individuals
	Lower consumption	
Re-use	Reusable packaging	
Recycle	Recycle paper and cardboard wastes	
Recovery	Obtain maximum energy from waste	
	Combustion of methane from anaerobic digesters	Local government
	Incineration with energy recovery	
	Combustion of methane from landfill	
Treatment	Incineration without energy recovery	
Disposal	Landfill	

reflecting what is best for the environment.[87] Certainly the relative merits of landfill and incineration, with and without energy recovery, are unclear.

Current waste management practices within the UK, with heavy reliance on landfill, are weighted towards the bottom of the hierarchy; generally the least environmentally friendly but most cost-effective and easiest waste management options for the local authority.

It is difficult to deliver waste strategies that focus on the top levels of the waste hierarchy. Successful implementation of such policies requires large-scale social change; many thousands of people each altering their personal waste disposal habits to a more environmentally benign method. Whilst some will be enthusiastic about such issues, achieving a widespread conversion is an uphill battle requiring resources and education.

UK Landfill Tax

The Landfill Tax was introduced in the UK in October 1996 and is levied on disposal of waste to landfill, with very limited exemptions, operating on the 'polluter pays' principle.[88] It intends to promote diversion of waste from landfill through increasing the economic viability of sustainable waste practices, such as re-use, recycling and composting, by imposing a tax on landfill waste.

Landfill operators are liable for the tax on all consignments of waste accepted for landfill disposal. In practice, the costs are passed through the waste management chain and the landfill operator pays the levy to Customs & Excise. Introductory tax rates were set in 1996 at £7 per tonne of active waste (mainly biodegradable waste), and £2 per tonne of inactive waste. The Landfill Tax 'escalator' was announced in the 1999 Budget. This raised the standard rate to £10 per tonne and included a commitment to increase it by £1 per tonne each year to £15 per tonne by 2004-05[79] and by at least £3 per tonne each year thereafter, towards a rate of £35 per tonne in the medium to long-term.[89]

Has the Landfill Tax been effective?

To date, there is still confusion over the effect of the Landfill Tax: the reduction in waste going to landfill has not been documented and there is no quantification of the amount of waste diverted. What is available is a measure of the amount of tax raised and fiscal contributions through the Landfill Tax credit scheme, which offsets waste going to landfill via investment in sustainable waste projects. In 2001/2, over £500M of Landfill Tax was generated, net of the contribution to the credit scheme,[90] representing almost a five-fold increase since introduction. However, despite the tax, there has been a rise in the amount of waste sent to landfill over the same period: in England, municipal waste increased from 20.6 million tonnes in 1996/97 to 22.1 million tonnes in 2000/01.[91] This puts into question the real effectiveness of the Landfill Tax as a policy instrument.

In 2000, the DETR[97] claimed the tax was already having a "notable impact" on waste management practices and a consultation paper[98] stated that the tax "is already encouraging some waste minimisation, re-use and recycling". On the contrary, a review of the UK Landfill Tax in 2002, commissioned by DEFRA,

Municipal waste has increased in quantity by approximately 3% per annum since 1996/7 – faster than the corresponding increase in GDP

suggests that the tax plays a limited role in encouraging people to recycle and compost and is "largely irrelevant" in helping the UK achieve the targets set out by the Landfill Directive.[92] The ineffectiveness of the tax to stimulate changes in behaviour has been attributed to its low level.[93-96]

The EU Landfill Directive

The EU Landfill Directive 1999/31/EC, which was adopted into UK domestic legislation in 2002, is the most explicit policy addressing the reduction of methane generated by landfill. It takes a dual approach, aiming to decrease reliance on landfill as a method of biodegradable waste disposal coupled with requirements to install best-practice methane recovery technologies. The Directive makes it clear that landfill is the least preferred method of waste disposal, with an emphasis on moving up the waste management hierarchy towards reuse, recovery and recycling. Compulsory installation of gas collection and disposal systems is stipulated, with emphasis on energy recovery at new landfill sites. The Directive also prohibits disposal of liquid wastes, tyres and clinical wastes to landfill and distinguishes between hazardous and non-hazardous landfill.

