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A Review of the Potential Health and Environmental Impacts from Municipal Waste Management Technologies which might be used in Milton Keynes

The Environmental Protection Team, Environmental Health Division
Milton Keynes Council **July 2005**

"How mortifying then to find, that one may be employed almost a lifetime in generalising the phenomena of nature, or in gathering an infinity of evidence for the forming of a theory, and that the consequence of this shall only be to give offence, and to receive reproach from those who see not things in the same light!

While man has to learn, mankind must have different opinions. It is the prerogative of man to form opinions; these indeed are often, commonly I may say, erroneous; but they are commonly corrected, and it is thus that truth in general is made to appear."

James Hutton (1795). *Theory of the Earth.* Edinburgh.

"The major problem in marrying policy and the science which informs it is that the time-scales of the two never match. This is true almost by definition, since if there were sufficient science in place, then the problem of characterising the scientific essentials of an issue is solved and policy formulation is then determined by consideration of other issues such as the social, economic and political aspects of the problem. Unfortunately, life is generally not this simple, and one often finds that there is insufficient scientific information compared with what ideally would be required."

Maynard., R.L., & Howard., C.V. (2000). *Particulate Matter: Properties and Effects upon Health*. BIOS Scientific Publisher. Oxford.

This review was prepared by the Environmental Protection Team part of the Environmental Health Division, Milton Keynes Council:

Dr. Steven J. Moorhouse, B.Sc. (Hons), M.Sc., Ph.D., FGS. Team Leader.

David A. Parrish, B.Tech., (Hons), Pg.Dip., MIAQM., MIES. Senior Scientific Officer.

Gillian Clarke, B.Sc. (Hons), M.Sc., MCIEH, MIOA. Senior Scientific Officer.

Nicola Adshead, B.Sc. (Hons). Scientific Officer.

Matthew P. Gilbert, B.Sc. (Hons), AMIOA. Senior Environmental Protection Officer.

Dr. Christopher J. Ward, B.Sc. (Hons), Ph.D., MRSC. Senior Environmental Protection Officer.

Neil P. Crook, B.Sc. (Hons). Environmental Protection Officer.

Dr Moorhouse wrote the review with contributions from all the other members of the team. Dr Ward undertook the proof reading.

The responsibility for the content of the review, including any remaining errors or unintentional misrepresentation, is solely that of Dr Moorhouse. The review was produced to a very short time-scale of only a few weeks and is very largely based on the work of others, as listed in the References. Dr Moorhouse apologises if their work is in any way misrepresented or inadequately acknowledged in the body of the text.

Preamble

The principal author of this review, who is an environmental scientist with over 35 years post-graduate research, academic and professional experience, has attempted to be as objective and unbiased as possible in dealing with what can be highly emotive and controversial topics. Nevertheless some parts of the review necessarily represent opinion based on a professional assessment of the available evidence.

The author would like to assure readers of the report that as a father of two pre-school children living with him in Milton Keynes, he is just as anxious as any other citizen and parent to do his utmost to ensure that the best possible environmental legacy is passed on to the next generation growing up in our green and pleasant city.

The scope of this review

This review surveys the concepts used by scientists in reaching their conclusions about health and environmental impacts and summarises and assesses the available evidence concerning the potential health and environmental impacts of waste treatment techniques that might be used in Milton Keynes.

It is essentially based on three areas where questions have arisen about possible health and environmental impacts from dealing with our waste:

Part A: Introduction to Impacts, Milton Keynes & Waste
What impacts might there be on health and the environment from dealing with Municipal Solid Waste?

Part B: Concepts, Emissions and Control
How do scientists reach their conclusions about potential health and environmental impacts? Is there a universal scientific consensus about these impacts?

Part C: Potential Health and Environmental Effects and Impacts
How concerned should we citizens of Milton Keynes be about the potential health and environmental effects of dealing with the waste that we produce?

This review was produced in order to gather together the information which might be used to produce some answers to these, and similar, questions

Summary

There are two summaries available as separate documents: a 3,500 word brief summary and a 12,500 word extended summary.

Navigating around the document

The Microsoft Word version of this document contains internal hyperlinks (in blue text) and bookmarks for navigation. The pointer will change to a ‘hand’ symbol when over a hyperlink. After left-clicking and jumping to a hyperlink you can return to the source of the link by clicking the ‘Back arrow’ button (Alt+left) on the menu bar.

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Part A: Introduction to Impacts, Milton Keynes & Waste

1. Introduction and overview of the local environment

1.1 Introduction to the most recent research

A recent lengthy and detailed report published by DEFRA (Enviros *et al.* 2004, "the DEFRA report") concluded that on the evidence of scientific studies so far Municipal Solid Waste (MSW) disposal has "at most a minor effect on human health and the environment".

The DEFRA report, after reviewing all the available evidence, concludes:

- burning municipal solid waste accounts for less than 1% of UK emissions of 'dioxins', while domestic sources such as cooking and burning coal for heating account for 18% ('bonfire night' alone is believed to account for 14% of annual UK 'dioxin' emissions);
- less than 1% of UK emissions of oxides of nitrogen, which reduce air quality, come from municipal solid waste management, while 42% come from road traffic;
- in some areas the science is less certain as there has been less investigation, including emissions to soil and water rather than air, and emissions from waste management techniques other than incineration and landfill, such as composting and mechanical biological treatment.

The report found no evidence of a link between the rates of cancer, respiratory diseases and birth defects and the current generation of incinerators, nor any "convincing" evidence that emissions from modern landfill sites harm health.

The report refers to one study which had reported a statistical link between birth defects and residence near landfill sites but that the study's authors themselves were clear the link they reported did not show that these health effects were caused by the landfill site.

Referring to the report's conclusions about incinerators the Environment Minister Elliot Morley said: " The report was not giving the green light for a new generation of incinerators to be built across the UK: it was simply saying that burning waste was at least no worse than burying it in landfills". He went on to say "This report is not a clear steer on incineration, but what it does is put incineration as an option in perspective. It's a fair assumption that there's no health reason why local authorities shouldn't opt for incineration, especially with energy recovery".

However, a review of the report by The Royal Society (the UK's premier scientific body) says that the final report addressed many of their concerns about the draft version but "we have stressed the need to clarify the uncertainties inherent in the data in this report and consider the implications this uncertainty has when evaluating the environmental and health effects of waste management" (Appendix 4 of the DEFRA report).

The National Society for Clean Air was welcoming, saying: "We hope the report will put an end to scaremongering over the health impacts of waste management facilities like incineration."

But Friends of the Earth, said: "This report fails to adequately consider the environmental benefits of recycling, or the wider global environmental impacts of the way we manage our waste, and must not be used as a green light for increased incineration." (Quotes from BBC News:http://news.bbc.co.uk/2/hi/science/nature/3690677.stm).

Clearly, in spite of this report being the most detailed and wide-ranging ever produced in the UK on the health and environmental impacts of waste management there is still a wide spectrum of views on this subject. Some of these views may be driven more by socio-political motives rather than any objective assessment of the scientific evidence. However, it is not necessarily the case that an objective scientific appraisal (assuming that is possible) is any more valid to society as a whole than the 'socio-political' conclusions reached by the general public and their representatives both from political organisations and environmental pressure groups.

1.2 The concept of health and environmental impacts

1.2.1 What is an impact? Are they always negative?

Waste treatment tends to be thought of in an unremittingly negative way, it's dirty, dangerous and best kept as far away as possible. But there are positive impacts from treating our waste collectively. Without centralised collection and treatment the health and environmental impacts would be very severe. Waste is now treated as a resource; we can reclaim materials and energy from waste rather than just dump it in a hole in the ground.

1.2.2 Can environmental impacts be separated from health impacts?

It can be argued that any effect on the environment, for example global warming, will have an impact on human health, eventually. It is just a matter of time. Care has to be taken that actions to minimise short-term health risks do not produce a negative impact on the environment leading to a health risk in the longer term. For example, catalytic converters on cars reduce the level of nitrogen dioxide (a health hazard) in the air but increase the amount of nitrous oxide (a 'greenhouse gas'). We need to minimise all negative impacts.

1.2.3 Whose health is most at risk? Residents or workers in waste?

As shown by the DEFRA report there is little or no evidence which shows direct health impacts from waste treatment sites on people who live near the sites. However, there is some evidence of significant health effects on workers in certain waste sites, which emphasises the need for strong occupational exposure limits to hazardous materials and the necessity for good personal protective equipment.

1.2.4 What potential health effects are of particular concern?

All the available research to date shows little, if any, causal connection between emissions from MSW treatment and health effects. However, the type of health effects which might arise from particular chemical emissions are listed in Table 1.1.

Table 1.1 Type of health effect produced by specific emissions	
Potential health effect	**Type of emission**
Eye irritation	**Volatile organic compounds (VOC)**
Bronchitis	**Particulate matter, sulphur dioxide SO_2**
Irritation of lung & throat; increased susceptibility to respiratory infection	**Sulphur dioxide SO_2**
Lung irritation; asthma attacks	**Nitrogen dioxide NO_2**
Reduction in oxygen-carrying capacity of blood impacts on the brain, nervous tissue, heart etc.	**Carbon monoxide CO**
Effects on central nervous system	**Pb, Mn, CO**
Effects on immune system	**Benzene, Cr, dioxins, Pb, Hg, PAH, PCB, Ni, toluene, vinyl chloride,**
Reproductive effects	**As, benzene, Cd, chlorinated compounds, Pb, Hg, PAH, PCB**
Cancer	**As, benzene, Cr, dioxins, Ni, vinyl chloride**
Effects on the liver	**As, chloroform, PCBs, vinyl chloride**
Effects on the kidney	**As, Cd, Cr, halogenated hydrocarbons, VOC, pesticides**

Key: As arsenic; **Cd** cadmium; **Cr**, chromium; **Pb** lead; **Mn** manganese; **Ni** nickel; **Hg** mercury; **PAH** polycyclic aromatic hydrocarbons; **PCB** polychlorinated biphenyls.

Landfill sites and incinerators have been investigated as possible causes of increased birth defects, cancers and respiratory illnesses including asthma, potentially associated with airborne emissions. 'Dioxin' emissions from incinerators have been particularly studied. Composting sites and Materials Recycling Facilities (MRFs) have been investigated for emissions of bioaerosols and odours and in connection with disease such as bronchitis.

1.2.5 What potential environmental effects have raised concerns?

The main environmental effects of concern are that emissions might affect global warming or cause increases in acid rain. The global warming potential (GWP) of MSW is estimated to be 2.32 tons of carbon dioxide per ton of landfilled waste. One ton of methane is equivalent to 25 tons of carbon dioxide in terms of 'greenhouse gas potential 'and emissions of methane from MSW in landfill sites are believed to represent about 27% of total UK methane emissions. Acid gases, which might contribute to acid rain, are given off from all combustion processes, including transportation of MSW (combustion of petroleum products).

1.3 Overview of the Environment of Milton Keynes

1.3.1 Air quality

Milton Keynes Council's Environmental Protection Team has recently completed the Local Air Quality Management Progress Report for 2005. This statutory publication contains a summary of new air quality monitoring data since the last report and lists new local developments that might affect local air quality. The report showed that improvements in air quality were recorded in 2004 when compared with 2003 data and that all national Air Quality Objectives are expected to be achieved throughout Milton Keynes by the relevant date.

Other towns in the South Midlands area of the UK, such as Northampton and Bedford, are not so fortunate in their air quality having predicted exceedances of Air Quality Objectives and as such have declared Air Quality Management Areas. The reason for the relatively good air quality in Milton Keynes, when compared to towns such as these is attributable to the lack of heavily polluting industrial processes and low levels of road traffic congestion due to the wide grid style road network. The new parts of Milton Keynes were also planned so that sensitive receptors are located away from the grid road routes and the population reaps the benefit of this foresight in better than average air quality.

Thus any MSW management facility in Milton Keynes will need to have the very highest quality air pollution control technology in order not to have any significant negative impact on the overall very good air quality in the area.

Despite its relatively good air quality, Milton Keynes Council still takes a proactive approach to air pollution and the Environmental Protection Team operates an extensive air quality monitoring network and is currently working towards a countywide air quality strategy with other local authorities in Buckinghamshire.

1.3.2 Water quality

With the exception of those properties with their own private water supply the drinking water in Milton Keynes is supplied by Anglian Water.

The majority of drinking water supplied to the borough is from Grafham Water, a major surface water storage reservoir in Cambridgeshire. Treatment works at Sandhouse and Wing also supply water to some properties in Milton Keynes. Sandhouse draws its water from deep boreholes in the Lower Greensand aquifer, whilst Wing is supplied from Rutland Water, a major raw water storage reservoir.

Because the drinking water is supplied from locations outside Milton Keynes it is highly unlikely that any MSW management facility could have any impact on the local water supply.

Each year Anglian Water release a Drinking Water Quality Summary Report and a detailed report on drinking water quality for the borough of Milton Keynes. Overall the quality of water supplied during 2004 was high and 99.95% of tests complied with mandatory standards set out in the Water Supply (Water Quality) Regulations 2000 (Anglian Water Services Limited, 2005). The Drinking Water Inspectorate (DWI) also releases an annual report on drinking water quality in the England. In 2004 Anglian Water was ranked 9 out of 23 for percentage of compliant tests (DWI, 2005).

Copies of the Drinking Water Quality Summary Report 2004 can be obtained from Anglian Water Services Ltd (Tel. 0800 91 91 55).

The Drinking Water Inspectorate Chief Inspectors Report can be viewed or downloaded from the DWI website http://www.dwi.gov.uk/

In Milton Keynes there are also 18 private water supplies providing water to 44 properties. These are all situated in the north of the borough. The regulation of the quality of the supplies is the responsibility of Milton Keynes Council. Most are single dwellings that do not require monitoring under the Private Water Supply Regulations 1991, however, two supplies, which provide drinking water to multiple properties, require annual sampling.

1.3.3 Land quality

Much of Milton Keynes is fortunate, in terms of the quality of its land, in being built on what was prior to the 1970's 'greenfield' land. Nevertheless there are areas of Milton Keynes where the land has been impacted by previous use. Examples include former railway land in Wolverton, the Bletchley Light Maintenance Railway Depot, the former tannery and gasworks sites in Olney and a number of closed landfill sites.

Milton Keynes Council is responsible for carrying out the provisions of Part IIA of the Environmental Protection Act 1990, which deals with investigating and if necessary remediating land which has been contaminated by some previous use. The Milton Keynes Council Strategy for Contaminated Land was produced by the Environmental Protection Team in 2001 and copies are freely available by contacting the Team (details below) or it can be found on the Council's web site at:

http://mkweb.co.uk/environmental-health/documents/CL_STRATEGY.DOC

1.3.4 Noise & vibration

Milton Keynes is fortunate in that there are relatively few sources of potentially intrusive noise compared to other built-up areas of similar size. The main sources of environmental noise exposure are road traffic, rail transport and industrial noise.

In Milton Keynes, this is mainly from the M1 and the A5 roads, and the West Coast railway line, which runs approximately north-south through Milton Keynes. Although Milton Keynes does have commercial noise sources, these are highly localised and of minor overall effect. The grid square planned layout of the new parts of Milton Keynes means that generally, major noise sources are separated from sensitive receptors, such as housing and schools by distances which significantly reduce the perception of noise.

As such Milton Keynes compares favourably with agglomerations of similar size. Traffic flows are for example, a fifth of those of comparable London Boroughs, and well dispersed over the city. With a population increasing above average, Milton Keynes can expect an above average increase in traffic flow. However, it will be many years before this results in significant increases in traffic noise levels. In addition, programmes of traffic noise mitigation on the major highways will have a beneficial future effect. For example, use of low noise resurfacing materials, and noise attenuation bunds and screens, to the M1 and A5 could significantly reduce their acoustic impact.

1.3.5 Odour and dust in Milton Keynes

The main sources of odour, leading to complaints from residents in Milton Keynes, have been from activities producing hydrogen sulphide at the landfill site at Bletchley, the agricultural spreading of organic fertilisers by farmers and emissions from brick kilns at the Stewartby brickworks operated by Hanson Brick. in nearby Bedfordshire.

Bletchley Landfill Site

Commencing in January 2001 complaints were received of gas-like odours in the Bletchley area. The odour was caused by hydrogen sulphide emissions formed from the breakdown of calcium sulphate (‘gypsum’) waste in the landfill. Following completion of works in August 2001, which included improved landfill gas collection, removal and flaring, leachate management, and capping, there have been no further complaints attributable to hydrogen sulphide from the Bletchley Landfill site. In total 412 complaints were received about odour believed to come from the landfill site in 2001, compared to 26 in 2000 and 73 in 2002 (investigation showed that a significant number of the 2002 complaints were actually caused by agricultural odours not the landfill). The Environment Agency regulates the site and Milton Keynes Council has no direct regulatory control over on-site activities.

Agricultural Spreading

Some odour complaints are received by the Environmental Health Division, particularly during late summer, as a consequence of the spreading of organic manures on farmland. In addition, an agricultural operator based at Drayton Road, Bletchley stores chicken manure on site and also applies and incorporates it into their fields adjacent to Bletchley landfill. This particular operation has caused frequent complaints of odour nuisance, in spite of it meeting all appropriate regulatory controls. Farmers must operate using the “best practicable means” in order to minimise odour emissions from spreading. Checks are made to ensure farmers comply with the Codes of Good Agricultural Practice, however, some odour generation during spreading operations is unavoidable and may still give rise to complaints. An area of uncertainty in regard to agricultural spreading is in respect of emissions of bioaerosols. Spreading actions must generate them but there is no specific regulatory control mechanism, which may be applied.

Stewartby Brickworks

Complaints are often received about the characteristic “burnt rubber” odour from Stewartby brickworks operated by Hanson Brick. This occurs frequently when an easterly wind blows the emissions over the southern part of Milton Keynes. This has a distinctly negative effect on air quality, in particular the levels of sulphurous compounds in the air. The Environment Agency regulates the brickworks and as a consequence Milton Keynes Council has no control over this process.

Dust in Milton Keynes

There are no specific issues that cause adverse dust emissions in Milton Keynes. However, in common with all local authorities complaints are received by the

Environmental Health Division about dust, usually from construction site operations. These problems are usually solved with the co-operation of the site management, normally by spraying with water. However, on occasions formal abatement notices (under the Environmental Protection Act 1990) have been served requiring operators to take measures to control dust emissions.

1.3.6 Obtaining information on the local environment

Further information on any aspect of the local environment can be obtained by contacting the Environmental Protection Team, Environmental Health Division, Milton Keynes Council, PO Box 105, Civic Offices, 1 Saxon Gate East, Milton Keynes MK9 3HH (ehept@milton-keynes.gov.uk; 01908 252398)

2. Techniques and technologies for dealing with MSW

2.1 Management of Waste

2.1.1 The UK government strategy for managing waste

The Government's strategy for managing waste was published in "The Waste Strategy 2000" (DETR 2000). The strategy was strongly influenced by the idea of sustainable development first described in the 1992 United Nations Earth Summit. This underpinning idea involves striving to strike a suitable balance between continued economic development and the need to protect and enhance the environment. Sustainable development is "development which meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland Report 1987). With regard to human health protection, the Waste Strategy refers to the recently adopted Landfill Directive with its stringent controls on new high temperature incinerators.

Clearly the waste management options chosen by waste authorities could impact on human health both directly and indirectly. Directly, by leading to potential positive and/or negative health impacts such as increased risk of cancer or decreased quality of life. Indirectly, via environmental impacts on global ecology, such as 'greenhouse gas' contribution to global warming, loss of bio-diversity and the depletion of non-renewable resources.

The government strategy includes the concept of the Best Practicable Environmental Option; i.e. "the option that provides the most benefits or the least damage to the environment as a whole, at acceptable cost, in the long term as well as in the short term". The Best Practicable Environmental Option is likely to be a mix of different waste management methods and the strategy proposes a "waste hierarchy" (Table 2.1).

A holistic approach to waste management and potential health impacts

The most effective solution is to reduce the generation of waste, the option at the top of the hierarchy. Only when the options at the top are not appropriate should disposal of waste be the option of last resort (Table 2.1). Use of such a holistic approach is a fundamental principle in the professional practice of Environmental Health. Its adoption in the field of waste management would represent a significant advance in controlling and reducing any health and environmental risks associated with particular waste management options.

However, there are major difficulties in adopting this approach. It will require integrated waste management systems, including the separation of waste into different categories, rather than treating it as a single composite material. In order to avoid introducing toxic materials into household items it will also require far-reaching changes to production systems putting considerations about product end of life management at the beginning of the design phase rather than tacking it on as an afterthought. For example, the use of cadmium and other potentially toxic metals in printing inks and plastic stabilising agents.

The current waste management system has to deal with many potential health risks from discarded materials precisely because these risks have not been considered at an early stage in the materials cycle of utilising resources and producing goods. The final stage of the materials cycle i.e. the disposal stage, has in the past been all too often forgotten resulting in health risks during disposal which are directly attributable to actions taken at the earlier stages of production, packaging and marketing.

For example, take toxic heavy metals in discarded materials. It is manifestly obvious that the most difficult and expensive method of reducing the risk of negative impacts from such metals on both human health and the environment is to take action after waste processing techniques have dispersed the metals into the environment.

Waste management is much more than the simple disposal of waste. It involves the generation, collection, transport and processing of waste, in addition to minimising waste production and incorporates the socially difficult concept of waste as a valuable resource. Clearly potential public health and environmental impacts are strongly influenced by the availability of safe, modern, well managed waste processing techniques within the overall waste management strategy adopted locally, regionally and nationally.

Table 2.1	**The Waste Hierarchy**	
Best option	**Reduction**	**Most desirable**
	Re-use	
	Recovery:	
	Recycling – Composting - Energy	
Option of last resort	**Disposal**	**Least desirable**

2.1.2 Types of waste

Waste is divided into controlled and uncontrolled waste depending on what legislation is used to deal with it.