The long-term objective of the Landfill Directive is to reduce methane emissions at source by diverting biodegradable waste away from landfill. The Directive provides a series of targets that require reductions in the amount of biodegradable municipal waste sent to landfill. These targets have been agreed by the UK Government and Welsh National Assembly, although, since the UK is heavily reliant on landfill to dispose of its waste, it has been given an extra four years by the EU to meet the requirements of the Directive.[82] This means that the UK is required to reduce the amount of biodegradable waste to landfill to:[99]

- 75% of that produced in 1995 by 2010;
- 50%, by 2013;
- 35%, by 2020.

For the UK, this equates to a maximum of 13.1, 8.7 and 6.1 million tonnes of municipal biodegradable waste to landfill in 2010, 2013 and 2020 respectively.[82] These dates include the four year extension, which the UK is to adopt for the first two target years with the decision still to be made on the final target year.[100]

IPPC Directive

The European Integrated Pollution Prevention and Control (IPPC) Directive 96/61/EC provides further support for the reduction of methane emissions from landfill. The IPPC Directive was implemented in England, Wales and Scotland through the Pollution Prevention and Control Act (PPC) in 2000. Industrial activities subject to control under the PPC regime include certain waste management operations. The PPC demands that operators show they have systematically developed plans to apply the best available technology to prevent pollution or, where that is not practical, to reduce it to an acceptable level.

5.3 Methane capture

Under the EU Landfill Directive, from 2002, all new landfill sites are required to capture the methane produced, with energy recovery being the preferred option. A recent study has found that the largest factor in the mitigation of methane from landfill is through methane capture, rather than diversion or recycling, due to the quantities of waste already in landfill sites.[154] Historically, control of methane at landfill sites was driven by safety concerns, rather than active GHG emission control, due to the flammable nature of the gas. The most basic systems merely attempt to control the movement of the gas, with the aim of avoiding lateral migration, thereby avoiding the risk of fire and explosion at nearby facilities. Such systems comprise impermeable liners and a capping layer (usually clay), often coupled with trenches or wells, which provide convenient 'vents' through which gas can escape to the atmosphere.

Technologies have become increasingly sophisticated over the past two decades. In particular, the integrity of impermeable liners and capping layers has been vastly improved and these are now considered a fundamental component of landfill design. Improved landfill caps on new sites are the main driver behind the 61% reduction in methane emissions from landfill between 1990 and 2002 (Table 8). Additionally, a variety of systems have been developed which not only control, but also capture, landfill gas. These more advanced gas control systems operate using a network of pipes, wells, fans and/or vacuums to provide a favourable migration route to a common end point. Once collected, the gas can be disposed of by flaring or recovered for its energy value – it is a valuable fuel which has added value due to its classification as a renewable energy source under the Renewables Obligation and so any electricity generated is eligible for ROCs. It is estimated that around 63% of landfill gas is currently flared or utilised – this is forecast to rise to 72% in 2005.[155]

Flaring

Flaring involves the collection of gas into a chimney, where it is ignited in order to oxidise methane to carbon dioxide prior to emission. Flares are the simplest technology for the prevention of methane emissions to the atmosphere and are of two types: 'open flame' and 'enclosed flame'. In an 'open flame' flare, the gas is simply combusted on top of a flame burner, with oxygen coming from the atmosphere. Such combustion is largely uncontrollable and will result in sub-optimal oxidation of the methane and therefore emission to the atmosphere. Conversely, in an 'enclosed flame' flare, the gas is combusted in a chamber with both landfill gas and airflow controlled to ensure optimum efficiency (in excess of 99%) of methane combustion.[26]

All flares require a minimum concentration of methane to operate. Stable ignition requires a methane content of between 30 and 60%, although special flare designs can accept lower methane concentrations of 5-15%.[75] Methane concentrations may be too low for the flare in the early and late stages of a landfill's lifecycle, and also possibly at intermediate times due to variable gas production rates over time. Under such circumstances, the flare can be primed with natural gas or propane, although the GHG consequences of this are not ideal.[75]

Energy recovery

Energy recovery is the conversion of waste to produce useful heat or electricity. The methane content of landfill gas makes energy recovery a desirable option. One tonne of biodegradable waste is thought to produce between 200 and 500 cubic metres of landfill gas with a calorific value of up to 20 MJ per m^3 (5.5 kWh/m^3).[101-103]

In order to exploit this resource effectively, a site must fulfil a number of requirements. In particular, a site must generate a sufficient quantity of landfill gas to make methane combustion economically viable, which means current projects are restricted to sites in receipt of relatively large quantities of biodegradable waste. The methane content of the gas must be relatively high (at least 40%) and also consistent, as fluctuations in methane concentrations can