(a) Controlled waste is covered by the Environmental Protection Act, 1990 (EPA) and the Control of Pollution Act, 1974 (COPA), it comprises five types:

- **(i)** **Household waste** from domestic premises including collected waste, waste collected for recycling and composting, waste deposited at civic amenity sites, waste from prisons, schools, campsites (legal and illegal), household hazardous waste (e.g. paint residues), household clinical waste, street sweepings and litter.

- **(ii)** **Special or hazardous waste,** controlled waste of any kind that may be dangerous to treat – covered by the Special Waste Regulations, 1996.

- **(iii)** **Industrial waste** from hospitals, commercial garages, laboratories, workshops, ships aircraft, premises for animals, dredging; including waste oils, scrap metal, noxious waste from certain processes (e.g. paint mixing, dry cleaning), and nuclear waste.

(iv) **Commercial waste** from offices, hotels, clubs, showrooms, private garages, markets, government departments, council offices, parks and gardens, corporate bodies.

(v) **Sewage sludge,** when it is landfilled or incinerated.

(b) Uncontrolled waste is covered by separate legislation and comprises four types:

(i) **Agricultural waste** including manure, slurry, crop residues animal treatment dips, packaging.

(ii) **Mining and quarry waste.**

(iii) **Explosive waste.**

(iv) **Sewage sludge**, when it is spread on agricultural land.

2.1.3 What is municipal waste?

In Britain, municipal waste is defined as waste collected by, or on behalf of, local authorities and includes:

Household wastes accounting for 89% of Municipal Solid Waste (MSW)

Household hazardous wastes.

Bulky wastes derived from households.

Sweepings and litter from street cleansing.

Park and garden wastes.

Non-hazardous trade wastes collected by local authorities.

Institutional wastes from schools, etc.

In the UK, taking into account all waste arisings, 430 million tonnes of waste was generated in 2000/01. Approximately 7% of this (28.8 million tonnes) was MSW (Office of National Statistics, 2003; DEFRA 2003).

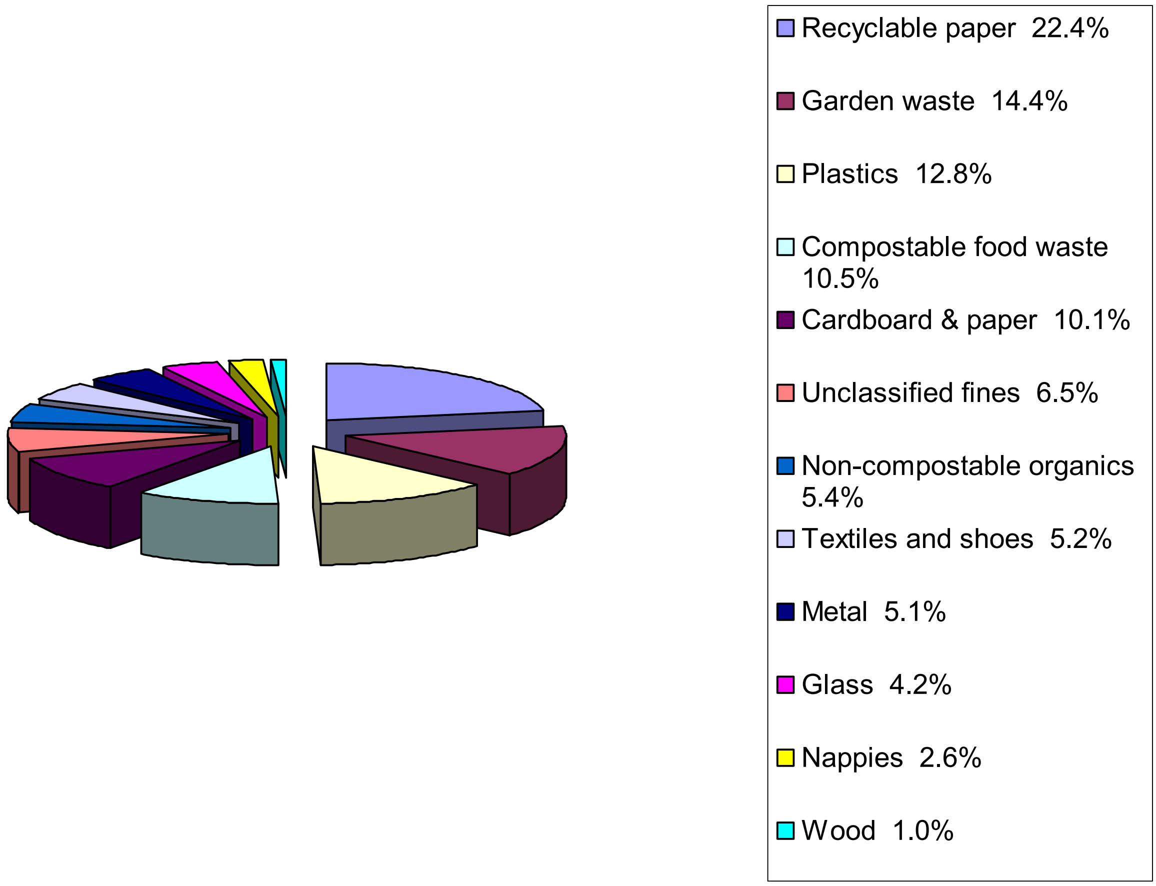
2.1.4 How do we dispose of it?

About three quarters of the UK's municipal solid waste is disposed of directly to landfill. Reuse and recycling (including composting) account for a further 13% of municipal solid waste. The remainder is pre-treated, mostly by incineration (approximately 9% of municipal solid waste). The remaining 1% is pre-treated using a variety of new or specialist methods which include gasification/pyrolysis; mechanical biological treatment (MBT); and anaerobic digestion.

2.1.5 The composition of municipal solid waste

Municipal solid waste comprises a variety of materials (Figure 2.1). It is a very variable material, dependant on a range of factors, including where and when it is collected. Household waste reflects population density and economic prosperity, seasonality, housing standards and presence of waste minimisation initiatives (for example home composting). The make-up of commercial waste will be influenced by the nature of commerce in a local area (Strange, 2002).

Figure 2.1 Composition of Municipal Solid Waste



(Source Enviros *et al.* 2004)

The fact that MSW varies with time and social conditions is emphasised by comparing modern MSW with that collected in the 1950's (Table 2.2). The overwhelming preponderance of ash in the 1950's relates to the fact that domestic heating was largely due to open coal-burning fires.

In Milton Keynes 124,685 tonnes of MSW was dealt with in 2004/2005. Some 68% of this was biodegradable material of which 26.6% was diverted from landfill by means of recycling, recovery and composting initiatives. The relative proportions of materials are comparable with those in Figure 2.1.

Table 2.2 Composition of refuse in the UK (1950s)	
Material	**Composition (weight %)**
Fine dust/large cinders (ash)	81.61
Bricks, pots / shards	6.5
Vegetable matter	4.05
Miscellaneous	2.4
Paper	2.26
Tins	1.3
Glass	0.83
Rags	0.54
Scrap iron	0.42
Bones	0.09

(Source: Encyclopaedia Britannica 1953)

2.1.6 Waste avoidance and reduction

Ideally we should all, corporately and privately, as far as possible avoid creating waste, particularly waste which requires centralised municipal collection and disposal. In a truly sustainable society there would be no waste, with materials discarded in one area being used as the raw materials for another process. Arguably a no waste society is not practicable, at least in the short term, as it will require major changes in patterns of consumption and economic growth. However, there is widespread agreement that nationally and locally we should set a target of 'no waste' as there are major health and environmental benefits to be obtained by reducing the amount of waste we produce as far as possible.

There are three main ways in which this can be done:

(a) **Waste minimisation** (Table 2.3), for example by wherever possible repairing products for continued use rather than replacing them; reducing packaging to a minimum e.g. reusing shopping bags, reducing the size of boxes etc. This is the most sustainable form of waste management but it is not something that can be solely implemented by waste management authorities acting in isolation because to be truly effective it requires major changes to society. To be really effective it will require every part of our society to be actively involved in every stage of the life cycle of every product, from extraction of raw materials, through transport, design and manufacturing, retailing, consumption and beyond.

Table 2.3	Waste minimisation
Advantages	**Disadvantages**
Local Authorities can lead by example.	Many actions necessary to reduce waste are beyond the powers of Local Authorities.
Conservation of resources, environmental & cost savings associated with production.	Investment needed in some manufacturing processes may have very long payback time.
Reduced costs of collection and disposal.	Requires major economic, social and psychological changes.
Reduction in hazards from waste and lower emissions from waste management.	Immediate action needed to deal with waste being produced now.
Reduction in greenhouse gas emissions.	
None of the disadvantages involve negative health or environmental impacts.	

(b) Product re-use (Table 2.4) e.g. by passing unwanted materials on to others; for example this can be done privately, via charities or via the Milton Keynes Council Community Recycling Centres.

A number of re-use initiatives are described in the Waste Strategy 2000 (DETR 2000) including bring-back schemes, refurbishment and reconditioning centres, and educational projects to encourage consumers to re-use products.

Table 2.4	Product re-use
Advantages	**Disadvantages**
Energy, raw material and emissions savings due to reduced need for new products.	Costs & emissions associated with the infrastructure and transport needed for return/refilling systems could outweigh the environmental benefits of re-use.
Cost savings for consumers and businesses.	Requires social and psychological changes to be fully effective.
Reduction in hazards from waste and lower emissions from waste management.	Necessary to extend useful life of products and not discard before absolutely necessary.
Reduction in greenhouse gas emissions.	Increased use of resources to make products more robust to last longer.

(c) Home recycling and composting (Table 2.5). Recycling is the recovery of materials from products after consumers have used them.

Table 2.5	Home recycling and composting
Advantages	**Disadvantages**
Raw material savings and source of raw materials to industry.	More energy may be used for processing than original manufacture in some cases.
Useful compost material for garden or allotment.	Significantly higher levels of microbial agents found in houses that separate organic waste and store it indoors
Reduction in hazards from waste and lower emissions from waste management.	Composting releases carbon dioxide, a 'green house gas'; emissions from transport collecting recyclables.
Reduction in waste going to landfill or treatment elsewhere.	Unstable markets for recycled materials.

Recycling is often divided into two types: (i) Materials recycling; (ii) Composting of biodegradable materials, which here is considered as a biological treatment process.

Recycling can be carried out both at home and centrally as part of MSW management. In Milton Keynes we are fortunate in having a kerb-side collection scheme for paper, cans, plastic bottles and glass, with a separate scheme for 'green waste'. However, we can still take other materials ourselves to recycling collection points, such as large cardboard items and textiles. Home composting of 'green waste' can also make a significant contribution to the minimisation of waste.

2.2 Techniques for treating MSW – advantages & disadvantages

Waste treatment techniques can be grouped into five categories, see Tables 2.6 to 2.18: Municipal Solid Waste Treatment Processes.

2.2.1 Mechanical Processes – Materials Recycling

Materials recycling is one of the principle mechanical processes for dealing with waste. It is the recovery of materials from products after consumers have used them. Recycling of fractions of MSW is usually carried out in dedicated facilities known as Materials Recycling Facilities (MRFs) such as the one in Milton Keynes. Prior to entering a MRF the waste materials have normally been pre-segregated in some way by the householder, for example in Milton Keynes paper, cans and plastic bottles into pink sacks, glass into blue boxes. However, further sorting is almost always required and MRFs are widely used for this in the UK.

Table 2.6	**Mechanical Processes**
Treatment	**Definition**
Remove objects **Reduce size** **Extract recyclables** **Produce resources**	**The simplest process for dealing with MSW, this normally involves:** **Removing bulky objects; reducing the particle size of the waste; extracting recyclables, e.g. metals; producing refuse derived fuel (RDF) and compostable organics.** **The RDF can be used for energy recovery by Advanced Thermal Treatment or co-fired in an existing facility e.g. cement kiln.** **The compostable materials can be treated by In Vessel Composting or Anaerobic Digestion both of which may be ABPR (animal by-products regulations) compliant.**

There are various types of MRFs, but in the UK they deal with source segregated, dry recyclable materials (such as paper, plastic, glass, metal textiles etc.), which are sorted mechanically or manually and processed into secondary materials. Most MRFs in the UK do not deal with biodegradable materials (ones that do are known as 'dirty MRFs'). Some MRFs have only limited sorting and processing; others involve more advanced mechanical or manual separation. MRFs may be part of other waste processing facilities, such as waste transfer stations, or they may be separate facilities dealing entirely with the recyclable portion of MSW.

Recycling may result in an overall reduction in negative health and environmental effects due to a lower requirement for raw material extraction and processing together with a reduction in the amount of material requiring landfilling or other treatment. For example, glass cullet derived from recycled glass improves glass-furnace efficiency compared to the use of raw materials alone. On the other hand there are potential negative impacts of recycling materials derived from MSW including impacts from the reprocessing operation and transport of materials to and from the facility.

Table 2.7	Materials recycling
Advantages	**Disadvantages**
Raw material savings and source of raw materials to industry.	More energy may be used for processing than original manufacture in some cases.
Reduction in some emissions to air and water from production processes.	Emissions from transport to and from site.
Reduction in hazards from waste and lower emissions from waste management.	Dust and bioaerosols proven health hazard to site workers requiring risk management.
Less waste to be dealt with by other processes e.g. landfill or incineration	Potential for problems from odour, noise and vermin if not properly managed.

2.2.2 Biological Processes (Tables 2.8, 2.9)

(a) Composting

Table 2.8	Composting
Advantages	**Disadvantages**
Reduces the volume of waste requiring landfill or treatment. Up to 68% of MSW is biodegradable and can be removed by composting.	Potential for problems from odour, noise and vermin if not properly managed (also true for other MSW facilities).
Can produce 'compost' suitable for soil improvement in gardening, landscape and agriculture.	Limited market for 'compost'; if not properly controlled the 'compost' is unusable and may have to be landfilled.
Reduced potential for emissions from landfill or other waste treatment.	Emits: volatile organic compounds and bioaerosols – potential health hazard to nearby residents; CO_2 - contributes to global warming; emissions from transport of waste & compost; liquid effluent requiring containment and disposal.
Increased employment opportunities at central facilities (also true for other MSW facilities).	Dust and emissions, especially bioaerosols, proven health hazard to site workers requiring risk management.

These processes can take place in the open or in enclosed buildings ('windrow' composting); or as 'in-vessel' composting inside closed vessels (see Table 2.9). Essentially these processes involve the controlled biological decomposition and stabilisation of the organic materials fraction of waste, such as vegetable; plant and sometimes food wastes, generating biologically produced heat.

Table 2.9	**Biological Processes**
Treatment	**Definition**
Centralised Composting:	**Uses micro-organisms to break down organic waste in the presence of air (aerobic) producing heat resulting in a stabilised and sanitised humic material rich 'compost'. The compost may have a market value, if free from contamination, and be suitable for adding to soil. Or the process may be used as a pre-treatment step. Normally uses the green waste fraction of pre-sorted MSW or specific organic waste collected separately e.g. garden (green) waste, kitchen waste, catering waste; it is also used for sewage sludges and agricultural and industrial bio-products.**
Windrow Composting	**Windrow composting normally uses only green waste and is carried out in the open air, or enclosed in a building. It is difficult to control the environmental conditions and the actions of pests; the emissions are less controlled than IVC.**
Biological-Thermal: In Vessel Composting (IVC)	**In vessel composting is being increasingly used. Where food waste is involved, this requires in vessel or enclosed systems. The process can be sufficiently tightly controlled to achieve and maintain temperatures high enough to facilitate bacteria/pathogen destruction that will satisfy the provisions of the Animal By-products Regulations (ABPR). May also accept certain commercial wastes e.g. catering waste, due to be banned from landfill under ABPR.**
Biological-Thermal: Anaerobic Digestion (AD)	**Bacteria decompose biodegradable wastes, in the near absence of oxygen in an airtight vessel (a 'digester'), under elevated temperatures, in much the same way as organic wastes degrade in landfill sites to produce methane but under accelerated controlled conditions. This leads to the production of a 'digestate' containing bio-solids that may be suited for application to land (if of suitable quality) and/or a liquid, and 'biogas', comprising methane & carbon dioxide, which can be used as a fuel to produce heat and/or electricity. Used to deal with certain high organic content sewage sludge or agricultural wastes but not widely used for MSW in the UK.**

In-vessel composting and anaerobic digestion, because they take place in sealed containers, can generate temperatures high enough to be able to deal with food waste, including catering waste, in a manner that is compliant with the Animal By-products Regulations. These processes can be regarded as hybrid biological-thermal processes (Table 2.9).

The final product is a sanitised and stabilised material rich in humic substances usually referred to simply as 'compost'. If it is free from contamination it may be beneficially applied to land as a soil conditioner. Composting is used as a treatment process for a wide range of materials including municipal solid wastes, sewage sludges and agricultural and industrial organic wastes.

(b) Anaerobic Digestion (AD) is the degradation of organic wastes in the near absence of oxygen by mixed microbiological cultures. The biological process is equivalent to that which takes place in the anaerobic sub-surface zone of landfills where methane is produced. Here it is used as a managed process in enclosed vessels where the feedstock is circulated and usually heated using some of the self-generated gas. It has been used for many years for the treatment of agricultural and sewage sludges. Although generally more expensive than composting, the process does have the advantage of producing gas (principally methane and carbon dioxide) which can be used for energy recovery, in addition to solid and liquid residues. After the in-vessel processing the digestate is dewatered and the solid and liquid fractions treated as necessary for subsequent disposal or use. For example, the solids can be composted aerobically to mature the residue for use on land and the liquids disposed to sewer.

Anaerobic Digestion is currently used in the UK to treat sewage sludge, some agricultural and industrial wastes and some waste waters. It has been promoted as being suitable for the treatment of mixed organic municipal waste in addition to source segregated organic waste in several European countries and there are successful commercial operations in several European countries using this technique for municipally derived organic wastes.

Table 2.10 Anaerobic Digestion

Advantages	Disadvantages
Reduces the volume of waste requiring landfill or treatment. Suitable for highly flammable, volatile, toxic and infectious waste, which should not be landfilled.	**Cost of separation from unsustainable wastes, needs careful screening to remove contaminants, particularly metals.**
Possibility of using remaining inert material as a soil conditioner.	**Limited market for such materials; can produce residue that requires landfilling.**
Reduced potential for emissions from landfill or other waste treatment.	**Biogas burning produces CO_2 and possibly other emissions.**
Produces biogas for energy production.	**Requires controlled conditions and careful management to optimise gas production. Gas may require cleaning before use to prevent hazardous emissions**

2.2.3 Thermal Processes (Table 2.11)

(a) Introduction and history

The overwhelmingly preponderant thermal treatment process in the UK is incineration (Table 2.11), even so only 9% of MSW is incinerated. Advanced Thermal Treatment (ATT), either pyrolysis or gasification, is currently only in use at pilot scale in the UK. All these thermal processes, including mass burn incinerators, are capable of meeting the requirements of the new EC Incineration Directive (2000/076/EC), with respect to gaseous and gas-borne emissions to air, albeit only after major investment in flue gas cleaning equipment. One of the major differences between these processes is in the nature of the solid residues, and the utilisation and/or disposal requirements for these residues, and also in the total releases of 'dioxins'. Some of the ATT techniques produce a fused ash product, which has environmental advantages because the ash is suitable for recycling and is preferred over the fly and bottom ash outputs of conventional incinerators. Those ATT processes that do not produce a fused ash may be at a significant disadvantage because there may be a necessity for additional processing of the ashes and other residues, prior to disposal.

Table 2.11	Thermal Processes
Treatment	**Definition**
Incineration with energy recovery: Energy from Waste (EfW)	**Combustion of mixed waste under controlled conditions, to substantially reduce its volume and hazardous properties (such as destroying pathogenic organisms and volatile organic compounds), generating electricity and occasionally heat. It uses a wide variety of combustion systems developed from boiler plant technology and also more novel systems such as fluidised bed gasification (FBG) where combustion occurs on a bed of inert and or ash fluidised through-flow of air. Principal residues produced are: bottom ash, which is non-hazardous and can generally be recycled as an aggregate; metals which can be recovered for recycling; fly ash and air pollution control residues which are classed as hazardous and requires specialist treatment/disposal.**
Advanced Thermal Treatment (ATT): Pyrolysis	**A thermal process (400-700^{0}C) where organic based materials are broken down under the action of applied heat in the near absence of oxygen to produce a mixture of gaseous and liquid fuels and a solid char fraction (mainly carbon). Most technologies prefer a homogenised feedstock containing limited non-organics. The outputs may be used as a fuel to generate electricity, while others may require disposal or additional processing for recycling/energy recovery. May be combined with gasification to maximise production of 'syngas'.**
Advanced Thermal Treatment (ATT): Gasification	**A high temperature (800-1200^{0}C) thermal process, similar to pyrolysis but involving breakdown of hydrocarbons into a gas via partial oxidation under the application of heat. May use the carbon residues from pyrolysis as feed stock for reaction with air and steam in the 'water-gas' reaction producing hydrogen and carbon monoxide. Some outputs ('syngas') can be used as a fuel to produce electricity, some may find a use as a chemical feedstock but may require disposal if no markets are available. May be used in combination with combustion of syngas producing energy and heat.**

Waste incineration generally refers to the incineration of MSW however, increasing amounts of hazardous, clinical, and sewage sludge wastes are also disposed of by incineration, mainly in dedicated facilities. There are currently 14 MSW incinerators operating in the U.K. burning approximately 2.0 million tonnes of MSW (8% of the total) each year.

Waste incineration is not new, the first fully functional MSW incinerator was built in Nottingham in 1874. It operated for some 27 years with the ash from the plant being used as a building material. The world's first waste fired electricity generation plant was opened at Shoreditch, London in 1885. By 1912 there were some 300 waste incinerators in the U.K., of which 76 were generating electricity.