One million tonnes of landfill waste will be adequate to generate 1MW of electricity for 10 years

cause severe operational problems. In order to avoid large variations in methane concentrations, collected gas must be closely monitored and adjustments made accordingly. For example, over-pumping could introduce air into the landfill site, reducing methane production. It is possible to optimise a site for landfill gas utilisation, since factors such as landfill temperature, moisture content and pH can have a large impact on the rate of landfill gas generation and composition. Development of techniques such as recirculation of landfill leachate also have the potential to increase rates of waste decomposition and gas generation.[77] If successfully implemented, such developments will improve the viability of landfill gas utilisation and may, in particular, improve the prospects for projects on smaller sites.

Landfill gas is considered a renewable energy resource[104] and therefore displaces greenhouse gas emissions from energy derived from fossil fuels. There are three main methods of utilising landfill gas for its energy value: direct use, electricity generation and purification. A fourth option, the use of fuel cells, is still a relatively new and expensive technology, but may become more viable in the future.

Direct use

The direct use of landfill gas as a fuel (to generate heat) is the most efficient energy recovery option, utilising over 80% of the calorific value of the methane. Piping the gas over long distances has proven problematic and costly, therefore the gas is most commonly piped directly to a local heat-intensive industry, such as fuelling kilns, boilers or furnaces. However, since landfill sites are typically located away from population centres due to the unaesthetic nature of waste disposal, they are rarely located near such industrial sites. This practice has worked best if the producer of the landfill gas is also the user, so that supply and demand are closely matched.

Electricity production

Landfill gas can be combusted to drive engines or turbines for electricity generation. Fuel conversion efficiencies typically range from 26% (for gas turbines) to 42% (for dual-fuel engines), which are comparable to conventional gas-fired power stations. Production capacity varies from a few kilowatts (kW) to several megawatts (MW).[75] The electricity generated can then either be used directly or sold to the grid.

Since the 1980s, the landfill gas technology for electricity generation has evolved dramatically and the necessary equipment is now readily available on the market. Landfill gas can also be used to generate combined heat and power (CHP), although this requires a use for the heat close to the landfill site itself.

In 2003, landfill gas generated about 3.27 TWh of electricity,[105] equivalent to 24% of renewable electricity production in the UK and 1% of net UK generation. Landfill gas is by far the largest single source of new renewable electricity (*i.e.* excluding large hydro plants) – by contrast, all the wind farms in the UK generated just 1.3 TWh.

Purification to natural gas quality

Landfill gas can be cleaned to pipeline quality (100% methane) and fed into the natural gas distribution network. This process involves removing the carbon dioxide and trace contaminants from the landfill gas. The high fixed costs of refining equipment and the relatively low value of natural gas have precluded the widespread uptake of this technology.

Fuel cells

A fuel cell is a device which converts a fuel feedstock, usually hydrogen, directly into electrical energy. Fuel cells that operate at high temperatures, namely 'solid oxide fuel cells' and 'molten carbonate fuel cells', can utilise methane directly.

Fuel cells rely on expensive catalysts to function, so the feedstock entering the fuel cell must be free of impurities to prevent poisoning of the catalyst. The purity required, in terms of removing the trace elements, is even higher than natural gas quality, which provides an additional expense. However, fuel cells can operate at low methane concentrations so carbon dioxide removal is not a requirement for successful operation.

Fuel cells are currently expensive and only a few pilot projects exist for converting landfill gas to electricity. However, they do offer some significant advantages over other technologies. The efficiency of fuel cells is currently around 40%, which is higher than conventional heat engines. Furthermore, nitrogen from air does not react in a fuel cell, whereas it does in combustion devices, so nitrogen oxides are not emitted. Fuel cells are also a modular technology and so the size of the fuel cell array can be adjusted to suit the output of the landfill over time: as methane emissions decline, fuel cells can simply be removed so that the remaining stack is better matched to the supply of methane. The removed fuels cells can then be redeployed at other landfill sites.