The 1960s and 1970s saw renewed construction with about 40 new MSW incinerators being built, although only five were equipped for power generation as the main objective was waste volume reduction (the resulting ash from incineration is approximately 10% by volume and 30% by weight of the original MSW). This greatly reduced costs of transport and disposal to landfill. These incinerators had very crude emission control equipment compared to modern facilities.

In 1989, two new EC Directives on the 'Reduction (for existing plant) and Prevention (for new plant) of Air Pollution from Incinerators', focused on emissions to air. By December 1996 when existing facilities had to comply with the new restrictions many of the old, heavily polluting incinerators closed down, as it was not cost effective to upgrade them.

(b) Feedstocks for Incineration Processes

There are three types of MSW derived feedstock for incineration processes:

(i) Mass Burning of Mixed Municipal Solid Waste
(ii) Burning Refuse Derived Fuels (RDF)
(iii) Burning Source Separated Material as Fuels

(i) Mixed Municipal Solid Waste is the bulk of the MSW after any 'front-end' materials have been removed e.g. recyclables.

(ii) Refuse derived fuel (RDF) is derived from the remaining waste after sorting of the mixed MSW to remove recyclable materials and wet putrescible materials. The combustible residue is then shredded and either burnt directly as a coarse 'floc' (cRDF) or compressed into pellets or briquettes of 'densified' (dRDF). Coarse RDF, which is essentially raw untreated combustible material, must be burned as it is produced whereas dRDF can be stored and transported but requires more energy to produce. RDF has a higher calorific value than unsegregated MSW as it represents the more combustible part of MSW. It also has a lower heavy metal content than MSW, which improves the quality of ash residues. It contains less non-combustible components so overall less ash is generated, concomitantly hazardous emissions are lower and as it is more homogeneous combustion can be better controlled.

(iii) Source-separated material as fuel basically uses collected material, which is in excess of recycling capacity. Due to low moisture content, it can be stored and transported easily and has a high calorific value, low ash generation and consistent combustion characteristics. As with RDF the heavy metal content is lower than unsegregated MSW so air pollution control (APC) residues should be lower and less toxic.

(c) Technologies for thermal treatment

There are four main technologies for the thermal treatment of MSW falling into two groups. Firstly incineration with energy recovery, including mass burn of relatively unprocessed MSW or burning processed MSW in an advanced furnace using a fluidised bed. Secondly so-called Advanced Thermal Treatment (ATT) a variety of techniques for the gasification and pyrolysis of waste derived materials.

(i) Mass Burn energy from waste. This is the simplest form of incineration where the waste is burnt as received with little or no pre-processing. The waste is fed onto a sloping, moving grate that agitates and moves the waste down through the combustion chamber so that by the time it is discharged into the ash pit, all combustible material has been burnt. The hot gases are directed to a boiler where the heat is extracted to generate steam that drives a turbine connected to an electricity generator. The flue gases then pass through a gas cleaning process to remove ash and pollutants before being discharged to the atmosphere via the chimneystack. One tonne of waste produces a nominal 550 to 650 kilowatt-hours of electricity or expressed another way a 100,000 tonne/year incinerator will produce 7 Megawatts of electricity net of power used to run the plant.

(ii) Fluidised Bed Combustion energy from waste. An alternative to mass burn is to pre-process the waste to remove the non-combustible and recyclable materials. The waste is then shredded to produce a floc type material, coarse Refuse Derived Fuel (cRDF), which has a higher calorific value than that of untreated waste. The combustion bed of the incinerator consists of a mixture of sand and dolomitic limestone (calcium magnesium carbonate) through which air is pumped in sufficient amounts to create a rapidly moving or ‘fluidised’ bed. This improves the combustion efficiency, generating more energy and reducing hazardous emissions. The main disadvantage of this technology, apart from being more complex, is that throughputs are up to 35% slower than for a mass burn unit. An incinerator constructed at Dundee was the first of its kind in the UK to use fluidised bed technology and is capable of generating 8.3 MW of electricity from 120,000 tonnes of waste per year.

(iii) Gasification is not a new technique, making town gas from coal, which was done on an large scale from the 19th century to the 1960’s, is a gasification process**.** Here wastes do not need to be pre-sorted but must be crushed. The gasification process involves the waste being heated at high temperature in a reduced oxygen atmosphere to produce metallic and minerallic solid residues plus a low calorific value synthesis gas that may be burnt in an engine or turbine that is coupled to an electricity generator. Most industrial gasification processes are thermally self-sustaining; i.e. little or no external heat supply is required. The output is approximately 90% gas, 10% solid. Ash residue becomes vitrified (glass like) and is separated and disposed of as a solid residue. Gasification of mixed MSW presents a range of problems and the commercial viability of plants processing mixed MSW has yet to be proven.

Table 2.12	**Gasification**
Advantages	**Disadvantages**
Reduces the volume of waste requiring landfill or treatment.	**Not commercially proven for MSW - mixed household waste; limited number of technology suppliers; waste must be crushed. Solid residue requires disposal.**
Produces gas for energy recovery.	**Gas is often of low calorific value.**
It is a low emission technology.	**Syn-gas burning produces CO_2 and possibly other emissions.**

(iv) Pyrolysis is also not a new technique, making charcoal from wood is a form of pyrolysis which has been carried out for hundreds of years. As with Gasification the waste needs to be crushed before heating at high temperature. The process is carried out in the almost complete absence of oxygen or with a limited supply of oxygen producing the thermal degradation of organic wastes. Both pyrolysis and gasification systems can be used to convert solid waste into gaseous, liquid and solid fuels. The heat breaks down complex molecules to produce gases, comprising mainly methane, complex hydrocarbons, hydrogen and carbon monoxide, that are burned in a combustion chamber at temperatures in the region of 1200 ^{o}C. The process products, gas, oil and solids consisting of the remaining inorganic fraction of the waste and an unreacted 'char' which can be used as fuel or as precursor compounds for manufacturing useful chemicals. The relative proportions of these products depend on the nature of the feedstock and the process conditions.

An important limitation is that normally the waste has to be dried before the pyrolysis reactions can occur. Both the drying and the pyrolysis process are endothermic; they require the input of heat, unlike incineration that is exothermic, giving out heat.

Both Pyrolysis and Gasification are currently more expensive than existing processes. No full-scale facilities exist in the UK but there is a demonstration facility in operation in Avonmouth near Bristol. As with Gasification, Pyrolysis of mixed MSW presents a range of problems and the commercial viability of plants processing mixed MSW has yet to be proven.

The residue from this type of thermal treatment comprises approximately:

Char	(30-40% by weight)
Gas and liquids	(50-60% by weight)
Residue	(10% by weight)

The residues include inorganic non-degradable materials. The gas can be used as a fuel for kilns (e.g. cement industry) or to generate steam for electricity production. The char can be used as a fuel (similar to coal) but would need a flue gas scrubbing system or it can be used as a filter material (activated carbon).

Table 2.13	Pyrolysis
Advantages	**Disadvantages**
Reduces the volume of waste requiring landfill or treatment.	Not commercially proven for MSW - mixed household waste; limited number of technology suppliers; waste must be crushed.
Produces gas/oily liquid for energy recovery.	Not likely to be suitable for untreated MSW; can be difficult to control product quality.
Produces solid 'char', which can be burnt as fuel or used as activated carbon filter material.	The impure char produces emissions if burnt requiring air pollution control treatment producing hazardous waste.
It is said to be a low emission technology.	Syn-gas/oil burning produces CO_2 and possibly other emissions.

(d) Incineration with energy recovery
All these four incineration techniques may be referred to as 'energy from waste' processes (EfW). All MSW incinerators in the UK generate energy in this way and they currently treat about 9% of MSW. Some plants, in addition to generating electricity, also produce hot water to supply neighbouring properties (combined heat and power CHP). A number of the UK's EfW facilities have a CHP system in place, but the absence of appropriate infrastructure restricts its use at other facilities. CHP is particularly suited to facilities that are close to new housing developments or industrial parks where a heating scheme can be incorporated at an early stage of construction. It is unlikely to be cost effective to retrofit a heating scheme to an older development.

Although incineration converts waste to energy, concomitantly reducing the volume of waste requiring other treatment, it only represents an intermediate stage in waste treatment as it produces gaseous and solid combustion products. These are emitted as gases to atmosphere or as ash which, in part goes to landfill, part may be used in construction materials.

(e) Control of gaseous emissions to atmosphere
After passing through the boiler the combustion gases must be cleaned. There is a range of designs for flue-gas cleaning equipment but a modern plant usually has four phases similar to the following:

Acid gas scrubbing using a lime mixture injected into the gas stream which reacts to neutralise the acid gases such as sulphur dioxide, hydrogen fluoride and hydrogen chloride.
Activated carbon injection to remove organic compounds such as dioxins and volatile metals such as mercury and cadmium.

Particulate (dust) removal using an electrostatic precipitator or filters. These fine particulates are known as ‘fly ash’.

Oxides of nitrogen reduction measures. The simplest technique is to control combustion conditions, for example by recycling some of the flue gas through the boiler. However, meeting the latest standards requires techniques such as **selective catalytic reduction** (SCR) and **selective non-catalytic reduction** (SNCR). They rely on chemicals such as ammonia or urea injected into the flue gas to react with and destroy oxides of nitrogen. SCR requires the use of special catalysts and natural gas burners to re-heat the flue gas to promote the reaction. Emission control equipment can account for about 60% of the capital cost of a modern waste incineration facility.

Table 2.14 Incineration with energy recovery (EfW)

Advantages	Disadvantages
Reduces weight and volume of waste to about 30% by weight, 10% by volume, left as ash.	Some residuals must be disposed of as hazardous waste.
Reduces potential for disease and bio-toxic effects from waste.	Emits air pollutants requiring APC, may discharge contaminated water from air pollution control process.
Yields five times greater useful energy per tonne of refuse than energy recovery from landfill	Costs generally higher than landfill.
Converts organic waste to other materials, thus unlike landfill does not produce methane and other VOCs.	High fixed costs of plant require long-term investment and possible ‘lock-in’ to incineration restricting future waste treatment choices.
Produces energy and heat, which can be used for electricity generation and in CHP schemes.	Produces carbon dioxide, a ‘greenhouse gas’.
Bottom ash can be reused in construction industry.	Emissions from transport of waste and residuals, some incinerators produce liquid effluent, needing disposal.
A renewable form of energy, according to proponents.	Not a renewable form of energy, according to opponents.

By using these techniques modern incinerators ensure near complete combustion with only extremely small amounts of pollutants emitted from the stacks to the atmosphere. Although many hazardous materials are effectively destroyed by incineration, such as bio-hazardous material and volatile organic compounds, it can be argued that incineration is a type of ‘transformation’ process. Thus instead of releasing large quantities of gaseous hazardous emissions, incineration produces solid products with some potentially hazardous properties.

There are two main forms of solid product: **Fly ash**, some 2 to 5% by weight of the original feedstock, and **Boiler Bottom ash** (usually just called bottom ash), 15 to 25% by weight of material incinerated.

(f) Fly Ash and air pollution control residues

Fly ash is fine particulate material extracted from the gaseous emissions by air pollution control (APC) techniques, such APC waste falls into two different types:

APC residues - A mixture of fly ash, carbon and lime.
Fly ash - Resulting solely from electrostatic precipitators.

The Environment Agency's report 'Solid Residues from Municipal Incinerators in England and Wales' describes air pollution control residues (APC residues) as:

A mixture of fly ash, carbon and lime - the result of a treatment process to clean the gases before they are released into the air. The waste results from the treatment of (usually acidic) combustion gases. Typically the gases are cleaned by adding lime to neutralise any excess acid, finely divided carbon is then added to remove dioxins and heavy metals. The fine particles, carbon and lime, are removed by high efficiency filters. APC residues (APCR) will normally be disposed of in a hazardous waste landfill site

Air pollution control residues

According to the Environment Agency report 88% of APCR is sent direct to landfill, half of this to Bishops Cleeve in Gloucestershire. The other 12% goes to treatment facilities (half of this to Castle Environmental in Derbyshire) where it is used to treat industrial waste which is then landfilled. APCR is composed of fine dust; analysed samples were found to contain dioxin in the range 200-5,800ng TEQ/kg, other organic carbon, heavy metals (particularly the more volatile metals) and chlorides.

The report reviewed the handling of APCR at incinerators and found that occupational exposures were within HSE (Health & Safety Executive) limits. However, one site had complaints of dust from the public and there was an example of leakage due to a fault.

For APCR deposited at landfill sites, the report modelled the dispersion of fine particles (PM_{10}) around the site which predicted a figure of 1.8 $\mu g/m^3$ at the nearest property compared to the Air Quality objective of 40 $\mu g/m^3$. At the highest dioxin concentration of 5,800ng TEQ/kg, this would result in an adult breathing in a maximum of around 0.2 pg TEQ per day (just over one thousandth of the tolerable daily intake, TDI, from all sources), which the report describes as 'negligible'.

(g) Bottom Ash

Bottom ash comprises mainly glass and ceramic-like materials, containing heavy metals and some organic carbon material. The Environment Agency report measured dioxins in the range of 0.64-23ng TEQ/kg. Typical measurements for dioxins in soil, taken from a German study, are 10ng TEQ/kg in rural areas, 10-30 urban, and 100-8,000 near major sources of dioxin pollution. The report considers that as bottom ash contains levels of dioxin similar to those found in urban soil it can be safely processed for construction use. At bottom ash processing facilities the ash is weathered to absorb water and reduce alkalinity. Oversize objects are removed, and then it is screened for size. Over the five year period studied in the report, 79% of bottom ash went to landfill and 21% for bulk fill or substitute aggregate in construction blocks or asphalt. In the year 2000, 42% of bottom ash was being processed for reuse. The report points out that bottom ash is widely used for engineering purposes, for example in the Netherlands (100% of ash), Denmark (70%), France (50%) and Germany (50%).

The report estimated that dioxin levels in blocks made from bottom ash would be around 4ng TEQ/kg (compared to 1ng for blocks made out of power station ash), though one was actually measured at 23ng. As this is comparable to levels found in soil, dust from drilling these blocks should be no more hazardous (as far as dioxins are concerned) than dust from soil. Therefore the report concludes that use of bottom ash for aggregate is safe (Environment Agency May 2002).

2.2.4 Mechanical hybrid processes (Table 2.15)

Table 2.15	Mechanical Hybrid Processes
Treatment	**Definition**
Mechanical Biological Treatment (MBT) or Whole Waste Composting	**A generic term covering a range of technologies for the processing of MSW (after removal of initial recyclables & compostables) using a combination of mechanical separation and biological treatment to dry the waste, separate recyclables (metal & glass, compostable organics) and produce a refuse derived fuel. In its simplest form MBT bio-stabilises the mass of residual waste to be landfilled. Normally the processing of the incoming waste stream involves the screening and extraction of non-compostable fractions of the waste stream with end purposes in mind, with biological processing of the residual compostable waste and landfill of the reject fraction. Some systems use in-vessel composting or Anaerobic Digestion to process the residual biodegradable elements of the waste. Most systems generate a material suitable for use as refuse derived fuel (RDF) which may be used for energy recovery in an ATT process. MBT is extensively used in Germany, Austria and Italy but not in the UK. Without IVC MBT is not ABPR compliant.**
Mechanical Heat Treatment: Autoclave (AC)	**Using mechanical and thermal processes to separate/prepare mixed waste into more usable fractions and/or render it more ‘stable’ for deposit into landfill. An example is the application of steam and pressure to a mixed waste stream in a sealed vessel (autoclave) to initially degrade the waste. Similar to, but much larger then, hospital instrument sterilisation units. Household bagged waste can be used directly in the vessel(s) where it is exposed to pressure and steam at over 140^{0}C. The combination of the pressure, temperature and rotation of the vessel breaks the organic fraction of the waste into a fibrous lignocellulosic biomass with the inorganics being sterilised and steam cleaned. The remaining material may be sorted, depending on the available applications. May be used in combination with advanced thermal treatment (ATT) for energy recovery.**

(a) Mechanical Biological Treatment or Whole Waste Composting (Table 2.16)

Mechanical Biological Treatment is a generic term for an integration of several processes commonly found in other waste management facilities such as Materials Recovery Facilities (MRFs), Refuse Derived Fuel (RDF) production, sorting and composting plant.

MBT is not new, facilities have been operating in continental Europe for 10 years. In fact two thirds of the world capacity of MBT plant is located in Germany, Italy and Spain. At least three companies are developing MBT processes in the UK, but there are no full-scale systems commercially operational. The facilities are usually enclosed in buildings and kept under negative pressure using biofilters to mitigate any odour and emissions to air.

Table 2.16 Mechanical Biological Treatment

Advantages	Disadvantages
Reduces weight and volume of waste.	**Some materials must still be landfilled.**
Stabilises organic component of waste, which can be safely landfilled.	**Landfilling organic component represents a loss of energy and will result in emissions from landfill.**
Can produce a ‘compost’ which may be suitable for use on soil.	**‘Compost’ may not be acceptable for use on soil, may have to be used as landfill cover.**
Can produce RDF for electricity generation, either solid or biogas.	**Burning RDF produces emissions; RDF & biogas produce carbon dioxide, a ‘greenhouse gas’.**
Produces recyclables such as metal and glass.	**Emissions from landfill, burning, transport of waste and residuals.**

There are a wide variety of systems that fall under the heading MBT. The various systems are designed to handle raw ‘black bag’ municipal waste after source segregated recycling and composting has taken place. Essentially an MBT facility processes the waste into less harmful and / or more beneficial output streams. MBT separates MSW mechanically into recovered recyclables (mainly metals and glass), residual material and an organic fraction that can be utilised for composting or anaerobic digestion (AD).

The recyclable component may be extracted either prior to or post biological ‘stabilisation’. In this latter case the process may be referred to as BMT treatment. The remainder of the waste is screened / sorted and homogenised to produce either a feedstock for another treatment process (e.g. a refuse derived fuel for energy recovery in a gasification, co-incineration, or Energy from Waste plant) or may be sent to landfill as a partially stabilised residue.

Some systems may screen the waste to produce a compostable stream appropriate for in-vessel composting processes. If AD is incorporated into the MBT system, the process is usually configured to maximise biogas production. However, the technology can be configured to optimise the production of 'compost' or biogas and refuse derived fuel (RDF). Even where the waste is used as a secondary fuel there is usually a minor non-combustible element which must be sent to landfill.

There are potential problems with MBT, which may militate against its widespread use in the UK. Because of the heterogeneous source material it is likely that the 'compost' produced will contain higher levels of contaminants than 'compost' derived from more homogeneous sources and it will probably have difficulty in meeting the UK composting industry standards. In addition there are increasing amounts of 'compost' being produced from garden waste, which will be more attractive than the mixed waste composts produced by some types of MBT process.

Research is still at a relatively early stage in using output from MBT as a RDF, there are many technical issues and even in continental Europe its use as RDF is much smaller than often suggested. It is probable that much of the organic output from MBT facilities will be used as 'daily cover' on landfill sites, which is why it is viewed relatively favourably by waste disposal companies, but may render it unattractive to waste disposal authorities. For a much fuller discussions of the process see for example: Juniper Consultancy Services Ltd. (2005).

(b) Mechanical Heat Treatment: Autoclave (AC)

This technique uses mechanical and thermal processes to separate and/or prepare mixed waste into more usable fractions and/or render it more 'stable' for deposit into landfill. An example is the application of steam and pressure to a mixed waste stream in a sealed vessel (autoclave) to initially degrade the waste. This is similar to, but much larger then, hospital instrument sterilisation units. Household bagged waste can be used directly in the vessel(s) where it is exposed to pressure and steam at over 140^0C. The combination of the pressure, temperature and rotation of the vessel breaks the organic fraction of the waste into a fibrous lignocellulosic biomass with the inorganics being sterilised and steam cleaned. The remaining material may be sorted, depending on the available applications. May be used in combination with advanced thermal treatment (ATT) for energy recovery.

2.2.5 Landfilling (Tables 2.17, 2.18)

Whatever combination of integrated waste management processes is used, landfilling will continue to be required for final disposal of residual material. Modern landfills accepting municipal solid wastes are designed to meet the requirement of the Landfill Directive (99/31/EEC), incorporating systems such as complete basal lining, leachate drainage, gas collection and burning for energy recovery together with restoration and aftercare provisions. However, costs are increasing rapidly due to the steady increase in Landfill Tax.

Landfill is, in effect, the dumping of waste in holes in the ground. In the past the term landfill has included a wide spectrum of sites ranging from managed, engineered regulated sites to illegal, uncontrolled dumps. Currently, in a typical UK landfill for MSW, waste is deposited in a pre-constructed cell in an engineered site. The base is impermeable clay or is lined with a plastic, rubber or composite layer covered by earth. At the end of each day, the waste is covered with an inert material, such as soil. When the cell is full, it is covered over with a layer of inert material usually followed by a soil medium and vegetated.

Table 2.17	**Landfill Processes**
Treatment	**Definition**
Landfill of bulk MSW: **'Dump and Decay'**	**Normally uses pre-existing void space such as former quarries or clay-pits. Modern landfills take the form of a number of separate cells, lined with impermeable material with advanced leachate and gas control systems. The cells are infilled with compacted waste materials, progressively covered with inert material, then sealed with a permanent capping layer or layers of material such as clay. Where biodegradable materials are landfilled the action of natural bacteria produces landfill gas, principally methane and carbon dioxide. Landfill gas is now normally collected and burnt to recover energy but a significant proportion of the gas is lost to atmosphere as fugitive emissions. During the decomposition water passes through the waste, facilitating biological and chemical reactions, dissolving some materials to produce 'leachate', a contaminated liquid that normally needs to be collected and treated. The landfill of bulk MSW is now a thing of the past – Landfill Directive.**
Landfill of residual materials	**Landfill will probably always be used for the final disposal of the residual material (that which cannot be used in any other way) from treatment technologies.**

During operation landfill sites have to be fenced to prevent the wind from blowing material off site. Insects, vermin and birds have to be controlled. Drainage systems must be constructed to collect water runoff and leachate. It is now the norm to have a gas collection system with the gas being burnt to generate electricity.

The Landfill Directive regulates the operation of landfill sites in the UK. To protect human health, the Directive bans the disposal of all liquids, infectious clinical wastes, and tyres to landfill and co-disposal of hazardous waste with municipal waste is no longer allowed. Except for inert wastes the directive requires treatment of waste prior to landfilling and aftercare of closed landfills.

In sites receiving biodegradable waste, landfill gas must be collected and used for energy generation or flared off (i.e. burnt) rather than being allowed to escape. This is to reduce the amount of methane, a potent 'greenhouse gas', which is emitted to atmosphere.

2.2.6 Transport associated with MSW management

However MSW is treated it needs to be collected and transported, possibly via a waste transfer station, to a treatment facility. After processing any products have to be transported away and any residues taken to landfill. Almost all this transport is by road and this contributes to the emissions from road transport as a whole. In addition there will be some non-vehicle emissions from the waste materials during transport, for example dust, odour, bioaerosols, odour and noise.

Clearly, vehicle movements have health and environmental impacts, indeed some commentators have questioned whether recycling is always worth it because of the negative effects of the 'extra' transport involved, but waste collection authorities have little choice but to target high recycling. Amongst other things, all of the authorities, including Milton Keynes, have been given very challenging recycling and composting targets by central government and this will require them individually and collectively to achieve high recycling levels.

Any new MSW management facility will generate a considerable amount of extra traffic in the surrounding area comprising:

Construction traffic; transport of MSW to the site; transport of materials away from the site; workers travelling to the site; members of the public travelling to and from the site (especially Civic Amenity Sites/Community Recycling Centres).

The greatest health impact associated with any MSW management site will not be due to any polluting emissions but rather it will be due to deaths and injuries caused by accidents associated with this 'extra' traffic (Section 4.1.11).

Table 2.18	**Landfilling**
Advantages	**Disadvantages**
Useful reuse of quarries, brickpits etc. Large landfill capacity remains in some areas.	**Not sustainable. Relatively little long-term capacity in south-east region.**
At present normally the lowest cost waste disposal method.	**Landfilling whole waste represents a loss of resources and energy from recyclable and biodegradable materials also resulting in hazardous emissions.**
Modern landfills have sophisticated systems for containing gas and leachate.	**Significant amounts of methane, CO_2, VOCs etc. escape to atmosphere with potential for health and environmental effects. Some leachate will still escape.**
Landfill gas may be collected as a source of fuel for heat and power generation.	**Energy recovery from landfill is less efficient than from some other disposal options, such as incineration and burning impure landfill gas produces emissions of CO_2, SO_2 etc.**
Restored land provides opportunities for wildlife or leisure activities.	**After landfilling, the land may retain some contamination and/or its geotechnical properties may make it unsuitable for some uses.**

Part B: Concepts, Emissions and Control

3. The concepts used in assessing potential impacts

3.1 Positive impacts

3.1.1 The benefits of municipal collection and treatment of waste

Without centralised collection and treatment of waste each of us would be responsible for dealing with our own waste. The consequences of this are entirely predictable. Those of us with more money and stronger environmental principles would make adequate arrangements for our waste; others would allow it to accumulate to the detriment of homes, neighbourhoods and the health of themselves and others. Indeed even with our current quite sophisticated municipal systems for dealing with waste, discarded items, garden waste, building rubble etc. are common sights at roadsides, in hedgerows and open spaces. No right-minded person can fail to see the obvious health benefits of municipal collection and treatment of waste. Whilst it is true that there are some serious potential problems with collecting and concentrating waste into a small area for treatment, there are a variety of positive impacts from collectively dealing with our waste, other than the obvious outlined above.

3.1.2 Positive impacts: Fuel saving; diversion of material from landfill; disease hazards

Municipal waste treatment provides valuable secondary resources, reduces emissions that contribute to global warming and reliably deals with potential disease hazards from waste. MSW can be regarded as a resource, some would say a renewable resource, and others say that because much of the material in MSW is produced using non-renewable natural resources it is not a renewable resource.

Whatever our beliefs, MSW is a source of materials such as paper/card, glass, metal, compost (see Section 2.2), which fed back into our industrial systems reduces the need to deplete primary natural resources and in so doing reduces the emissions from such primary resource exploitation. This should have a net positive benefit on human health and the environment. However, it is true to say that there is little evidence about the direct health impacts of recycling and any health impacts of recycling on the general population will only be seen in the future. It is quite possible that there are significant health effects on workers involved in recycling and this may point to the need for stricter controls on exposure.

(a) Energy recovery from waste

Arguably the most important positive impact of some MSW treatment methods is energy generation from the waste. Processes such as anaerobic digestion, advanced thermal treatment, energy from waste incinerators and landfills with gas generation engines represent energy sources that can produce heat and/or electricity. This may occur directly as part of the process; e.g. energy from waste incineration, or indirectly via the production of refuse derived fuel, e.g. from mechanical biological treatment (Section 2.2). This means that less non-renewable natural resources have to be extracted, treated and used to generate energy, probably representing a net reduction in emissions which is a positive impact. However, the reduction in emissions would occur at a different location to the waste treatment site.

(b) Reduction in landfill

Modern waste treatment methods are significantly reducing the amount of MSW that is landfilled. Not only is dumping our waste in holes in the ground physically unsustainable (there is a finite limit to landfill capacity) but, in addition to emissions which may have a direct impact on health, landfill emissions make a significant contribution to global warming which has the capacity to directly change the global environment and indirectly impact on our health. Thus treatment of MSW which avoids or reduces the need for landfilling probably has a positive impact on human health and the environment. However, we have to ask the question: "is it a genuine net positive impact"? This will depend on the scale of any negative impacts from the alternative treatment used to deal with the waste (see later).

(c) Reduced potential for disease and nuisance

Without collection and treatment MSW, particularly the organic fraction, would be likely to act as a source of disease; both from uncontrolled putrefaction, caused by micro-organisms, and from the interaction of larger organisms such as insects and rodents with the waste. The waste would also be a source of visual and olfactory nuisance.

All MSW treatment options have a variety of both positive and negative impacts; it is the overall net balance of these impacts that is important. However, as shown later in this report although it is relatively easy to give qualitative assessments of impacts from various waste management processes the overall net impacts on health and the environment are difficult to quantify in any meaningful way. In large part this is due to a lack of good quality data. However, with few exceptions it appears that the health and environmental impacts of treating MSW are a tiny fraction of such impacts from other processes such as transport and energy generation.

3.2 Assessing risk from potential health impacts

3.2.1 Toxicity, hazard, risk

Determining whether the potential environmental and health effects of any new waste management facility, or indeed any new development, are acceptable is now founded on a scientific risk-based framework of assessing and dealing with potential source-pathway-receptor linkages that are the critical concept in identifying, assessing and managing health and environmental impact. This framework embodies the fundamental distinctions between toxicity, hazard and risk that are recognised throughout the environmental sciences but are often a source of confusion and misunderstanding:

Toxicity: the potential of a material to produce injury in biological systems;
Hazard: the nature of the adverse effect posed by the toxic material;
Risk: the probability of suffering harm or loss under specific circumstances.

Risk is used in a multitude of ways in this context and it is essential to be clear about what form of risk is under consideration and what are its components.

The relation of risk to hazard may be expressed as:

$$R = f\ (H \times E) = f\ (H \times D \times t)$$

where R is risk, f is function of, H is hazard, E is amount of exposure, D is dose and t is time.

Therefore, substances which pose only a small hazard but to which there is frequent or excessive exposure may pose as much risk as substances which have a high degree of hazard but to which only limited exposure occurs.

A variety of characterisation methods are available to measure the human and eco-toxicity impacts of substances. These impacts are generally referred to human toxicity potential (HTP) and ecotoxicity potential (ETP). Human Toxicity Potentials and ETPs are usually based on the impact of a reference chemical on human and ecosystems. The toxic potentials are substance-specific, quantitative representations of potential impacts per unit emission of a substance that can be used as weighing factors in aggregation of emissions coming from life cycle inventories (Huijbregts *et al.* 2000). For example, 1,4-dichlorobenzene is often used as a reference chemical and impacts are measured related to 1,4-dichlorobenzene equivalents (e.g. Entec 2005, report for MK Council).

3.2.2 The concept of source-pathway-receptor linkages

Potential risks to human health and the environment can be regarded as comprising the three components that make up a source-pathway-receptor linkage:

Source: anything associated with a waste management facility with the potential to cause harm;

Pathway: a route by which a receptor can be exposed to, or affected by, the potentially harmful source;

Receptor: a particular entity that may be harmed or adversely effected by the emission.

Receptors include, people inside or outside the site boundary; properties outside the site boundary; ecosystems; surface water in the vicinity of the site; groundwater in the vicinity of the site; the atmosphere, (in terms of risk of climate change).

Consider some examples:

There is potential for wide exposure to dust/particulate matter from many MSW treatment facilities and in many cases there is likely to be a complete source-pathway-receptor linkage in this respect. This will include the possibility of deposits of dust, combustion products and/or raw gas constituents in areas of food production such as allotments or market gardens; irrigation of crops with water contaminated with emissions could impact on receptors including people. Accidental or deliberate consumption of soil, particularly by children may be a consideration where there are houses with gardens, schools or play areas.

Some of the trace constituents of gaseous emissions, whether direct from waste or from treatment of the waste, have known hazardous properties. Such gaseous emissions may be dispersed over a wide area with varying levels of dilution depending upon the meteorological and topographical conditions. At all facilities with gaseous emissions, where there are relevant receptors, there will be the potential for a complete source-pathway-receptor linkage.

If there is a drinking water supply down gradient of the facility (in the sense of either wind direction or groundwater flow direction) there will be the potential for a complete source-pathway-receptor linkage. Public water supplies are carefully monitored and controlled and there is normally some form of water treatment prior to use. It is highly improbable that the public drinking water supply to Milton Keynes (MK) could be significantly impacted by any facility within MK as our drinking water is provided from sources well outside MK (principally from Grafham Water). In any case provided the problem was identified and the source-pathway–receptor linkage broken, the impact would be the temporary loss of the resource rather than an impact on public health.

For example, consider a landfill facility for MSW situated on a non aquifer, with no local abstraction of groundwater for drinking water supplies and no local surface water receptors used as a source of drinking water, there would be no need to consider the human health impact of drinking contaminated water as for this scenario there would be no potential for complete source-pathway-receptor linkages. This applies to a large part of MK that is underlain by the Oxford Clay and specifically to the Bletchley/Newton Longville landfill site.

Hazards arising from exposure to a potentially harmful source are specifically characterised by the nature of the potential adverse effect, the pathway and the receptor they affect. Like physical hazards they are only realised when there is a linkage between the source, the pathway and the receptor. If this linkage does not exist, or can be broken, then there is no hazard.

As an illustration take a physical hazard such as loose roof slates (potential emission from source), falling due to gravity (pathway), hitting pedestrians walking next to the building (receptor). This hazard can be dealt with by breaking the linkage in one of a number of ways including: removing or re-fixing the loose slates (treating the emission source); erecting a barrier on the roof to intercept falling slates (cutting the emission pathway); preventing pedestrians from walking near the building (protecting/removing the receptor).

In a similar way hazards from emissions are dealt with by breaking the pollution linkage in one way or another. For example, sulphur dioxide (SO_2) emissions from coal-fired power stations leading to acidification of lakes. In principle, this could be reduced by using low-sulphur coal (treating the source); installing equipment to remove SO_2 from the gaseous emissions (cutting the pathway); or adding limestone to the lakes to prevent acid build-up (protecting the receptor).
@@
With waste management facilities, wherever possible, the source is managed so as to prevent potentially harmful emissions (e.g. by heat treatment at a sufficiently high temperature to break down volatile organic compounds), or the emissions are captured and treated before release (e.g. treating water used in a process before

discharge to sewer). All waste management facilities are subject to strict regulatory control regarding any emissions (Section 4.4).

The **probability** of a hazard being realised, i.e. the **risk**, depends on the context of the source-pathway-receptor linkage, including site-specific factors such as emission concentration, the ease of access to the exposure pathway and the duration of exposure. The consequences of the risk under consideration depend on site-specific factors such as the toxicological potency of the contaminant under consideration, the specific adverse effect on the receptor, the duration of exposure and the sensitivity of the receptor (e.g. a child is more sensitive than an adult).

In making decisions about source-pathway-receptor relationships for waste management facilities, it is important to give consideration to taking a precautionary approach in the light of possible changes and events over the lifetime of the facility. These may result in the nature of the relationship changing with time. For example, changes to the physical and/or chemical structure and composition of waste materials will influence the nature of the associated hazard(s). Decisions should be made on a site-specific basis, bearing in mind the need to take both a proportionate and precautionary view.

If a plausible source-pathway-receptor relationship is identified for a particular site, this will normally be taken to demonstrate the need for appropriate risk management measures to prevent the anticipated risks being realised. In many cases, detailed consideration of the potential presence of a plausible source-pathway-receptor relationship will be sufficient for decision-making about the need for risk management measures. The resources applied to risk assessment should be proportional to the potential risk and this means that it may not always be necessary to undertake a detailed quantitative risk assessment. An exception is where detailed quantitative assessment of the probability and scale of risks involved may be necessary to enable detailed design of the risk management measures, for example, design of landfill liner systems. In other cases, relatively simple assessments of probabilities and consequences may be sufficient to allow appropriate decisions to be made.

3.2.3 Chronic and acute exposure and health effects

Acute refers to exposures and effects occurring on a relatively short time scale (hours or days). Acute illness starts suddenly and is short-lived, for example occurring within a short time after a relatively high exposure to a hazardous material.

For example, toxic pneumonitis or organic dust toxic syndrome: this is an acute illness occurring during or shortly after exposure to a high level of airborne dust leading to influenza-type symptoms.

Chronic refers to exposures and effects occurring on a relatively long time scale, (years, even decades). Chronic illness usually starts slowly and continues for a long time. This could be caused by an acute exposure to a relatively high level of a hazardous substance producing long-term chronic effects or by chronic exposure to low levels of a hazard over prolonged periods of time.

For example, chronic bronchitis and chronic obstructive pulmonary disease, are inflammatory diseases of the respiratory system where long-term rather than intermittent changes in the lung cause obstruction of air exchange. There is some evidence that airborne bacterial endotoxins, for example from composting operations, and other factors may be a causative factor in these diseases.

Acute and chronic effects are not necessarily due to separate causes; for example both acute and chronic respiratory symptoms may be produced by inadequately controlled incinerator emissions causing respiratory morbidity.

3.2.4 Toxicological research and dose-response assessment

Toxicological research involves laboratory based controlled studies of organisms (e.g. rats) or tissue samples. These subjects are exposed to measured levels of potentially toxic chemicals for specific periods of time, and any effects are measured. Extrapolation of the data from such experiments allows estimates to be made of the acute and longer term biological effects of the chemicals studied. Frequently such experiments examine specific effects on development, reproduction, the immune and nervous systems and the ability of the chemicals to cause cancer. There are many problems associated with the design and interpretation of the results of toxicological experiments. Whilst in many ways it may be easier to understand the results of laboratory toxicology studies rather than human epidemiology investigations, there are often difficulties in applying the results to human populations (Section 3.2.4 and Chapter 5).

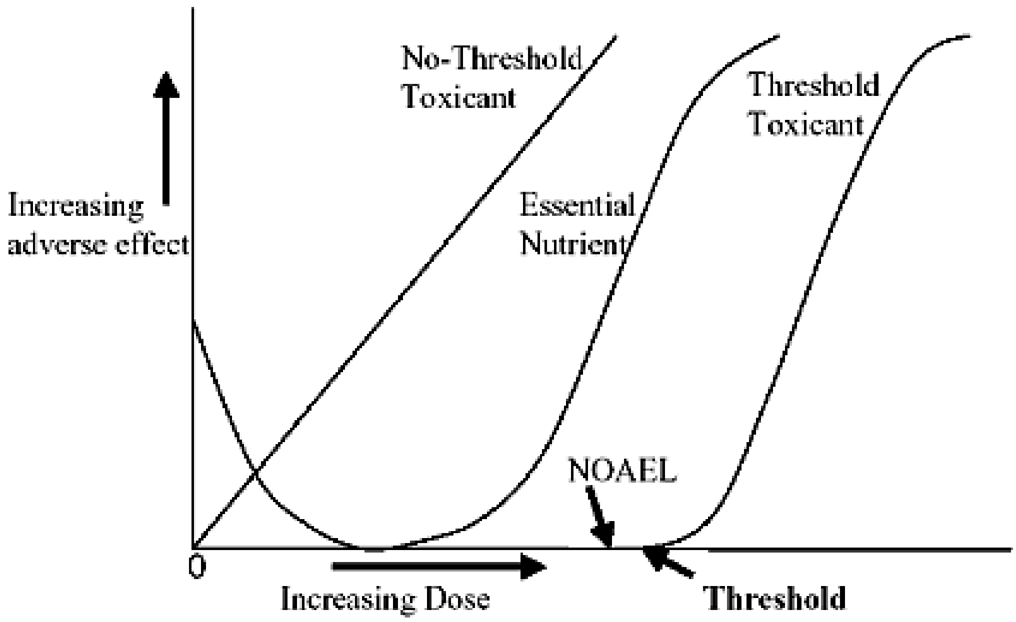
Combinations of chemicals

Another problem with toxicological studies is that they normally investigate the effects of one chemical under closely controlled laboratory conditions. However, in real life we are exposed to combinations of chemicals from numerous sources. Even if we narrow this down to potential emissions from MSW management most waste materials contain a combination of potentially toxic substances and more may be generated during treatment. Little is known about the toxicity of combinations of chemicals, there may be interaction effects that make the risks higher or lower than that predicted by analysing individual contaminants separately. There may be no interaction at all, with each compound acting independently. Nor is there an adequate understanding of the effects on toxicity of the changes that may occur when chemicals migrate through soil or water. These are just some of the problems inherent in toxicological research.

Dose-response assessment is an essential aspect of assessing possible health risks from chemicals. It involves the investigation of the relationship between the amount of the substance to which the subject is exposed and the frequency and severity of any adverse effects. For many types of adverse effects, such as organ-specific effects, neurological, immunological, reproductive, developmental and non-genotoxic carcinogenesis, there may be a **threshold dose**, below which no observed adverse effect will occur (see Figure 3.1). However, there is a generally held assumption that there is no threshold for safe exposure to substances that may cause cancer by mutation of the genetic information in DNA (genotoxic substances). This is because it is believed that there is some probability of effect at any given dose, no matter how low. In the absence of data in humans to the contrary, chemicals that can induce cancer in experimental animals are regulated as if they could induce cancer in humans.

An important aspect of dose-response assessment is the investigation of the relationship between the amount of the substance to which the subject is exposed and the frequency and severity of any adverse effects. Data from experiments is used to derive reference doses of potential toxins that represent statistically safe levels of exposure (see below, increased lifetime risk). For non-carcinogenic substances (so-called 'threshold substances'), the highest observed dose for which no significant effect can be detected, the '**no observed adverse effect level'** (NOAEL), is taken for purposes of setting exposure levels (Gargas *et al.* 1999). Where a NOAEL does not exist, the '**lowest observed adverse effect level**' (LOAEL) may be used.

Figure 3.1 Dose-response curve



For a contrary view on threshold and non-threshold substances see 3.2.5 below, on endocrine disrupters and hormesis effects.

Advanced statistical modelling techniques are usually necessary to estimate the dose response for certain effects, particularly for the extremely low doses that are often observed in human population exposure studies of the emissions from municipal waste treatment and derive statistically safe reference doses.

These reference doses (RfD or TDI 'tolerable daily intake') are defined as the amounts (with associated uncertainty factors) that it is estimated can be taken up each day by the majority of the population without producing an adverse effect. Differences between species (important where the research has been carried out on animals such as rats) and the variability of the human population introduce a level of uncertainty to this dose-response estimation. Extrapolation of responses in animal studies may not always be appropriate when subsequently applied to human populations. Biologically motivated models for risk assessment have been developed which help to remove some of the uncertainty from this extrapolation process. These models incorporate data on the physiological and biochemical structure of the animal system being described (Clewell & Anderson, 1989). Safety factors have been derived for use when estimating these values (Renwick & Lazarus, 1998). These factors, often a multiplier of 10, 100 or 1000, provide a safety margin when incorporated into estimations of effects in humans using animal data.

Increased lifetime risk of one in a million:
Regulatory permitted levels of agents that can cause cancer are normally based on calculations of lifetime risk. It is generally considered that exposure levels corresponding to a calculated increased lifetime risk of one in a million are considered acceptable since an increased incidence of cancer at this level would be undetectable with current epidemiological methods. Because such calculations are normally based on the worst possible case, the true potential increase is likely to be much less then 1 in a million.

To put this in perspective it is interesting to consider what risks are believed to produce a lifetime risk of one in a million. According to Wilson (1979) the following actions increase the probability of death by one in a million.