Encouraging capture

Both flaring and energy recovery reap substantial greenhouse gas emission savings by oxidising methane and releasing only carbon dioxide. It is estimated that 1.7 Mt of methane was abated in 2000, forecast to rise to 2.47 Mt in 2005.[155] The degree of savings depends largely on the efficiency of the gas collection system. No system has yet been developed which completely inhibits the release of landfill gas to the atmosphere. In a modern landfill with a comprehensive gas collection system, an average of 85% of the gas will be collected,[25] whilst the remaining methane will migrate through the capping layer where 90% will be oxidised by methanotrophic bacteria en route.[26] So, at a minimum, methane emissions from new landfill will be just 2% of total generated methane.

Emissions from pre-1996 sites (prior to implementation of 1994 regulations) have been shown to be negligible.[156] However, since landfill sites generate significant methane for 15 to 20 years,[106] post-96 sites which have been closed because they do not meet the regulations may represent an important source of methane emissions. The extent of this issue is unclear: data on the number of landfill sites are uncertain, as are data on methane emissions from these sites. It is difficult to establish a firm baseline for emissions from this sector since methane concentration decreases over time due to natural processes.

In 2002, only 211 landfill sites in the UK extracted landfill gas for energy recovery[107] – a very small proportion, given that there are 2300 working landfill sites in England and Wales alone. The main incentive for methane capture in the UK has been through ROCs under the Renewables Obligation, which has improved cost-effectiveness of landfill gas electricity production. As of June 2002, landfill gas utilisation contracts had been awarded to around 10% of licensed sites in the UK, of which around 60% (201 of 329) were operational[108] (Table 13).

Table 13: Contracts under Renewables Obligation, December 2001

	Capacity (MWe)	
	Projects awarded	*Projects live*
England and Wales	653.4	384.6
Scotland	40.0	16.6
Northern Ireland	6.3	0
Total	699.7	401.2

Source: DUKES, 2003[105]

Further growth is expected in the foreseeable future, encouraged by the Landfill Directive, since the resource potential is far from maximised. In fact, the DTI estimates the UK landfill gas resource to be equivalent to around 6.75 TWh per year, over twice the generation in 2003 of 3.27

TWh, and representing around 2% of present electricity demand.[8]

5.4 Alternatives to landfill

In order to comply with the Landfill Directive, in combination with best-practice methane recovery, alternative waste disposal methods are necessary to reduce reliance on landfill. In effect, this means progressing up the waste hierarchy towards more sustainable waste management options.

UK Waste Strategy

The targets under the Landfill Directive pose a tough challenge for the UK, exacerbated by the current 3% annual growth in municipal waste.[70] Reducing the amount of biodegradable waste disposed to landfill will require considerable effort by the entire UK waste management chain, including central and local government, waste producers and the general public. Consequently, the UK Government's Waste Strategy 2000[97] has been developed in accordance with the principles of the waste hierarchy and wider sustainability, with a strong presumption against sending waste to landfill.

Under the Strategy, the Government has established a number of other targets to complement those for biodegradable waste reduction. In particular, the following targets have been established for the recovery of value from municipal waste, via recycling, composting and other forms of material and energy recovery:

- to recover value from 40% of municipal waste by 2005;
- 45%, by 2010;
- 67%, by 2015.

The UK has a target to recycle and compost at least 33% of household waste by 2015

Recycling and composting

In addition to diverting biodegradable waste from landfill, both recycling and composting enable value to be reclaimed from the waste. Of the biodegradable component, paper, wood and some textiles can be recycled successfully, with the resultant materials used in a range of products. Food, garden waste and cardboard can all be composted, with the residue forming a valuable organic fertiliser.

Neither recycling nor composting avoid greenhouse gas emissions. However, if managed well, both options offer significant advantages over landfill. Whilst recycling demands a significant energy input, the associated greenhouse gas emissions are relatively low when compared to those offset from both the production of virgin materials and disposal of materials to landfill. Recycling is also pivotal to resource conservation.

Composting is a largely aerobic process, meaning that the major by-product of waste decomposition is carbon dioxide. The majority of the carbon remains within the compost, hence giving it high value as an organic fertiliser. However, the process must be well managed, with the compost well mixed and regularly turned to ensure sufficient aeration, else methane can be generated under anaerobic conditions. Composting has the advantage of being feasible on a local level, for individual households, or as community compost schemes. Large scale, centralised composting systems tend to be mechanised, although the sophistication of the system can vary markedly. Highly complex systems may have the capacity for up to 100,000 tonnes of organic waste per year.[109]

Both composting and recycling depend upon separation of the waste. At the household level this may require significant education of the public, whereas on larger scales, labour is required to perform an often unpleasant task. However, mechanical biological separation schemes (see below) may offer a viable alternative that does not require separation of the waste stream.