Table 3.1 Actions that increase the probability of death by one in a million

Activity	Cause of death
Smoking 1.4 cigarettes	Cancer, Heart Disease
Drinking 0.5 litre of wine	Cirrhosis of the Liver
Travelling 10 miles by bicycle	Accident
Travelling 300 miles by car	Accident
Flying 1000 miles by airliner	Accident
One chest x-ray	Cancer from Radiation
Eating 40 tablespoons of peanut butter	Liver Cancer from Aflatoxin
Eating 100 barbecued steaks	Cancer from PAH e.g. benzo(a)pyrene
Drinking 30 cans of diet soda	Cancer from Saccharin (artificial sweetener)
Living 150 years within 20 miles of a Nuclear Power Plant	Cancer from Radiation
Living within 5 Miles of a Nuclear Reactor for 50 Years	Cancer from Radiation due to nuclear accident

[Note: A risk level of 1 in a million, e.g. for a cancer, implies a likelihood that up to one person, out of one million equally exposed people would contract that cancer if exposed continuously (24 hours per day) to the specific concentration over 70 years (an assumed lifetime). This would be in addition to those cancer cases that would normally occur in an unexposed population of one million people. Note that this assessment looks at **lifetime** cancer risks, which should not be confused with or compared to **annual** cancer risk estimates. To compare an annual cancer risk estimate with a lifetime assessment, you would need to multiply that annual estimate by a factor of 70 or alternatively divide the lifetime risk by a factor of 70.]

3.2.5 Human Toxicity Potential (HTP)

The most prominent characterisation method for human health effects of toxic chemicals in LCA is the Human Toxicity Potential (Guinée and Heijungs 1993). In parallel to risk characterisation, it combines indicators for exposure and toxicity. The exposure indicator is the 'potential dose' and it is the calculated individual dose resulting from a constant 1 kg/day release of the chemical to a specific environmental compartment (e.g. air, surface water, soil).

The potential dose is calculated by an integrated multimedia fate and exposure model based on data for a generic reference environment. The model calculates the presented dose of the chemical to an individual living in this model environment. It takes into account the partitioning of the chemical between different compartments, the chemical persistence, and its ability to accumulate along food chains and other exposure pathways (see http://www.epa.gov/ttn/fera/multi_gen.html).

For the toxicity potential, a basic choice is whether to treat cancer differently to other toxic effects. For cancer, risk assessors usually employ a linear dose-response curve, meaning that any non-zero exposure has some probability of effect. Most other toxic effects are thought to occur only above a specific toxicity threshold. Huijbregts *et al.* (2000) in line with normal European regulatory practice use the 'Allowable Daily Intake', which takes a cancer risk of 10^{-5} (one in one hundred thousand) as equivalent to a toxicity threshold.

Hertwich *et al.* (2001) following normal USA regulatory practice define two different HTPs, one for carcinogens based on the cancer potency and one for non-carcinogenic effects based on the Reference Dose (RfD) and Reference Concentration (RfC). Both cancer potency and reference dose/concentration are defined by the US Environmental Protection Agencies. For non-carcinogens, the 'allowable daily intake' (ADI) and the RfD/RfC represent a health-protective estimate of the toxicity threshold. The RfD is a dose rate (in mg/kg/day), the RfC a concentration (mg/m^3).

In a similar manner to the Global Warming Potential (GWP), which is expressed in terms of equivalent amounts of carbon dioxide CO_2, the Human Toxicity Potential is expressed in terms of a reference chemical. Huijbregts *et al.* use 1,4-dichlorobenzene; Hertwich *et al.* use benzene for cancer and toluene for non-cancer effects.

The characterisation factor for each chemical c released to compartment n (air, soil, water etc.) is calculated in this manner:

$$HTP_{c,n} = \frac{\sum_i PD_{c,n,i} Q_{c,i}}{\sum_i PD_{refchem,air,i} Q_{refchem,i}}$$

where **PD** is the potential dose per intake route i (inhalation, ingestion, dermal uptake, Section 3.3.3);
Q is the toxic potency of the chemical (chemical potency or *inverse* of the safe dose). **refchem** is the reference chemical (benzene, toluene, 1,4 dichlorobenzene).

In the characterisation part of a specific life cycle assessment, human toxicity potential (HTP) is calculated in this manner:

$$HTP = \sum_{c} \sum_{n} HTP_{c,n} M_{c,n}$$

where $\mathbf{M_{c,n}}$ is the mass of chemical c released to compartment n, as contained in the life cycle inventory. (After Hertwich 2001)

3.2.6 Negative low dose effects, endocrine disrupters and dose response assessment

(a) Endocrine disrupters and low-dose effects

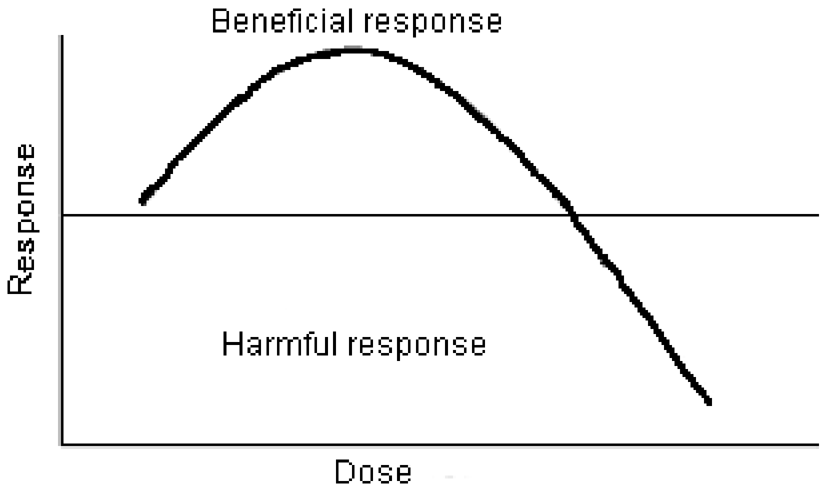
Within the last decade the terms endocrine disrupter, endocrine modulator and hormone mimics have entered the lay and scientific jargon as terms to describe chemicals that are believed to alter the function of part of the endocrine system and consequently cause adverse health effects in an organism. There is still a great deal of controversy about such chemicals (for example, Krimsky, S. 2000)

Chemicals for which such effects have been reported include: persistent organo-halogens such as dioxins & dibenzofurans and PCBs; organochlorine pesticides such as DDT, lindane, malathion; phthalate esters; metals such as As, Cd, Pb, Hg; and many others. Many of these chemicals are present in MSW or may form part of emissions from MSW treatment.

It has been argued that these so-called endocrine disrupters produce recognisable effects on organisms at doses far lower than those used in traditional dose-response assessment. Thus they may give rise to dose-response curves markedly different to those of classical toxicity determinations where it is normally found that the higher the dose the greater the effect. Such classical dose-response curves are described as monotonic; i.e., they increase or decrease over the entire dose range.

However, in some cases the reaction of a complex biological system to a potentially toxic substance may produce a non-monotonic (or biphasic) dose-response effect relationship, showing a decreased effect at low doses followed by an increased effect at high doses, or *vice versa* (e.g. Figure 3.2).

Figure 3.2 Example of a non-monotonic dose-response curve



[Note: a 'non-monotonic dose-response curve' means that as the dose increases or decreases the response does not increase or decrease in line with the dose. The produces 'U'-shaped or inverted 'U'-shaped curves as in this example above.]

After much controversy the US National Toxicology Program (NTP) confirmed the reality of such low-dose effects in 2001 by a scientific peer review. This NTP assessment also showed that non-monotonic dose response curves do occur for some substances and there are circumstances when a low dose may produce a greater response than a high dose. This is extremely significant from a regulatory and health impact perspective. Until recently almost all regulatory science has been based on the classical toxicological assumption that the basic form of the dose-response curve is monotonic. The idea is that anything can be toxic at a high enough dose "the dose makes the poison". For example drink enough water and it will kill you.

If it really is the case that many chemicals exhibit non-monotonic dose-response effects at low doses then many safety standards, RfDs and/or TDI's, established using traditional dose-response testing may need to be reassessed, as it raises the possibility of biologically important negative impacts well beneath the levels of exposure that are normally tested.

This could be highly significant in the field of health impact risk assessment from MSW treatment as it might mean that many of our assumptions in respect of potentially hazardous emissions need to be revisited. Unfortunately, as yet there is too little evidence available about 'endocrine disruption' and 'low-dose effects' to come to any definitive conclusion. In addition the situation is further confused by so-called hormesis effects at low doses (Section 3.2.7 below) and disagreement about these effects within the scientific community.

(b) What are 'endocrine disrupters' and how do they work?

The European Commission's Environment web-site defines endocrine disrupters as follows:

(http://europa.eu.int/comm/environment/endocrine/index_en.htm)

"An endocrine disrupter is an exogenous substance or mixture that alters function(s) of the endocrine system and consequently causes adverse health effects in an intact organism, or its progeny, or (sub) populations"

Mechanisms of disruption:
Some chemicals can act on the endocrine system to disturb the homeostatic mechanisms of the body or to initiate processes at abnormal times in the life cycle. The chemicals can exert their effects through a number of different mechanisms:

- They may mimic the biological activity of a hormone by binding to a cellular receptor, leading to an unwarranted response by initiating the cell's normal response to the naturally occurring hormone at the wrong time or to an excessive extent (agonistic effect).
- They may bind to the receptor but not activate it. Instead the presence of the chemical on the receptor will prevent binding of the natural hormone (antagonistic effect).
- They may bind to transport proteins in the blood, thus altering the amounts of natural hormones that are present in the circulation.
- They may interfere with the metabolic processes in the body, affecting the synthesis or breakdown rates of the natural hormones.

Up to now, because of a series of observations in both humans and wildlife, the spotlight has focused on disruption to those hormones that play a major part in the control of reproduction and development. The main area of concern has been the steroid hormones produced by the gonads which, in conjunction with some other hormones (particularly those produced by the pituitary), control processes such as reproduction and sexual behaviour, foetal differentiation and development, and maturation. They also influence the immune system and general metabolism.

The main sex steroids are:

Oestrogens: a group of chemicals of similar structure mainly responsible for female sexual development and reproduction. They are produced mainly by the ovaries but also by the adrenal glands and adipose (fat) tissue. The principal human oestrogen is 17beta-oestradiol.

Androgens: chemicals responsible for the development and maintenance of the male sexual characteristics. They are structurally similar to oestrogens; indeed, oestrogens are produced in the body from androgenic precursors. Testosterone, produced mainly by the testes, is the principal human androgen.

More recently, research has indicated that some chemicals may disrupt thyroid function, with concerns focusing particularly on the role of the thyroid in the developmental process. There is some evidence that known endocrine disrupters may affect the immune system and may also have some neurotoxicity although the mechanisms by which these effects may occur have not been elucidated.

(c) What do we know about endocrine disrupters?

The main evidence suggesting that exposure to environmental chemicals can lead to disruption of endocrine function comes from changes seen in a number of wildlife species. Effects suggested as being related to endocrine disruption have been reported in molluscs, crustacea, fish, reptiles, birds and mammals in various parts of the world (for example see: Colborn *et al.* 1993).

There is also some limited evidence in humans that adverse endocrine-mediated effects have followed either intentional or accidental exposure to high levels of particular chemicals. The clearest example of an endocrine disrupter in humans is diethylstilbestrol (DES), a synthetic oestrogen prescribed in the 1950s and 1960s to five million pregnant women for the prevention of spontaneous abortion. It was found that some of the children who had been exposed in the uterus had developmental abnormalities, and that some of the girls developed an unusual form of vaginal cancer when they reached puberty. As a consequence, DES was banned in the 1970s (Herbst & Bern 1981). In addition, a number of adverse changes have been suggested to have occurred in a population living near a chemical plant in Seveso, Italy as a result of the accidental release of the chemical dioxin, a suspected endocrine disrupter (Bertazzi *et al.* 2001).

[Note: The *Seveso accident* happened in 1976 at a chemical plant manufacturing pesticides and herbicides (De Marchi *et al.* 1996). A dense vapour cloud containing kilogram quantities of 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD or simply dioxin) was released from a reactor used for the production of trichlorofenol. More than 600 people had to be evacuated from their homes and as many as 2,000 were treated for dioxin poisoning. The accident resulted in one of the largest ever-reported outbreaks of chloracne, the typical skin disorder due to halogenated-hydrocarbon compounds. This particularly affected children. Follow-up research has found significant increases in cancer and other diseases amongst the effected population].

Chemicals with hormonal activity, i.e. potential endocrine disrupters, include:

- **Natural hormones** from any animal, released into the environment, and chemicals produced by one species that exert hormonal actions on other animals, e.g. human hormones unintentionally reactivated during the processing of human waste in sewage effluent, may result in changes to fish.
- **Natural chemicals** including toxins produced by components of plants (the so-called phytoestrogens, such as genistein or coumestrol) and certain fungi.
- **Synthetically produced pharmaceuticals** that are intended to be highly hormonally active, e.g. the contraceptive pill and treatments for hormone-responsive cancers may also be detected in sewage effluent.
- **Man-made chemicals** and by-products released into the environment. Laboratory experiments have suggested that some man-made chemicals might be able to cause endocrine changes. These include some pesticides (e.g. DDT and other chlorinated compounds), chemicals in some consumer and medical products (e.g. some plastic additives), and a number of industrial chemicals (e.g. polychlorinated biphenols (PCBs), dioxins). The hormonal activity of these chemicals, is many times weaker than the body's own naturally present hormones, e.g. nonyl phenol (a breakdown product of alkylphenol ethoxylate surfactants), found as a low level contaminant in some rivers in Europe, has an oestrogenic activity only about one-ten thousandth that of the natural hormone, oestrogen.

(d) Are all substances that alter hormone levels 'endocrine disrupters'?

In a recent paper Agzarian & Foster (2004) argue that the term "endocrine disrupter" is confusing as it is used to communicate divergent meanings with the net result being confusion concerning the potential for such chemicals to interact with physiological systems and to induce endocrine toxicity.

They point out that not all chemicals, which cause changes to the endocrine system, represent a hazard. For example, eating food causes changes in numerous hormones involved in digestion and metabolism. Bright light alters hormone levels in the brain affecting human behaviour and depression. Thus, even food and light could be considered as 'endocrine disrupters' since they induce functional changes in hormone levels. Hence, use of the terms disrupter, modulator or mimic does little to help distinguish between chemicals that do or do not **adversely** alter endocrine homeostasis.

Agzarian & Foster prefer the use of the term "endocrine toxicants" to describe chemicals that disrupt endocrine homeostasis and induce adverse health effects. They believe this term would clearly communicate that a chemical has been shown to be toxic through an endocrine mechanism and would enable us to discriminate between chemicals with this property and those that are not hazardous, even though they may have an effect on the hormone system. Having said that, as always we must remember that just because a chemical has not been shown to produce a hazardous effect does not necessarily mean it cannot do so. It may be that the necessary research just has not yet been undertaken.

3.2.7 Positive low dose effects, hormesis and dose response assessment

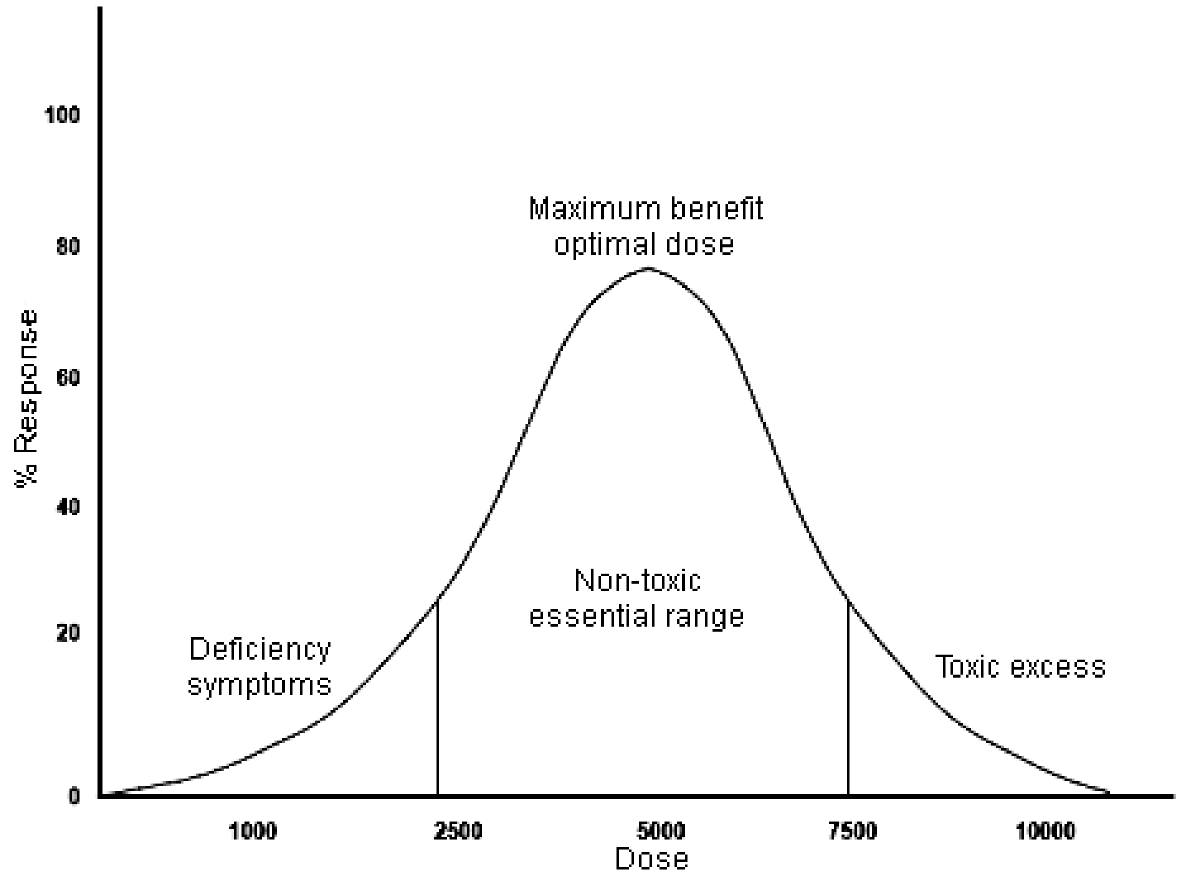
(a) What is hormesis?

The term hormesis (from Greek meaning 'to excite') is often used to describe positive beneficial effects exhibited at low doses by chemicals that are toxic at high doses, i.e. low dose stimulation, high dose inhibition effects (Calabrese, E.J. 2000; Salem, H. 2000). Proponents of positive hormesis effects argue that it should change how regulators determine safe exposure levels to radiation or to toxic chemicals. In fact they maintain that regulatory controls which protect humans from exposure to minute amounts of toxic substances, and radiation, may increase risk rather than reduce it and that beneficial exposure to some chemicals and even radiation, may be at levels now widely considered unacceptably high. What they are proposing is that not only do most toxic chemicals have a threshold effect (3.2.4), below which they show no adverse effect, but in fact below their threshold level they show positive effects.

Is this the science of the madhouse, or is it an emerging valid scientific field, which could substantially change our approach to regulation and the derivation of tolerable daily intakes (Section 3.2.4) of potentially toxic substances?

Before dismissing the idea consider vitamin A. Deficiency in vitamin A is the leading cause of preventable blindness in children, especially in Africa and south-east Asia, where it is a direct result of poverty ('deficiency' doses in Figure 3.3). However, vitamin A is a toxic substance. In the affluent western world overdosing on vitamin supplements can cause vitamin A toxicity ('excess' dose in Figure 3.3). Symptoms include accumulation of water in the brain (hydrocephalus), vomiting, tiredness, constipation, bone pain, and severe headaches. The skin may acquire a rough and dry appearance, with hair loss and brittle nails. Vitamin A toxicity is a special issue during pregnancy. Expectant mothers who take 10 mg vitamin A or more on a daily basis may have an infant with birth defects such as abnormalities of the face, nervous system, heart, and thymus gland. Therefore we could say that vitamin A exhibits a hormetic effect with high doses being toxic and low doses being beneficial.

Figure 3.3 Example of a dose-response curve for a substance like vitamin A



Fat-soluble vitamins may be one thing, but toxic chemicals like dioxin cannot show this effect, or can they? In fact some scientists argue that there is evidence to show that even dioxin exhibits a positive hormetic effect at low doses.

Hormesis is not a new phenomenon. In 1888, German pharmacologist Hugo Shulz observed that small doses of poisons appeared to stimulate the growth of yeast. Schulz also studied the work of Rudolph Arndt, who had carried out animal studies of drugs at low doses. These early studies suggested the presence of hormetic effects. The science lost credibility between the 1920s and the 1930s because of its association with homeopathy, it has recently been resurrected within the scientific community (Kaiser, 2003).

(b) Hormetic dose-response relationships have been reported as widespread and several recent studies have argued for the pervasiveness of hormesis in toxicology. In one such study, Calabrese, a leading proponent of the hormesis argument, studied dose-response curves already present in the published toxicological literature. Out of 664 dose-response relationships, he found that hormetic dose-response curves outnumbered curves showing no effect at the lowest doses by a ratio of 2.5 to 1 (Calabrese, 2003). Overall, Calabrese estimates that U-shaped (or j-shaped) dose-response curves (Section 3.2.6 above) may be reliably expected in about 40% of experiments with appropriate study design. However, his views have been strongly criticised by Thayer *et al.* 2005.

Calabrese points out that classical toxicological studies rely on high-dose animal tests, which are then extrapolated to low doses. While environmental exposure standards are generally based on a threshold model or, for carcinogens, a linear model, where no level of exposure is deemed safe, he argues the dose-response curve for most toxins is actually J-shaped rather than a straight line. According to this hormesis model, exposure to toxins at small doses often has a protective effect irrespective of whether the toxic challenge is natural or synthetic. Even DDT, the synthetic organohalogen that has been largely banned because of its bioaccumulating effect on wildlife, has a hormetic dose-response relationship (Sukata, T. *et al.* 2002). Calabrese maintains that hormesis occurs at a frequency that is greater than any other dose-response model and so he contends that it should replace those models (Calabrese, 2005).

However, other scientists believe that Calabrese's conclusions are too far-reaching. A senior US Environmental Protection Agency officer (Farland, W. quoted in Kaiser, 2003) said that although paradoxical dose responses (i.e. non-monotonic dose-response curves, 3.2.5a above) do occur, the concept of hormesis "has been taken over by rhetoric" and it is too soon to conclude that the positive impacts of low level exposures outweigh the negative impacts. Referring to numerous recent studies, which show that endocrine disrupters may be *more* harmful at low doses than at high doses, vom Saal (quoted in Kaiser, 2003) is sceptical about claims of positive low-dose effects made by Calabrese.

Calabrese argues that chemical carcinogens are being over-regulated with an excessively cautious approach because hormesis "emphasises that there are thresholds for carcinogens," and "the economic implications … are substantial,"

[Note: quote from Calabrese & Baldwin 2003:
"What are the implications of the hormetic perspective? Most notably, it challenges the belief and use of low-dose linearity in estimating cancer risks, and emphasizes that there are thresholds for carcinogens. The economic implications of this conclusion are substantial. The EPA has been struggling to harmonize how it assesses risks from non-carcinogens and carcinogens, having mistakenly assumed for a long time that non-carcinogens act via a threshold model whereas carcinogens act via a linear model at low doses. As both types of biological response follow the hormetic paradigm and display similar quantitative features of the dose response, the EPA could use the hormetic model as default to assess risk in both non-carcinogens and carcinogens. The hormetic perspective also turns upside down the strategies and tactics used for risk communication of toxic substances for the public. For the past 30 years, regulatory and/or public-health agencies in many countries have 'educated' — and in the process frightened — the public to expect that there may be no safe exposure level to many toxic agents, especially carcinogens such as radiation and dioxins. If the hormetic perspective were accepted, the risk-assessment message would have to change completely. Changing a dominant risk-communication paradigm is not as simple as flicking on a light switch. It changes beliefs, attitudes, and assumptions, not unlike changing from a Soviet-style society to a western one. It would certainly be resisted by many regulatory and public-health agencies as an industrial-influenced, self-serving scheme that could lead to less costly, less protective clean-up standards, reminiscent of attempts by early opponents of hormesis to link it with homeopathy."]

(c) 'Positive' effects may be undesirable and far from universal

But vom Saal (quoted in Kaiser, 2003) says that hormesis suggests exactly the opposite and that regulators have missed a range of harmful effects of chemicals because they have not been adequately tested at low levels. Even if they produce an effect that appears positive, such as faster growth, larger offspring or increase in size of prostate gland, it is not necessarily beneficial, he points out. Obesity, for example, is associated with other diseases later in life and who wants an enlarged prostate gland?

Nevertheless there appears to be some evidence that low levels of substances such as cadmium, dioxin, saccharin, polycyclic aromatic hydrocarbons (PAH), and even certain gamma-ray sources reduce certain tumours in some species (Calabrese & Baldwin 2003). Moreover, even toxic heavy metals such as arsenic, lead, mercury and selenium are reported to show similar effects, whilst low doses of X-rays have prolonged the life-span of mice and guinea pigs, leading to the claim that radiation displays hormetic effects (Kaiser, 2003b). Even alcohol consumption can be said to show hormetic low-dose effects with low or modest consumption of ethanol reducing total mortality in humans, whilst high ethanol consumption is a well-known cause of life-shortening disease (Calabrese & Baldwin, 2003b).

However, there are problems with a simplistic application of the idea of hormetic effects. For example, whilst there is some evidence that implies that low doses of dioxin suppress breast tumours, other studies have shown that small amounts of dioxin can promote liver tumours and only when all tumours are taken into account do the dioxins exhibit a U-shaped dose-response curve (Kaiser, 2003b).

Another contradictory substance is cadmium, small doses could help prevent some cancers, but they may promote other kinds of cancers. Calabrese & Baldwin (2003b) noted that animal studies suggested that low doses of this element could help prevent some cancers. But in the same year other researchers (Johnson *et al.* 2003) reported that at these low doses, even lower than those recommended as safe in the diet, cadmium acts as an endocrine disrupter in female rats, causing growth in uterine and breast tissues that could lead to cancer.

(d) Opponents of a positive hormetic effect

In a very recent paper Thayer *et al.* (2005) take a very strongly opposing view to that of many proponents of hormesis. They do not agree with the idea that beneficial hormetic effect from low levels of toxic substances is a general phenomenon nor that because of this effect the default assumption for risk assessments should be that toxic chemicals induce stimulatory (i.e. “beneficial”) effects at low exposures.

Thayer *et al.* argue that in many cases, non-monotonic dose-response curves have been said to exhibit hormetic responses even in the absence of proof that such as response has actually occurred. They say that use of the term hormesis, with its implications of beneficial effects, distracts from the broader and more important questions regarding the frequency and interpretation of non-monotonic dose responses in biological systems. Further, they consider that some assumptions made about hormesis are oversimplifications of complex biological processes. They go on to say that even if certain low dose effects were sometimes beneficial, this should not influence regulatory decisions to allow increased environmental exposures to toxic and carcinogenic agents, given complicating factors such as inter-individual differences in susceptibility and multiplicity in exposures.

(e) Conclusions about low-dose effects

In summary Sections 3.2.5 and 3.2.6 show that low-dose effects, whether negative or positive, are complex and to some extent contradictory, however, they pose some serious questions in regard to dose-response, regulatory policy, the precautionary principle and risk assessment in respect of potential impacts from MSW management in particular and toxic substances in general.

3.2.8 The principles of risk assessment

(a) Risk assessment put simply is an evaluation of the probability of harm from a particular hazard. In the context of waste management facilities it is normally concerned with gathering and interpreting information on the characteristics of emission sources, pathways and receptors at specific sites and attempting to understand the uncertainties inherent in the assessment of these specific risks. This frequently involves an attempt to determine the environmental biogeochemistry of the emissions, together with relevant properties of the host materials and the characteristics of the area around the site, which influence emission transport, fate and biochemical impact.

(b) Geochemical distribution of substances in emissions
It is the geochemical properties of particular chemical components in the emissions from waste management sites that determine how they will be transported around and off the site and where contaminants are likely to end up. This is referred to as a chemical's 'distribution'; i.e. will a particular chemical occur in solid inorganic particles or carbonaceous biotic materials, or in the gases or liquids involved in the waste treatment?

For example chemicals that have:
(a) High aqueous solubility (dissolve easily in water) will tend to be transported via surface and/or ground water and end up in ponds and streams, possibly impacting people through drinking water e.g. phenol;
(b) High vapour pressure (easily evaporate and form gases) will tend to escape to the air, possibly then being breathed in by people e.g. benzene;
(c) Low aqueous solubility, low vapour pressure and a high organic carbon-water partition coefficient (tendency to bind to organic carbon in soil) will tend to travel as wind blown dust and end up in soil, possibly sticking to root vegetables and being eaten by people e.g. hexachlorodibenzo-*p*-dioxin.

After such chemicals come into contact with the human body it is their biochemical properties that determine what effect they have on the human body. The bioaccessability and bioavailability of a chemical are particularly significant in respect of potential health impacts.

(c) Bioaccessability refers to that fraction of a substance that is available for absorption by an organism. It depends on physical and chemical characteristics such as particle size (e.g. more easily absorbed when finer), morphology (e.g. more easily absorbed when 'rougher' because of greater surface area to mass ratio) and crucially speciation (e.g. lead in oxide form is more easily absorbed than uncombined metallic Pb).

Bioaccessability mainly equates to the fraction of a substance that is dissolved in the gastrointestinal fluid. In most cases solubility is a prerequisite of absorption, although small amounts of some materials in particulate or suspended/emulsified form may be absorbed by pinocytosis (where cells engulf small particles and break them down). Moreover, it is not simply the fraction dissolved that determines bioavailability, but also the rate of dissolution, which depends on physiological and geochemical factors.

(d) Bioavailability refers to the fraction of the chemical that can be absorbed by the body through the gastrointestinal system, the pulmonary system and the skin. The quantity of bioavailable contaminant is always less than, or equal to, the quantity of bioaccessible contaminant due to the fact that human bodies will typically not adsorb the total amount of bioaccessible contaminant, leaving some to be excreted from the body.

In addition to these parameters the effects of a potentially toxic substance may be mitigated by the action of the human body's variety of defences against harmful entities.

3.2.9 Environmental epidemiology – human environmental risk assessment

Epidemiology is the study of the patterns and causes of disease in human populations. These studies produce information about the possible effects of hazards to which humans are exposed in their natural environment. The information they produce is derived from human populations, unlike laboratory toxicology studies of animals and tissue samples. Environmental epidemiology may be defined as the study of environmental factors that influence the distribution and determinants of disease in human populations. Recent developments have resulted in a shift from a solely disease-based focus to include the study of exposures. This shift has brought epidemiology closer to the risk assessment process (Elliot *et al.* 1996).

Unfortunately most such studies investigating links between waste management and health outcomes use unreliable evidence, that of residence or employment near the site. Only a tiny minority of studies is based on quantified ambient or personal measurements of pollutants taken at the time of potential exposure. In most studies, the waste management facility is just assumed to be a box emitting toxic compounds but no actual measurements are taken to use in the exposure assessment.

This means that even when an epidemiological study does find a statistical association between a waste management site and a health effect, it is difficult or impossible to decide if this is caused by emissions from the site. It may be just a chance association produced by random coincidence or it may be caused by factors unconnected with waste management.

Such factors include the pre-existing health of the people studied; their relative wealth or poverty; the standard of local health and social care services; lifestyle effects such as smoking, alcohol and drug use, diet, fitness; home and work exposure to hazardous substances; other past or present sources of pollution; population movements; genetic factors etc. See Chapter 5 for more detailed information about epidemiological research.

Table 3.2 ***Guidelines on assessing public exposure to hazards from potential emissions from waste management sites***

Step 1:Site characterisation : hazard identification

What is the current use of the site?
Is there any information on the nature of the waste handled by the site?
Was the site specially constructed to deal with waste or not?
Is the site accessible to the general public?

Key question: Are there any contaminants of concern and are there any potential emissions from the site?

Answer NO: then no further action is necessary in respect of hazards from emissions

Answer YES or UNCERTAIN: Proceed to step 2

Step 2:Characterisation of receptors : hazard assessment (a)

What is the size and composition of the population at risk?
What are the characteristics of the most highly exposed population?

Key question: Are there direct or indirect pathways leading to human exposure?

Answer NO: then no further action is necessary in respect of hazards from emissions

Answer YES or UNCERTAIN: Proceed to step 3

Step 3:Characterisation of exposure pathways : hazard assessment (b)

Consider each potential pathway in turn.
For each pathway ask the key question.

Key question: Are there any potential emissions of concern, which might travel from the facility along this pathway?

Answer NO: then no further action is necessary in respect of hazards from emissions

Answer YES or UNCERTAIN: Proceed to step 4

Step 4:Determination of concentrations of contaminants : risk estimation (a)

Measure or estimate the concentration of the emissions of concern in the environmental media with which humans might be in contact.

Key question: Do the maximum levels exceed any applicable limits, standards or guidelines?

Answer NO: then no further action is necessary in respect of hazards from emissions

Answer YES or UNCERTAIN: Proceed to step 5

Step 5:Exposure estimation : risk estimation (b)

Carry out exposure assessment by calculating the intake of contaminants using data on concentration intakes and the population at risk.
Is there potential for population exposure that might result in a health concern?

Answer NO: then no further action is necessary in respect of hazards from emissions

Answer YES or UNCERTAIN:
Consider whether epidemiological studies or health surveillance should be carried out and if additional data for exposure assessment could usefully be collected.

Key outcome: Risk management
What risk management actions should be taken?

(Modified from WHO European Centre for Environmental Research 2000)

3.2.10 The process of risk assessment

The process of risk assessment for MSW treatment facilities is usually undertaken in four key stages similar to the following:

(a) Hazard Identification. This is the identification of the inherent capability of any aspect of a waste management facility to cause adverse effects in terms of all possible sources, pathways and receptors. This stage assesses any potential hazards that are likely to be present at the site, taking into account its actual or intended use and environmental setting.

(b) Hazard Assessment. Considers the plausibility of the source-pathway-receptor linkages, the possible concentrations of substances at the point of exposure and the potential for health and environmental risks. It will include consideration of the exposure duration and frequency, the characteristics of the exposed population and the potential magnitude of the exposure in such terms as the daily dose and/or lifetime average daily dose.

(c) Risk Estimation. Estimation of the risk(s) that identified receptors will suffer adverse effects under defined conditions. May include consideration of dose-response assessment i.e. how potent are the toxic substances that may reach the receptor? (Section 3.2.4-3.2.6). Expression of risk may be in qualitative form (e.g. the risks are low or high) or more rarely in quantitative (numerical) terms (e.g. one in a million increased lifetime risk, Section 3.2.4).

(d) Risk Evaluation. This stage is a synthesis of critically evaluated data from the preceding stages into a summary that identifies clearly the strengths and weaknesses of the data, the criteria applied to evaluation and validation of the data, and the conclusions reached from the review of scientific information. The output is an evaluation of the need for risk management action (i.e. risk reduction or control measures) having regard to the nature and scale of actual or anticipated risk, the uncertainties of the assessment procedure and a broad cost-benefit analysis of any proposed actions.

Risk assessment of potential human health impacts from MSW is critically reliant on the available data on human exposure. Much of this data comes from epidemiological studies investigating possible links between waste management sites and the incidence of various types of disease.

A hierarchy of data types can be constructed as follows:

Table 3.3 ***Hierarchy of exposure data***

Best data

1. Quantified personal measurements
2. Quantified area or ambient measurements in the vicinity of the residence or other sites of activity
3. Quantified surrogates of exposure, such as estimates of drinking water use
4. Distance from site and duration of residence
5. Residence or employment in reasonable proximity to site where exposure can be assumed
6. Distance or duration of residence
7. Residence or employment in defined geographical area of the site

Worst data

As mentioned above most studies investigating links between waste management and health outcomes rely on the worst type of evidence, that of residence or employment near the site.

For example, take the risk assessment methodology used by Eduljee (1992) to characterise and evaluate the health effects arising from exposure to three landfill sites in England. The risk assessment involved simplifications of the exposure scenarios, of off-site transport of pollutants and of uptake at the point of exposure. According to Eduljee it is still possible to develop a credible estimate of the health risks to exposed populations even with these simplifications. This is difficult to accept because, amongst other things, adequate data needed, even for such simplified risk assessments, are not routinely collected. For example, on the level of the most basic data, unlike industrial waste for MSW there is rarely an adequate characterisation of the composition of the waste within the site nor are there useful data about flow characteristics. On this basis it might be concluded that truly meaningful and reliable risk assessments could not be carried out for the majority of waste management sites in the UK.

3.2.11 Risk management

Risk management involves evaluating alternative options within a political, regulatory, social, economic, scientific and technological framework, in order to determine the most appropriate and practical means of reducing risk to an acceptable level. Risk can never be reduced to zero. All human activity carries with it some risk. In practice the overriding principle is that risk is managed by breaking the source-pathway-receptor pollutant linkage(s). This may be done by such means as treating, removing or isolating emission sources, intercepting exposure pathways and/or by protecting or removing receptors. Risk management is based on the scientific output of the risk assessment procedures but takes into account other factors such as risk perception by the general public, planning constraints and the economic and technological feasibility of particular technologies.

Of major importance in this respect is the communication of risk by the professionals who carry out the assessments and the perception of that risk by the general public who are the, frequently unconvinced, recipients of the professionals' efforts and advice.

3.2.12 Risk communication and the perception of risk by the general public

(a) Perception of risk

The communication and effective comparison of the extent of risk, from a complicated scientific and technical field such as the potential health impact of waste management, is not an easy matter. Even experts in the field frequently disagree about the exact nature of the risks involved (as seen above in 3.2.5).

The individual person's perception of risk is strongly influenced by these following factors or personal heuristics:

Familiarity there is increased concern about unfamiliar issues.
Control there is increased concern when the individual feels unable to exert any control over events.
Proximity in space there is increased concern about nearby events.
Proximity in time there is increased concern about perceived immediate consequences rather than long term effects.
Scale can often be distorted, particularly by media coverage, where one large event appears much worse than a number of smaller events.
'Dread factor' lack of understanding may cause concerns to be exaggerated, leading to stress making further explanation more difficult.

Individuals' views of the world and the kind of society they wish to live in, also strongly influence judgements about risk. We live in a culture where readily understandable risks, such as road accident injury, are to a great extent accepted and even mentally minimised, whilst the less easily understandable risks, such as from pollution, are considered unacceptable. Indeed it is often naively considered that such risks should be completely eliminated even though the risk of death or serious harm from pollution is many orders of magnitude less than that from road accidents.

(b) Judgements about risk

Disagreement about the management of a potentially risky activity, for example incineration, occurs partly because of differences in interpretation of scientific evidence and also because of the different judgements people make about how risky they believe the activity to be, based on their individual set of heuristics.

Individuals and regulatory bodies try to avoid or control activities they judge to be too risky and ignore or tolerate others. Conflict occurs when people form different judgements about the perceived risk of an activity. Disagreements about risk are inevitable because there is no way to define risk that does not include values, beliefs and assumptions.

Disagreement occurs especially when information about a particular activity is scarce. This leads to uncertainty, with judgements about risk being based on the qualitative aspects of a potential hazard using assumptions and mental strategies to help form a decision.

When scientists make judgements about risk, the process is described as **risk assessment**. When members of the public make judgements about risk, the process is described as **risk perception**.

Scientists and technologists, for example, may consider public opposition to an incinerator to be irrational and based on ignorance but in fact, these 'experts' also make use of the same mental strategies, known as heuristics (simply put 'rules of thumb'), as the non-scientifically trained public.

Some commonly used heuristics are:

Availability. Where the frequency of rare, unusual, memorable causes of death (e.g. accidents) can be overestimated whilst more common ones (e.g. diseases) are underestimated.
Overconfidence. Where there is an unwarranted certainty in scientific measurements, which are only ever estimates and never the true or absolute value.
Trustworthiness of public institutions and officials. A recognition that human errors, organisational failings and patterns of management have very significant effects on the real life operation of technological systems.
Framing effect. Attitudes to risk may be influenced by the way choices are presented, e.g. a half empty glass seems worse than one that is half full.
Optimistic bias. The impression that one is less vulnerable and more knowledgeable about a hazard than other people.
Dose response. A belief that chemicals are either safe or dangerous, for example, seen in the controversy about endocrine disrupters and hormesis (3.2.5, 3.2.6).

When there is a lack of good scientific data, as is often the case with MSW management (4.3), and consequent uncertainty, experts are as prone to the use of these heuristics as the general public. Scientists may underestimate risks of technologies they are familiar with, may suffer from overconfidence in their judgements and may be insensitive to wrong assumptions in their work. They are often under political or economic pressures which can bias their judgements either consciously or sub-consciously. They are, after all, only human.

(c) Outrage factors

There are other aspects of risk that affect how risky individuals judge the activity to be and how much dread or distress is associated with it. For example there are the so-called 'outrage factors', which can be measured, assessed and controlled in the same way that hazard can be (Table 3.4).

In this case it is possible, indeed probable in most cases, that all the activities in the lower scoring column are of higher risk than the corresponding high scoring activity which is usually believed to be a higher risk.

Given the diversity of groups and views in society, there will never be complete consensus on risks or how to manage them. Better management of risks is possible if the different approaches to risk are recognised as valid. The main lessons for education and communication are making value judgements explicit, acknowledging and validating the outrage factors and communicating truthfully. For public decision making, the lessons are about sharing power and responsibility and about fostering public trust.

Table 3.4 Outrage factors: qualitative factors

Outrage factor	Higher scoring activities	Lower scoring activities
Lack of personal choice	Residence near a landfill site	Hang gliding
Lack of personal control	Residence near an incinerator	Garden bonfires
Global catastrophic potential	Train crash	Car crash
Fatal consequences	Cancer from fluoride	Pain from tooth decay
High risk to future generations	Birth defects from landfill sites	Sporting accident
Artificial source vs natural source	Pesticide residues in food	Aflatoxin in peanut butter
General unfamiliarity, new risk	New incineration technique	Landfill
Affects you personally	Living near landfill site	Living near stables in rural area
Uncertainty, lack of scientific knowledge	Health impacts of incineration	Impact of smoking

(d) The precautionary principle

Part of managing the risks associated with MSW treatment is to apply the precautionary principle, which is defined in The Rio Declaration on Environment and Development (UNCED 1992) as follows:

"Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation. When in doubt about the impact of a development, it will be managed according to the worst-case scenario of its impact on the environment and human health"

The conditions under which the precautionary principle applies are:

When health effects are most serious or irreversible.
When the subject is a matter of scientific uncertainty and full evidence is lacking.
When cost-effective risk management measures are possible.

All three conditions apply to waste management (Hens *et al.* 2000). Hens argues that to protect health, adherence to the waste hierarchy is necessary (see Table 2.1). Although this is universally accepted as a good idea in the UK, the majority of our waste is still sent to landfill, the option of last resort in the waste hierarchy. To move away from landfill and towards waste minimisation and re-use, we need to avail ourselves of new technologies and management techniques whilst at the same time applying the precautionary principle in all waste management decisions.

(e) Questions the public wants answered

Standard health risk assessment methods tend not to address the general public's view of judging risk. In a recent study of a proposed new waste incinerator in southern England McCarthy *et al.* (2005, pers. com.) state that during public consultation about this incinerator local residents considered health effects more important than environmental effects and that their primary concerns were about air-borne carcinogens and the effects of traffic.

In this respect it is important to note that the technique of life cycle assessment (LCA), particularly the Environment Agency's software tool WISARD, which may be used to evaluate the potential environmental impacts associated with waste management facilities (e.g. in MKC's Best Practical Environmental Option Assessment, Entec 2005) is designed to help inform decision-makers. When using WISARD, the Environment Agency recommends looking at four key environmental impacts, these being:

(1) Air acidification
(2) Eutrophication of water (enriching water with excess nutrients)
(3) Depletion of non-renewable resources
(4) Greenhouse effect.