Current situation

Recycling rates in the UK are currently amongst the lowest in Europe at 9%,[97] although they are increasing. Large scale waste composting is growing at an exponential rate and doubled in size in the two years to 2002.[110] Individual households have practised small-scale composting for many years and the UK Government is encouraging this on a wider scale.

Under the UK Waste Strategy, there is particular emphasis on improving recycling rates in the UK. These efforts have included a focus on producer responsibility, particularly with regard to paper and packaging waste. Regulations have been introduced which specify targets for the recovery and recycling of packaging waste.[111] This is supported by the 1994 EU Packaging Directive, which aims to pass the responsibility for packaging waste onto the producer thus providing an incentive to minimise such waste.

The Government has also been working with the Newspaper Publishers Association to increase the recycled content of newspapers, which had increased from 28% in 1991 to approximately 54% in 1999. Targets were introduced to increase this to 60% by 2001, 65% by 2003 and 70% by 2006. The 2001 and 2003 targets were both met ahead of schedule.[112] The Government is also working with the Direct Marketing Association and other trade bodies to reduce the quantity of junk mail, which had more than doubled between 1990 and 1999, from 1.5 to 3.3 billion junk items per year.

Table 14: Financial incentives for electricity generation from waste streams

Technology	*Useful output*	*RO eligible?*	*CCL eligible?*
Landfill	CH_4	Yes	Yes
Energy from waste	Heat	No	Yes
Pyrolysis	Oils, hydrocarbons, CH_4	Biodegradable fraction only	Yes
Gasification	CH_4, H_2	Biodegradable fraction only	Yes
Anaerobic digestion	CH_4	Yes	Yes

Energy from waste

Energy from waste (or incineration) is seen as a key technology for diverting waste away from landfill sites and is widely used throughout Europe. It is a well-developed technology, cost-effective and makes use of the calorific value of the waste material.

Energy from waste does not require the separation of waste prior to treatment and, once burned, the original volume of the waste is typically reduced by around 70%.[26] The inert ash residue is suitable for landfill and in some cases may be recycled (*e.g.* for road surfacing). Energy can also be recovered from the incineration process for district heating or electricity production. Interestingly, electricity generated from incinerating mixed (biodegradable and non-biodegradable) waste is not eligible for ROCs, whereas energy generated from landfill methane from the same initial waste feedstock is eligible[113] (Table 14). However, electricity from waste incineration is exempt from the Climate Change Levy.

The combustion of waste in incinerators does not produce any methane, since carbon dioxide is the main by-product of any efficient combustion system. There has been concern about emissions to the atmosphere of heavy metals and dioxins from municipal solid waste incinerators.[114, 115] The introduction of the Waste Incineration Directive 2000/76/EC alleviates this concern as it sets stringent operating conditions and minimum technical requirements for waste incineration and co-incineration. The Directive is aimed at

Pyrolysis plants are found in Europe but are not yet widespread in the UK

preventing and limiting negative environmental effects of emissions into air, soil, surface and ground-water from the incineration and co-incineration of waste, and the resulting risks to human health.

Current situation

More than 9% of UK municipal waste is dealt with by incineration.[116] Energy from waste technologies are almost always used – just 0.3% of waste is incinerated without energy recovery and this value is falling. The UK incinerates a smaller proportion of its municipal waste compared to other European countries, such as Denmark (52%) and France (24%).[117]

However, despite the introduction of tighter emissions controls, incineration is still socially unpopular in the UK, with incineration schemes attracting widespread opposition, especially at a community level. This makes promotion of incineration schemes a politically sensitive issue.

In addition, since any electricity generated is not eligible for ROCs there is less financial incentive to invest in this technology.

Advanced thermal treatment

Energy from waste is simply combustion of the waste in an excess of oxygen, which generates heat that may be used for electricity generation. However, advanced thermal treatment methods have been developed that also allow value to be recovered from the calorific value of waste materials. Advanced thermal treatment plants are of two types – pyrolysis and gasification – depending on the availability of oxygen and temperatures reached. Pyrolysis heats the waste to approximately 500°C in the absence of air and may be considered analogous to the formation of charcoal. This process produces oils and gas which may then be used as fuels in their own right. Gasification is a higher temperature process (1000-1200°C) which partially combusts the waste in the presence of some oxygen. This produces hydrogen and gaseous hydrocarbons which may then be combusted as a fuel.