These environmental impacts are not directly indicators of potential effects on health and are not what the general public is principally interested in when they are consulted about waste management facilities.

To answer the questions most often posed by the general public the ideal approach would be to carry out a full quantitative health impact assessment on specific facilities that includes a full evaluation of alternative risks and courses of action, the potential for catastrophic incidents and ways for people affected to contribute to the assessment and risk control in a meaningful way.

In an overview of the scientific evidence about the effects of particulates on health Maynard & Howard (2000) suggest that there is a significant degree of uncertainty about the impact of waste management operations on health, which may or may not ever be resolved by further research.

They conclude (quote):

"*The major problem in marrying policy and the science which informs it is that the time-scales of the two never match. This is true almost by definition, since if there were sufficient science in place, then the problem of characterising the scientific essentials of an issue is solved and policy formulation is then determined by consideration of other issues such as the social, economic and political aspects of the problem. Unfortunately, life is generally not this simple, and one often finds that there is insufficient scientific information compared with what ideally would be required*."

In effect they are suggesting that, despite the impressive amount of research and the high quality of many of the studies, further scientific research is almost always desirable if not essential. (Partly after Pheby *et al.* 2002).

3.2.13 The two opposing positions regarding potential health impacts

It is manifestly obvious that waste management decisions have to be made and the health of the public has to be protected. In an ideal world decision-making would be based on a rigorous assessment of abundant high quality scientific evidence. In reality, waste management decision making takes place in a highly charged political environment, with different interest groups driven by conflicting values and belief systems as well as by contrary interpretations of the same, unfortunately rather patchy, scientific evidence.

In effect informed debate has polarised into two apparently equally defensible positions:

The first position is essentially that there is little or no evidence of significant harm to human health from waste management operations. No human activity is completely safe but compared to other environmental health hazards (e.g. vehicle traffic) or compared to other causes of ill health (e.g. poor diet, lack of exercise, smoking, alcohol consumption, diseases), waste management operations are not a major public health concern. This position is exemplified by the (UK) National Society for Clean Air and Environmental Protection, which in its recent report on incineration, concludes (quote):

"While we cannot discount effects resulting from the small quantities of some pollutants emitted by MSW incinerators where impacts may occur at background levels (e.g. dioxins) or where current standards (limit values) may be exceeded (e.g. nitrogen dioxide) the large number of other important sources of such pollutants suggest that these deserve a greater emphasis on regulatory control" (Farmer & Hjerp 2001).

The second position takes as its starting point that lack of evidence is not the same as evidence of lack of health impacts. Waste management methods may have a major impact on health but the limitations of the research make it impossible to determine whether this is the case. This position is exemplified by the Greenpeace incineration report, which concludes (quote):

“With the limited data available, it is, therefore, impossible to predict health effects of incinerators, either new or updated installations. There is an urgent need for the complete phase out of incineration and the implementation of sound waste management policies based on waste prevention, re-use and recycling."
(Allsopp *et al.* 2001)

Within the context of the effects of MSW management on health and the environment we have to decide whether either, or both of these positions is based on a sound rational interpretation of all the available data, or if either, or both, are seriously flawed by not being primarily concerned with potential health and environmental impacts or being based on an unwarranted set of heuristics, possibly compounded by preconceived assumptions and socio-political standpoints.

Whatever we believe as individuals, in the real world we still have to manage our waste using currently available techniques. How we do this has to be based on our best estimates of overall cost-benefit, using those techniques that are the least damaging to health and the environment within a tight regulatory controlled system to manage the inevitable risk involved in any human activity.

3.2.14 The attitude of the general public to hazards from MSW management

A survey carried out in the UK in 2002 (Eurobarometer 58.0, European Commission, Spadaro, 2002) showed that waste management was not one of the public’s principal environmental concerns. Less than a quarter (24%) were “very worried” about domestic waste, whilst 37% were “very worried” about industrial waste.

Domestic waste management was the 18th highest concern, with industrial waste management the 11th highest concern out of 25 listed.

If this is the case why are public attitudes to specific waste management facilities usually strongly negative? Unfortunately waste treatment facilities frequently produce negative responses based on the heuristic judgements of the acceptability of risk outlined above (Section 3.2.10). Waste management facilities have many of the characteristics noted as increasing the unacceptability of the associated risks:

- **Familiarity:** The risks are unfamiliar (e.g. emissions with obscure names, dioxins, PAH, endocrine disrupters etc.).
- **Control:** The risks are imposed, cannot be controlled by individuals;
- **Proximity in time:** The risks may not be immediately apparent to local residents, and may be delayed.
- **Proximity in space:** The risks are focused around the individual facilities, whereas the benefit of the facilities is shared across society as a whole.
- **Scale:**
    - The health and environmental risks of waste management have been frequently exaggerated and subject to controversy and contradictory information from pressure groups and industrial sources;
    - Particular attention has been focused on emissions of dioxins from MSW facilities, to the extent that a balanced message is not communicated;
    - Improvements in the control of dioxin emissions from MSW facilities, and the significance of other sources of dioxins are not always appreciated.
- **Dread factor:**
    - Implied risk of dread disease or deaths (e.g. cancer, birth defects);
    - The risks arise from man-made facilities and materials in the waste;
    - Some of the risks affect children and future generations.

We instinctively believe that waste is dirty and unhealthy, which in part is a survival mechanism to avoid disease from direct contact with putrefying materials. This instinct is also applied to waste management facilities. This is exacerbated by the public's lack of understanding of what is involved in MSW management.

The National Society for Clean Air and Environmental Pollution (Farmer & Hjerp 2001) noted that *"public understanding and awareness of waste issues is currently very poor"*. A similar conclusion was reached in a survey carried out for the Environment Agency Hazardous Waste forum.

The negative public attitude to MSW facilities is hardened when those facilities give rise to odours which raises the profile of the facility with the local community. We all tend to believe 'if it smells bad it may cause harm' and some odours are indeed associated with potentially harmful chemicals.

This effect was exemplified in Milton Keynes in January 2001 when due to a lack of proper management control the Bletchley/Newton Longville Landfill site emitted large quantities of hydrogen sulphide (H_2S) gas over a period of several months (Section 1.3.5). This gas not only smells bad ('rotten eggs') but is highly toxic. Although the concentration of the gas encountered in nearby residential areas was judged to be too low to have any significant long-term health effects, at times the odour was appallingly nauseous. It is then no surprise that the entirely justified concerns engendered in the local community at the time have in no way convinced them that there are any benefits in having any type of MSW treatment facility in their locality.

All industries can have environmental problems, particularly if there is a failure of management and control. Unfortunately, as with the case in Bletchley, this can raise the profile of the problems, to the extent that the whole industrial sector becomes “tarred with the same brush” even though such problems may not be relevant to the vast majority of facilities.

Another very significant problem, particularly in ‘post-industrial Britain’ is the tendency for people to oppose any new large-scale facility close to their residence. With the shift away from manufacturing industry towards a service economy, there are relatively few new industrial facilities currently being constructed. In addition whereas in past years a new industrial development might have been welcomed for its job creating potential, in these times of relatively full employment this is often no longer the case.

Waste management is one of the few areas where new facilities are being proposed, thus they tend to become the focus of greater attention. In many cases health and environmental concerns are given as the main reasons for opposing the development of a MSW facility whereas in reality the main, unspoken, concern is that such a development will have a negative impact on property values.
(Largely after Enviros *et al.* 2004).

3.3 Emission sources, pathways and receptors

3.3.1 Emissions released by normal, abnormal and ancillary operations

Almost all the information available about emissions from MSW treatment facilities deals with operation under normal conditions with the facility meeting, or exceeding, regulatory requirements. However, there will be occasions when the facility will experience conditions that are not normal and the regulatory conditions might not be met, leading to higher emissions for a short period.

For example, slope failure on a landfill site might allow the uncontrolled escape of gas and leachate; abatement equipment in a chimney-stack might fail allowing excess gaseous emissions; the waste feed to a pyrolysis/gasification plant might be interrupted, etc.

However, since the evidence for health and environmental effects is obtained from studies undertaken during actual operation of facilities they will include periods when the facility was operating under abnormal conditions. Thus the epidemiological evidence in respect of human health, and the field evidence for environmental effects should include the effects of temporary operation under abnormal conditions.

If abnormal operation led to short periods of higher than normal emissions this probably would not be significant when considering long-term effects of exposure, such as cancer incidence. It could, however, be significant when considering conditions such as respiratory irritation and compounds with developmental toxicity.

It is pertinent to note that past evidence of frequency of operation under abnormal conditions, outside regulatory requirements, does not necessarily indicate the future frequency of such events. Regulation and control has improved substantially in recent years, for example modern landfill sites are much better designed than those of previous decades; breaches of licence conditions for MSW incinerators are decreasing year by year.

Ancillary operations are rarely fully included in assessments of impacts from a particular facility. This would include such things as transport impacts (gaseous and particulate emissions to air, noise, dust, odour etc.) from transporting waste to the facility and transporting products away from the facility. Even the emissions generated by the workers in travelling to the site should be considered as an ancillary impact, as they would not occur if the site did not exist. Then there are the potential impacts on health and the environment during the construction phase of the facility. Ideally all these impacts need to be assessed and measured. In reality this is very difficult to do in a truly meaningful manner. However, this is where the future thrust of health impact assessment will have to be if our decisions about such things as MSW management facilities are to be made on a sound basis of well-founded information.

3.3.2 Introduction to emissions from MSW treatment

(a) Origin of emissions

Direct outputs of gaseous, liquid and solid materials leading to the pollution of air, water and land are the three most obvious categories of negative effect that might result from inadequately controlled emissions from a MSW management site.

Less obvious but still potentially damaging emissions include those of indirect deposition from air to land of inorganic (dust) particulates and organic dust (bioaerosols) leading to biological hazards, and also odour and noise emissions. All of these emissions have the potential to cause annoyance and health problems if MSW facilities are not managed in such a way as to minimise such emissions.

Some of the potentially hazardous substances encountered during waste processing are already in the waste prior to treatment and may be emitted when it is handled, some are produced or released when the waste is treated, others are leached into water which is then treated and discharged.

The specific emissions from a facility are dependent on the material being treated (e.g. whole MSW or particular fractions of MSW such as organic waste), the type of facility, the efficiency of the emission controls and to some extent the effectiveness of the management of the facility and its regulatory control. This means that a non-site specific review such as this can only give an approximate overview and comparison of what the emissions might be from particular MSW management facilities.

(b) Emissions to air

All MSW management facilities will give rise to some emissions to air, even if it is only the 'extra' emissions generated by transport associated with the facility. However, emissions to air directly from the process, such as gaseous emissions from thermal treatment, will be subject to regulatory control (Section 4.3.2) and will be treated prior to discharge to meet with regulatory requirements. However, once the emissions are released into the atmosphere they can no longer be effectively controlled and it is a case of 'what is there is what we breathe'.

Emissions to air can be divided into three types:

(i) **Gaseous emissions** such as sulphur dioxide (4.1.1, 4.1.2);
(ii) **Inorganic particulate** (dust) emissions (below and 4.1.3);
(iii) **Organic dust** (bioaerosol) emissions (4.1.4).

(c) Emissions to water

Emissions to water are commonly associated with MSW treatment, particularly landfilling and composting but also from other processes, for example some thermal treatment involves using water which becomes contaminated and has to be treated and/or discharged in an appropriate manner. Such waters are normally discharged to off-site sewage treatment works, usually after on-site treatment to a standard agreed by the regulatory controls and the sewage treatment company. Leachate may also be slowly released from a landfill, even in modern landfills with a fully engineered liner system there will still be some leakage through the system. At some landfills the leachate is first treated on-site and then discharged to surface water in much the same way as discharges from sewage treatment works (4.1.6).

(d) Emissions to land

Emissions to land fall into two categories indirect and direct:

(i) **Indirect:** emissions deposited from air to land. For example, deposition from gaseous emissions to air (4.1.2) or as particulate deposition from dust emissions (4.1.3);

(ii) **Direct:** such as by spreading composted material to land; recycling residues from incinerators, or pyrolysis/gasification processes; and landfilling of residual materials (4.1.5).

All of these have the potential to form pathways for contaminants from waste treatment sources to reach human or environmental receptors. However, they do not in themselves necessarily constitute a complete source-pathway-receptor linkage.

In contrast to inhalation of airborne emissions there are 'secondary' controls on water and food quality, which limit the potential for complete source-pathway-receptor linkages from MSW treatment via emissions to land and water resulting in ingestion by humans (Section 3.3.3). Even if such emissions did occur, in such a way as to represent a possible health hazard via food or drinking water, this should be detected by normal regulatory monitoring allowing action to be taken to break the pathway.

However, it has to be said that in spite of these controls, the major human body burden of some very significant toxins is still from food and drink e.g. 'dioxins'. Furthermore there is considerable controversy over the potential for 'low-dose effects' from what are currently considered 'tolerable daily intakes' of such toxins (Sections 3.2.4, 3.2.5).

(e) Emissions of particulate matter (PM)

All MSW treatment techniques are capable of generating particulate emissions either directly from the process itself or indirectly from transport to and from the facility.

Airborne particulate matter includes a wide range of particle sizes and many different chemical constituents. It contains both primary components emitted directly into the atmosphere and secondary components, which are formed within the atmosphere as a result of chemical reactions. Airborne particulate matter is much more complex than most other common air pollutants. Not only is it a mixture of different chemical substances, individual particles also span a wide range of sizes. Both chemical composition and size are related to the sources of airborne particles, and these parameters also determine the atmospheric behaviour and fate of particles and their influence on human health.

(f) Emissions of bioaerosols

The main biological hazard associated with MSW treatment is related to the formation of bioaerosols (more or less synonymous with organic dust). These are airborne particles comprising large molecules or volatile compounds that are living or contain living organisms or were released from living organisms. The size of a bioaerosol particle may vary from 100 microns to 0.01 micron. The behaviour of bioaerosols is governed by the principles of gravitation, electromagnetism, turbulence and diffusion, which control all airborne particles.

(g) Emissions of odour

Most MSW treatment techniques have the capacity to generate odour and complaints to Environmental Health departments about such odours are quite common. For example, in Milton Keynes there have been very significant numbers of complaints (up to hundreds in a period of a few months) about odour from landfilling and from composting operations (both the composting process and the spreading of composted materials). In these cases the complaints are primarily caused by occasions of abnormal operation when normal management control has failed. Even the process of rubbish collection from the roadside can produce odours with resulting annoyance to those in the vicinity, particularly in the summer months.

There is a commonly held intuitive feeling that if something smells bad it may cause damaging health effects. In some cases this is undoubtedly true, for example hydrogen sulphide (‘rotten egg’ smell) smells bad and is highly toxic, even more so than hydrogen cyanide. However, in many, probably most, cases of odour there are no direct toxic effects.

(h) Emissions of noise and vibration

All MSW management facilities generate noise and vibration, which if inadequately controlled can represent a hazard to health, particularly to workers engaged in the noisy activity.

Excessive noise from any activity, whether industrial or domestic, is considered a particular nuisance by most people. This is especially so if the noise occurs at night or during otherwise quiet periods such as weekends and national holidays. Complaints about noise make up one of the largest categories of complaints to Environmental Health departments. Here in Milton Keynes the Environmental Health Division receives many noise complaints each year. These include complaints about early morning refuse collection and complaints about noise from sources such as landfill sites. Noise is rarely considered as a health problem, but it can lead to definite negative health effects (4.1.7). However, such effects are usually from activities that would be categorised as extremely noisy, or at very anti-social hours, and properly managed MSW treatment facilities should not generate such noise.

3.3.3 Exposure pathways, routes and doses

(a) Exposure pathways are the essential link between the source of potentially hazardous emissions and a receptor that may be at risk from that hazard (3.2.2). The potential pathways for emissions from MSW treatment sites are principally via air, water or land. The transfer of emissions in and out of the various environmental media and the dispersion of emissions within those media are governed by geochemical, biochemical and physical principles, such as partitioning, dilution, biodegradation and bio-concentration etc.

This is quite distinct from the exposure route, which refers to the way in which a hazardous substance enters an organism after contact.

(b) Exposure routes

There are three principal exposure routes to potentially hazardous emissions from MSW treatment sites, inhalation, ingestion and dermal contact, which fall into four categories:

(1) Inhalation of contaminated air
(2) Ingestion of contaminated soil, either by deliberate eating of soil or soil attached to vegetables
(3) Ingestion of contaminated water
(4) Dermal contact with contaminated soil or water.

[Note: Soil eating is a well know phenomenon of which there are three classes:
Soil ingestion is the consumption of soil. This may result from various behaviours including, but not limited to, mouthing, contacting dirty hands, eating dropped food, or consuming soil directly.
Soil-pica is the recurrent ingestion of unusually high amounts of soil (i.e., on the order of 1,000-5,000 milligrams per day). Groups at risk of soil-pica behaviour include children aged 6 years and younger and individuals who are developmentally delayed.
Geophagy is the intentional ingestion of earths and is usually associated with cultural practices.]

The most important point about the ingestion of soil is that children do it far more than adults do.

(c) Exposure dose. The amount of any potentially toxic substance that is received by a body is usually termed the dose. The dose will be dependent on the duration and intensity of the exposure. Organ dose refers specifically to the amount that reaches a named human organ where the relevant effects can occur, e.g. the lung.

Human exposure to potentially toxic substances occurs as a result of contact with contaminated food, water, air, or soil. In many cases, exposure may occur simultaneously from many sources and through multiple routes. A number of different pathways, such as eating, drinking, breathing indoor air, and so on, may contribute to the dose of a particular substance that a person receives. Pathways of exposures to the heavy metal lead (Pb), for example, include air pollution from traffic and industrial (including MSW treatment) emissions, drinking water, food, tobacco smoke, dusts, paints and from soil. Part of the dose of most substances originates from natural sources, e.g. heavy metals in natural soil minerals. Part of the dose results from anthropogenic activities, e.g. industrial activities such as fall out from metal smelters increases the amount of heavy metals in soil.

To characterise health risks, it is essential to estimate the cumulative dose of a chemical received via all pathways contributing to the three main exposure routes of ingestion, inhalation, and dermal contact. A valid exposure assessment requires detailed knowledge about the geographical distribution of the pollutants of concern, the temporal variations in pollution levels, and the processes of exposure. The total dose a person receives is a function of contaminant concentrations in different media and various exposure factors. These factors include a person's breathing rate, body weight, time spent in various locations, at school, work, in the garden, etc., time spent engaging in various activities such as showering, swimming, resting, etc., and dietary choices.

3.3.4 Background pollution

The term ‘background pollution’ is frequently used in environmental impact assessments, and other reports, but unfortunately it has been defined in a variety of different ways, for example:

The level of pollution experienced when all more immediate and intrusive sources (contaminants, sounds etc.) are eliminated; that constant level of pollution from more faraway sources. Or:

The pollution that would exist at a given point if it were unaffected by pollution arising from a specific source.

The second definition is subtly different from the first and is often used when the contribution to the pollution load of a specific development, such as a waste management facility, is being estimated. Here background pollution is often considered to be the pollution load existing prior to the development of the facility.

While total pollutant concentration is the sum of locally and non-locally produced pollution, only the locally produced pollution can be locally regulated. In such cases pollutants that are transported in from the outside, or which would have been present naturally, are sometimes called background pollution.

Here we have another definition of ‘background pollution’ that of ‘naturally produced pollution’. In the case of air pollutants this ‘natural background pollution’ would include the following:

1. Wind blown dust.
2. Volcanic ash and gases.
3. Ozone from lightning and the ozone layer.
4. Esters and terpenes (volatile organic compounds) from vegetation (especially pine and citrus).
5. Smoke, gases, and fly-ash from forest fires.
6. Pollens and other aeroallergens.
7. Gases and odours from natural decomposition.

8. Natural radioactivity.

Thus there is a distinction between 'natural pollution', for example metals in soil, such as Pb or As, liberated by the weathering of naturally occurring minerals, and 'anthropogenic pollution' representing the contribution to the pollution load from human activities, industry, transport etc.

In the case of the assessment of waste management facilities perhaps the best definition of background pollution would be the pollutant load that exists or existed prior to the development of the facility. Part of this 'background pollution' would be anthropogenically derived, part would be derived from natural processes.

3.3.5 The exposed population and population studies

(a) Exposed population studies
The term "exposed population" is frequently used in studies of potential health effects from waste management facilities. The term usually means those people who might be expected to be exposed to any potentially harmful effects of the facility. Often the plural of the term is used - "populations". In effect this is used to refer to sub-populations such as: workers on the site (occupational exposure); people living near-by (residential exposure); people using the surrounding area for recreational purposes; even trespassers on the site represent an exposed population.

Most exposed population studies involve people living near potential sources of environmental pollution. There are many well-known examples of such studies, which not uncommonly lead to sensationalised reporting in the mass media. For example studies of people living near nuclear facilities, waste disposal sites etc. (Shaddick & Elliott 1996; Michelozzi *et al.* 1998; Dolk *et al.* 1998; Viel *et al.* 2000; Kokki *et al.* 2001; Elliott *et al.* 2001; Pukkala & Ponka 2001; Vrijheid *et al.* 2002).

(b) Difficulties with exposed population studies
There are a number of significant difficulties with this type of study. For example:

- How do you define what the health of the population would have been had the facility not existed?

- Waste management sites are often located in or near industrial areas. Industrial facilities are normally located in areas of relative socio-economic deprivation where the inhabitants may have substantially worse health than more affluent people. Therefore, a population living in such an area tends to have higher rates of many diseases than the general population.

- Workers in a facility often live near their place of work. This means that the observed health effect of living near a facility may be a combination of the effects of working in the facility and the effects of exposure to off-site emissions.

- Studies of occupational exposure have a great deal of information about the worker population such as, occupational health records, pension records, employment histories, exposure measurement, details of processes etc. These allow a detailed assessment of the likely level of exposure, and give many opportunities to identify some of the consequences of that exposure.