Unlike energy from waste, advanced thermal treatment plants do require the separation of waste prior to entering the plant. Recyclable materials such as glass and metals are removed before entering the plant. Post treatment, the flue gases are scrubbed to remove particulates and higher hydrocarbons before using the gases as fuel. Advanced thermal treatment plants are comparatively small as they deal with only specialised sections of the waste stream. They can also act as a modular component for a larger waste plant, such as mechanical biological sorting plants.

Electricity generated from by-products of the advanced thermal treatment of waste is eligible for ROCs. However, only the fraction generated from biodegradable waste is eligible, so the financial returns will be dependent of the composition of the waste entering the plant[113] (Table 14).

Current situation

There are currently no demonstrated advanced thermal treatment facilities in the UK other than on a pilot scale.[154]

Anaerobic digestion

Fully-optimised anaerobic decomposition of waste is possible using purpose-built anaerobic digesters in a process known as biogasification. A wide range of biodegradable waste can be treated in this way, including wastes that are unsuitable for composting, such as meat and cooked food. Typically, biodegradable waste is separated from other material before digestion, either manually or mechanically, although newer mechanical biological separation plants can avoid this requirement.

Anaerobic digesters can reduce the time it takes for waste to fully degrade from a few decades to a few weeks, hence maximising the production of methane over a shortened time period.[26] Because anaerobic digesters are enclosed systems, more methane can be recovered, enhancing the efficiency of the system and allowing maximum value to be recovered from the waste stream. The use of anaerobic digesters also yields a more regular and sustained supply of gas compared to landfill. Between 10 and 50% more methane is produced per tonne of waste (depending on waste composition and digester design) than if sent to landfill, yet emissions are typically 1% or less.[26] The gate fees charged for taking the waste are the key economic driver behind this technology. The biogas may be burned as a fuel and is eligible for ROCs, providing an additional financial driver for investment (Table 14).[113] Greater efficiency also means that large areas are not required, although a sizeable industrial-style plant must be built. In addition to the valuable methane, the process also produces a solid digestate, which can be used to improve soil quality, and a nutrient rich liquid residue, which can also be applied as a fertiliser.

Current situation

In contrast to countries like Denmark, which uses anaerobic digestion to treat about 1.1 Mt of waste per year, this method is less common for waste disposal in the UK.[118] Sewage sludge and agricultural wastes have been treated by anaerobic digestion for several years, but the process is now slowly extending to municipal solid waste with a small number of plants in operation, each of which can handle approximately 260-300 tonnes of waste per year.[118] Encouragement to invest in such schemes already exists in the form of the waste gate fees and ROCs.[113] However, as a relatively unproven technology in the UK, additional support through grants or subsides may be necessary to stimulate the market.

Mechanical biological separation schemes

Several commercial mechanical biological separation schemes have been developed in the UK to recover value from all parts of the waste stream. In each case, the initial stage is to shred the municipal waste into small pieces. Biffa's integrated waste management process separates the biodegradable waste at this stage and sends it to an anaerobic digester. Conversely, Shanks' Intelligent Transfer Station passes all waste into an aerobic digestion chamber, which rapidly degrades biodegradable waste. Value is recovered from the rapidly biodegradable component in the form of methane and then energy. The waste material from both systems is dry, clean and sterile and can be sorted into component materials, with ferrous and glass materials recovered for recycling. Approximately 50% of the waste material, mainly cardboard and plastic, is only slowly biodegradable and is not removed by the digestion process. This material has a high calorific value and can be used as a secondary fuel in fossil fuel combustion plants capable of co-firing, where it counts as a renewable energy resource (as far as the UK's 10% target is concerned) and is exempt from the Climate Change Levy. Renewable Obligation Certificates can also be obtained if the plastic portion of the fuel is not too high.[119]

Current situation

As with anaerobic digesters, there are only a few of these schemes currently in operation in the UK. Gate fees and ROCs could provide the incentive for further investment in this area. This method of waste disposal is highly flexible and will be able to cope with the changing waste composition over the next 20 years.

5.5 Recommendations

Data uncertainties

Landfill sites are a major source of methane emissions, with significant methane generated for at least 15 to 20 years at any one site. However, there is uncertainty as to the extent of this problem due to lack of data on the exact number of landfill sites in the UK and associated methane emissions. Although it is impossible to predict how much methane is actually produced within a landfill site, the quantity of gas captured is easy to measure.

A comprehensive inventory of UK landfill sites, both working and closed, detailing the type of capping layer and other methane capturing technologies installed and amount of gas captured, is needed. This is particularly important for older and closed sites which are unlikely to utilise modern technologies and so could represent a significant source of emissions.

Policy

For maximum savings in this area, there needs to be a stronger policy focus on methane mitigation, as in the EU Landfill Directive, rather than relying solely on achieving emissions reductions indirectly through waste reduction policy.

Methane capture

The energy content of waste should be recovered wherever possible. Encouraging and supporting the installation of suitable methane recovery technologies is central to the Landfill Directive. The crucial issue is how this will be implemented in practice. The Renewables Obligation has been a key driver in encouraging energy recovery from methane in the UK by providing an economic incentive to capture as much of the generated methane as possible, relying on market-based mechanisms. This could be underpinned by the provision of grants or subsidies by the Government to encourage the uptake of best-practice technologies.

Lower production volumes of methane from landfill in future years (assuming the Directive is successful) would open up the way for new landfill gas technologies capable of operating at lower concentrations, such as fuel cells, provided there are sufficient economic incentives to attract investment. Grants or subsidies from the Government would encourage the development of such technologies.

Anaerobic digestion of waste generates electricity without any methane emissions

Alternatives to landfill

If biodegradable waste is to be diverted from landfill, as required by the Directive, support must be given to viable alternatives (without associated methane emissions) for the disposal of this waste. Given the political sensitivities around incinerators in the UK and the lack of a strong financial incentive in the form of ROCs, incineration looks to be a less politically favoured method of waste disposal. Anaerobic digesters and mechanical biological separation schemes appear to be more attractive options, with the waste gate fees and eligibility for ROCs providing economic drivers for investment. As with the methane capturing technologies, the introduction of these schemes could be further encouraged through the provision of grants or subsidies.

Waste reduction

Waste reduction still has an important role in reducing methane emissions. The problem here is not really the lack of relevant policies but merely a problem in implementation of existing policies. The UK Government's primary concern, particularly for municipal waste, is to move up the waste management hierarchy towards waste avoidance and minimisation. This requires action by manufacturers, to reduce packaging, and local councils, working with their residents to achieve widespread changes in lifestyles and attitudes.

Conflict with the Renewables Obligation

In the UK, the Renewables Obligation is one of the key drivers behind investment in methane recovery technologies through the provision of ROCs. However, the Landfill Directive also aims to reduce the amount of biodegradable waste sent to landfill. This will result in less methane being produced and so the financial rewards from generating electricity from landfill gas will be lower. Hence, there is a danger that the incentive provided by ROCs to introduce best-practice capturing and electricity generating technology at landfill sites will be lessened and other incentives may be needed in the future. However, there will be a significant delay before the impacts of biodegradable waste reduction are felt, since current landfill sites will continue to produce methane for tens of years.

Trading

Two possibilities exist for trading in the waste sector: trading the actual waste itself and trading of methane emissions from landfill.

Trading of waste

The opportunity of trading waste is currently under consideration in the UK. The system of biodegradable waste trading is a system, underpinned by the Waste and Emissions Trading Bill, which would enable waste disposal authorities to meet the objectives of the Landfill Directive and thus reduce methane emissions at minimum cost. Operating on a system of tradable allowances, those authorities that exceed their allowances by sending less biodegradable waste to landfill will be able trade the excess allowances with those that send more.[120] Such a policy tool will certainly help meet the targets set out by other waste policies such as the Landfill Directive.

Methane trading

In terms of trading, the possibilities from landfill sites are limited since methane capture is already required at all sites for safety reasons, with best-practice technology specified for new sites under the Landfill Directive. None of the methane savings would be 'additional' and are therefore not tradable. Similarly, diversion of waste from landfill to reduce methane emissions is not a viable route into the trading process either as this is also required under the Directive. Poor capping technology at older landfill sites may result in higher methane emissions and so any further reductions would count as additional. However, there is no easy way to capture the methane that leaks out through the cap – retrofits are not possible. Even if there were methane available to trade, because the market price of ROCs is currently higher than that of methane, obtaining ROCs would be the preferable option, thus removing the incentive to trade.