- A typical residential study will only know that a person was recorded as living in a given location. It is often not possible to say how long they lived there, or precisely where they lived in relation to the source of exposure because, for example, location may be based only on postcode not individual addresses.

- Population movement within the study period may not be adequately recorded. So it might be that a person was diagnosed with cancer shortly after moving into the study area; whereas another person could live in the study area for many years, move away, and then fall ill. In the first case the illness would have had no connection to the facility being studied, in the second case there may have been a link but the case would not have been included in the statistics. (After Crowley *et al.* 2003).

Changes to the health of a particular population result from interactions between impacts affecting health and the state of health of the exposed population prior to such impacts. In any population, whether or not it is exposed to anthropogenic pollution, there will be unexplained health problems. Potential health problems experienced by the population exposed to emissions from waste management sites and no different to health problems experienced by the population as a whole. There are no unique health effects specifically resulting from exposure to emissions from waste management sites. There are only a limited number of ways in which the human body reacts to negative, or positive, impacts. This makes it difficult to isolate any possible effects arising from exposure to emissions from waste sites, or indeed any other emissions. This is compounded by factors such as: in many studies there is a long time gap between possible exposure and the start of the study; immediate health problems can be missed; people move out of the area making it hard to trace them; etc.

Exposed population studies which do not include a control group are unreliable because health is strongly affected by characteristics such as race, social class, smoking, alcohol use, age, sex, diet and occupation which have little to do with exposure to contaminants from waste management sites. It is difficult to find an appropriate control group matched for all such confounding risk factors. Ideally the only difference between the control group and the study's exposed population should be exposure to potential hazards from the waste management site under investigation. The control group should not be exposed to those hazards, either from the waste management site being studied or any other location.

(c) Vulnerable sub-populations. The human population is very variable, unlike laboratory animals used in toxicology tests, which are bred for homogeneity. Within the spectrum of the human population are sections, or sub-populations that are especially vulnerable. In particular, children, foetuses, women of childbearing age, the elderly, and anyone who is already ill or has a compromised immune system, are particularly sensitive.

Children are very different to adults and cannot be treated merely as mini-adults. They differ substantially in body composition and maturity of biochemical and physiological functions (Hansen *et al.* 2000). The foetus is particularly vulnerable. It is a proven fact that many chemicals cross the placenta and can affect foetal development without obvious effects on the mother. Young children exposed to contaminants in soil are more at risk than adults are, because of their behaviour, which leads to ingestion of soil from dirty hands and toys (Section 3.3.3).

The older population is more vulnerable to some contaminants as, for example, they are more likely to have impaired cardiovascular systems. In addition to differences between age groups, inter-individual variation affects an individual's predisposition to health outcomes. There is an interaction between a person's genetic inheritance and the environment they live in which affects their resistance or sensitivity potentially health-effecting impacts and may explain why some families exposed to certain pollutants are affected while others are not. Within families an individual's genetic make-up may strongly affect their reaction to environmental pollution.
(After Pheby *et al.* 2002.)

4. Review of information on potential hazards and impacts

4.1 Overview of emissions and hazards

Most of the available information on emissions from MSW treatment concerns emissions to air. This is not necessarily because the impacts of emissions to air are more significant than other releases. It suggests that there is a lack of information on releases to other media. There is no information available which enables emissions from composting (other than particulate matter), MBT or anaerobic digestion to be properly quantified.

4.1.1 Emissions to air

The main emissions to air, from MSW treatment, which have the potential for significant health and environmental impacts are:

(i) **'Greenhouse gases'** with global climate altering potential, most significantly carbon monoxide CO, carbon dioxide CO_2, methane CH_4 and nitrous oxide N_2O (Section 4.1.10 below);

(ii) **Acidic inorganic gases** such as nitrogen oxides NO_X (mainly nitrogen dioxide NO_2, and nitric oxide NO), sulphur oxides SO_X (mainly sulphur dioxide SO_2), halides of hydrogen (mainly hydrogen chloride HCl, with much smaller amounts of hydrogen fluoride HF);

(iii) **Volatile organic compounds** (VOCs), the ten most abundant (by weight, kt kilotonne) non-methane volatile organic compounds (NMVOCs) emitted from waste treatment are ethane (5.5 kt), propane (5.11 kt), formaldehyde (3.4 kt), ethylene (1.07 kt), benzene (0.89 kt), ethanol (0.27 kt), toluene (0.16 kt), ethylbenzene (0.12 kt), tetrachloroethene (0.12 kt) and hexane (0.1 kt);

(iv) **Organic chemical micro-pollutants**, these are often present where combustion has not been complete, or are formed after incineration has occurred. The organic compounds may be released as vapour or bound to particulates. Primarily dioxins and dioxin-like compounds such as some furans and some polychlorinated biphenyls (PCBs), most of these occur adhering to particulate matter.

(v) **Polycyclic aromatic hydrocarbons** (PAH); a group of over 100 different chemicals that are formed during the incomplete burning of coal, oil and gas, waste, or other organic substances like tobacco or grilled meat. PAHs are usually found as a mixture containing two or more of these compounds, such as in soot. They may occur in emissions attached to particulate material.

(vi) **Volatilised metals**, such as As, Cd, Ni, Hg; these are present as soluble compounds, such as chlorides and sulphates, and less soluble compounds, such as oxides and silicates. Hg, and some Cd, is released as vapour.

(vii) **Particulate matter**, fine particles including dust and soot, often consisting of inorganic materials such as silica (SiO_2, silicon dioxide), frequently with metals and organic compounds on their surfaces. They vary greatly in size, but recently, concern has focussed on ultrafine particles of less than one hundred thousandth of a metre (10 microns) – these are known as PM_{10}. (Section 4.1.3 below).

(viii) **Bioaerosols,** airborne particles comprising large molecules or volatile compounds that are living or contain living organisms or were released from living organisms (Section 4.1.4 below).

With the exception of methane and cadmium (Cd), less than 2.5% of total UK emissions to air come from MSW management. However, 27 % of UK emissions of methane and 10% of emissions of Cd come from MSW, in both cases very largely from landfill sites.

Table 4.1 Emissions from Waste Treatment in the UK

	Total emissions from waste (kilotonnes)	Waste emissions as % of UK total emissions	UK total emissions (kilotonnes)
Methane	690*	27	2,427
Carbon dioxide	3,600	2.4	147,500
Carbon monoxide	18	<1	3,200
NMVOCs	0.2	<0.02	1,676
Benzene	0.002	<0.02	16
NO_x as NO_2	10	<1	1,512
Nitrous oxide	4.2	3	132
Sulphur dioxide	2.0	0.17	1,165
Halides of hydrogen (HCl, HF)	0.47	0.53	88
Ammonia	12	4	285
Particulates PM10	0.2**	0.12	172
PAH		<3	2.04
'Dioxins' in g TEQ	2.9 g TEQ	0.81	360 g TEQ

* Nearly 90% of waste methane emission is from landfill

** Bonfire Night is responsible for about 0.9 kt.

TEQ expressed as a concentration equivalent to the most toxic dioxin – 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD).

Data from National Emissions Inventory 2000; National Society for Clean Air.

There is little available data about PAH (polycyclic aromatic hydrocarbon) emissions. Overall PAH emissions from MSW treatment are probably rather less than 3% of total national emissions to air (data from Dore *et al.* 2004), but the available data suggests emissions from incineration are unlikely to be significant. Road traffic will have a more significant effect on local levels of PAH than a MSW incinerator.

Data on metal emissions is mainly for incineration and landfill. Taken together metal emissions from incineration and landfill as a percentage of total national emissions amount to about 0.1% for As, 10% for Cd, 1.65% for Hg and 0.2% for Ni (data from Dore *et al.* 2004; Enviros *et al.* 2004).

McCarthy *et al.* (2005, pers com), who have carried out research into quantifying the potential health impacts for a proposed new waste incinerator, when considering the extra traffic generated by such a facility conclude (quote) "Traffic probably contributes to local air pollution more than the incinerator…".

4.1.2 Gaseous emissions deposited from air to land

Atmospheric deposition is the process by which airborne pollutants are deposited to the earth. Emissions of such pollutants from MSW treatment include, but are not limited to, sulphur dioxide, nitrogen oxides, ammonia, and mercury (also particulates see below). Total deposition consists of both wet and dry components. Wet deposition occurs when pollutants are deposited in combination with precipitation, predominantly by rain and snow, but also by clouds and fog. Dry deposition of particles and gases occurs by complex processes such as settling and adsorption.

Sulphur dioxide combines with water vapour in the atmosphere to produce acid rain. Both wet and dry deposition lead to damage and destruction of vegetation and the degradation of soils, building materials and watercourses.

Nitrogen dioxide has a variety of environmental and health impacts. It is a respiratory irritant, may exacerbate asthma and possibly increase susceptibility to infections. In the presence of sunlight, it reacts with hydrocarbons to produce photochemical pollutants such as ozone (see below). In addition, nitrogen oxides have a lifetime of approximately one day with respect to conversion to nitric acid. This nitric acid is in turn removed from the atmosphere by direct deposition to the ground, or transfer to aqueous droplets (e.g. cloud or rainwater), thereby contributing to acid deposition.

Acidification of water bodies and soils, and the consequent impact on agriculture, forestry and fisheries are the result of this deposition of acidifying compounds resulting principally from the oxidation of primary SO_2 and NO_2 emissions from combustion processes.

However, these effects are mainly a result of long-range transport of pollutants from sources such as power stations, refineries and iron and steelworks. Most other activities, including MSW treatment, have a negligible contribution to these effects (Table 4.1).

4.1.3 Particulate emissions to air

Particulate metals in air result from activities such as fossil fuel combustion (including vehicles), metal processing industries and waste incineration. There are currently no EC standards for metals other than lead (Pb), although several are under development. Lead is a cumulative poison to the central nervous system, particularly detrimental to the mental development of children

The most important distinction is between *primary* and *secondary* atmospheric particles. Primary particles are those emitted directly from a source and therefore include particles arising directly from combustion sources such as road vehicles and power stations, as well as those generated by mechanical processes, for example, quarrying and agricultural harvesting. The land and the sea are both major sources of primary particles through entrainment of soil dust by the wind and the generation of marine aerosol particles by the bursting of air bubbles entrained in breaking waves.

Secondary particles are not emitted directly from sources, either natural or anthropogenic. Rather, they are formed in the atmosphere as a result of chemical reactions producing substances of low volatility, which consequently condense into the solid or liquid phase, forming particulate matter. Such particles are generally the result of atmospheric oxidation processes and the substances oxidised may be either natural or anthropogenic in origin.

MSW management is responsible for emissions of 0.2 kt of particulate material per year. This is about 0.1% of the UK total emissions of particulates. This is much less than the particulate emissions from bonfire night, which amount to about 0.9 kt (data from National Society for Clean Air).

Descriptions of particles often refer to size of particles in the following categories:

Nanoparticles: particles smaller than 50 nm (nanometres, 10^{-9} m) diameter.
Ultrafine particles: particles smaller than 100 nm diameter.
Fine particles: most often taken to be those in the $PM_{2.5}$ fraction.
$PM_{2.5}$: mass concentration of particles passing a size-selective inlet designed to exclude particles greater than 2.5 µm aerodynamic diameter, i.e. those smaller than 2.5 µm (micrometres 10^{-6} m).
Coarse particles: most often taken to be those in the $PM_{2.5\text{-}10}$ fraction.
$PM_{2.5\text{-}10}$: particles measured by mass, determined by the difference between PM_{10} and $PM_{2.5}$.
PM_{10}: particles measured by mass passing a size-selective inlet designed to exclude particles greater than 10 µm aerodynamic diameter, i.e. those smaller than 10 µm.

Fine particles are so small that several thousand of them could fit on this full stop. It is believed that the finer particles may represent a greater hazard to health as they can be breathed deeper in to the lungs.

Some constituents of airborne particles, most notably ammonium nitrate and polycyclic aromatic hydrocarbons (PAH) are termed semi-volatile and are able to partition (i.e. be partly in one phase partly in the other) between particles and the vapour phase. Major chemical components of airborne particles include sulphates, nitrates, ammonium, sodium chloride, elemental and organic carbon, mineral particles and coarse, iron-rich particles generated by vehicles. Some particles in the atmosphere also contain chemically bound water that is not removed completely under the drying conditions used in the standard European weighing procedures so the water contributes to the measured particulate mass.

Based on studies of human populations exposed to high concentrations of particles (sometimes in the presence of SO_2) and laboratory studies of animals and humans, particles have very significant effects on human health. These include effects on breathing and respiratory symptoms, aggravation of existing respiratory and cardiovascular disease, alterations in the body's defence systems against foreign materials, damage to lung tissue, carcinogenesis and premature death.

The major subgroups of the population that appear to be most sensitive to the effects of particulate matter include individuals with chronic obstructive pulmonary or cardiovascular disease or influenza, asthmatics, the elderly and children. The fine particles are the major health concern because they easily reach the deepest recesses of the lungs. Numerous scientific studies have linked particulate matter, especially fine particles either alone or in combination with other air pollutants, with a series of significant health problems.

These include: premature death; respiratory related hospital accident & emergency visits and admissions; aggravated asthma; acute respiratory symptoms, including aggravated coughing and difficult or painful breathing; chronic bronchitis; decreased lung function experienced as shortness of breath; work and school absences.

It has been estimated that tens of thousands of elderly people die prematurely each year from exposure to ambient levels of fine particles. Studies also indicate that exposure to fine particles is associated with thousands of hospital admissions each year. Many of these hospital admissions are elderly people suffering from lung or heart disease. Breathing fine particles can also adversely affect individuals with heart disease, emphysema, and chronic bronchitis by causing additional medical treatment.

(See for example:
http://www.defra.gov.uk/corporate/consult/particulate-matter/index.htm
http://www.epa.gov/air/urbanair/pm/what1.html)

4.1.4 Emissions of bioaerosols

(a) Biological hazards

The main biological hazard associated with MSW treatment is related to the formation of bioaerosols (more or less synonymous with organic dust). These are airborne particles comprising large molecules or volatile compounds that are living or contain living organisms or were released from living organisms. They can include fungi, pathogenic or non-pathogenic live or dead bacteria, viruses, high molecular weight allergens, endotoxins, mycotoxins (and other parts of bacterial and fungal cells) and other particles. The size of a bioaerosol particle may vary from 100 microns to 0.01 micron. The behaviour of bioaerosols is governed by the principles of gravitation, electromagnetism, turbulence and diffusion, which control all airborne particles. The size range is from that of pollen 100 microns (μ, micrometre, one millionth of a metre), pollen spores 10 μ, bacteria 1μ and viruses 0.01 μ. Many millions of viruses or virions could fit within the cross-section of a single pollen.

[Note: Endotoxin is occasionally used to refer to any "cell-associated" bacterial toxin. However, properly it should be reserved for the lipopolysaccharide complex (LPS) associated with the outer envelope of Gram-negative bacteria such as *E. coli*, *Salmonella*, *Shigella*, *Pseudomonas*, *Neisseria*, *Haemophilus*, and other leading pathogens.]

[Note: Mycotoxins are non-volatile, relatively low-molecular weight secondary metabolic products of fungi that may affect exposed persons in a variety of ways. Fungi that produce mycotoxins are referred to as toxigenic fungi. The most frequently studied mycotoxins are produced by species of Aspergillus, Fusarium, Penicillium, Stachybotrys and Myrothecium. However, toxins have been detected from many other fungi under certain growth conditions. Fungi that produce potent mycotoxins are seldom abundant in outdoor ambient air. Most toxic exposures occur from indoor growth of fungi related to excessive moisture. Some mycotoxins are carcinogenic, some are vaso-active, and some cause central nervous system damage. Often, a single mycotoxin can cause more than one type of toxic effect.]

Exposure to bioaerosols, particularly within the working environment, is associated with a wide range of health effects with major public health impact, including infectious diseases, acute toxic effects, allergies and cancer. Respiratory symptoms and lung function impairment are the most widely studied and probably among the most important bioaerosol-associated health effects. New industrial activities have emerged in recent years in which exposures to bioaerosols can be abundant, e.g. the waste recycling and composting industry, biotechnology industries producing highly purified enzymes and the detergent and food industries that make use of these enzymes. Dose–response relationships have not been established for most biological agents and knowledge about threshold values is sparse (Douwes *et al.* 2003).

Workers in the waste industry (e.g. waste sorting, organic waste collection and composting) are often exposed to very high levels of micro-organisms (van Tongeren *et al.* 1997; Douwes *et al.* 2000) and several studies have indicated a high prevalence of respiratory symptoms and airway inflammation in these workers (e.g. Douwes *et al.* 2000; Wouters *et al.* 2002).

(b) Incineration and biohazards. Most information sources on incineration do not reference biohazards. This reflects the main focus of attention on emissions from the incinerator chimney. Crook *et al.* (1987), on behalf of the Health and Safety Executive, examined bioaerosols in two incinerators in addition to other waste disposal locations. This study, together with that of Rahkonen (1992) measured concentrations of biohazards within the facility or immediately outside. It was found that levels reduced to background levels within 50 metres of the sites, suggesting that emissions from incinerators are not likely to be significant particularly as incineration involves combustion of waste at high temperatures for a sustained period achieving a substantial reduction in the volume of waste and effectively destroying pathogenic biological organisms.

(c) Biological treatment and biohazards. Enviros (2003) suggests that the primary atmospheric issue of concern at composting sites is the release of bioaerosols. Environment Agency research is quoted suggesting that bioaerosol levels tend to reach background levels within 250m of composting operations. The main hazards identified from composting are bioaerosols containing bacteria such as *Clostridium botulinum* and endotoxin-producing Gram-negative bacteria and/or fungal spores such as *Aspergillus fumigatus*. MBT plants also generate bioaerosols, as do materials recycling plants, especially dirty MRFs.

The main health impacts from composting (Bunger *et al.* 2000) are:

Inflammatory responses of the upper airways: congested nose, sore throat and dry cough.
Toxicoses: toxic pneumonitis due to endotoxins.
Infections: respiratory tract and skin.

Allergies: bronchial asthma, allergic rhinitis, extrinsic allergic alveolitis (hypersensitivity pneumonitis).

The association between bioaerosols and these health outcomes is clearly biologically plausible with an exposure route via inhalation (see Douwes *et al.* 2003).

4.1.5 Direct emissions to land

With the exception of particulate material (Section 4.1.3) deposited on land from the air these emissions are mainly due to the disposal of solid residues from the treatment of MSW. There are three principal mechanisms:

(a) Disposal to landfill
Any biodegradable component of the residue will degrade within the landfill. Its degradation will generate landfill gas and landfill leachate, which may subsequently be emitted to air, sewer or groundwater.

(b) Land spreading
Spreading of compost or digestate from anaerobic digestion to land is considered as an emission from MSW treatment to land. The effect of potentially toxic chemicals contained in materials spread to land depends on their quantity and bioaccessability. These are controlled through the application of standards such as British Standard BS PAS 100. This sets limits for human pathogens; potentially toxic elements (e.g. heavy metals); physical contaminants (e.g. glass, metal and plastic); substances toxic to plants; and weeds.

(c) Re-used materials

Some ash and char residues from thermal treatment processes can be re-used. Again, the potential exists for trace constituents of these substances to be leached out and potentially impact on receptors. Emissions to land, groundwater or surface waters in this way could potentially be significant.

(d) Availability and quality of information

Information on emissions to land from mass-burn incineration is generally of good quality, following a recent Environment Agency study. Information on emissions to land from other processes is of moderate or poor quality, or is not known. Because land spreading represents a possible pathway for public exposure to contaminants, further research should concentrate on the quantity and composition of residues from composting, MBT and anaerobic digestion of MSW, which are spread to land. Further work should also be carried out on the composition of ash arising from incineration of pre-sorted wastes (Enviros *et al.* 2004).

(e) Sources of MSW emissions to land

MBT results in the greatest mass of solid residue per tonne processed (60% of the mass of MSW processed). This is to be expected because MBT is an intermediate step in waste management.

Composting also gives rise to a significant mass of solid residue (50% of the mass processed). Residues from composting can provide a benefit when used to improve soil structure, and so this quantity of solid residue should not necessarily be viewed as a disadvantage of composting.

Mass burn incineration gives rise to an intermediate quantity of solid residue (bottom ash). Currently, in the UK, about one third of this is re-used, and two-thirds sent to landfill.

Pyrolysis/gasification gives rise to a relatively low quantity of solid residue per tonne processed, about half the quantity produced by mass burn incineration.

All waste combustion processes use some form of air pollution control system to remove acids from the exhaust gases. The residues from these air pollution control systems are strongly alkaline, which means that they need to be disposed of as a special waste.

Emissions of dioxins and furans in solid residues per tonne of waste processed are greatest for mass burn incineration. This may reflect the presence of dioxins and furans in the unsorted feedstock to MSW incineration processes. Also, while steps are taken to minimise the formation of dioxins and furans in the combustion process, a low level of dioxin formation will nevertheless take place. The primary fate for dioxins formed in this way is in the air pollution control residues.

The metals content of composted MSW is generally lower than that of ash residues from combustion processes. No clear pattern of levels of metals between different combustion processes emerges.

Materials Recycling Facilities provide an opportunity for materials in the waste stream to be recycled. Reprocessing materials in this way could result in increases or decreases in solid residues from processes remote from the MRF itself (Enviros *et al.* 2004).

4.1.6 Emissions to water

MSW treatment emissions to water are mainly from landfill and also from some composting, anaerobic digestion and incineration operations. They derive from water already contained in the waste or rainwater which 'leaches' out chemicals from the waste, producing a 'leachate'. Leachates, and other waters emitted from MSW treatment, comprise chemicals that have been dissolved in water, or form colloids or suspensions of particles in water. Such waters may look 'cloudy' (turbid) and may have a distinct odour, or they may be clear and odourless, but not necessarily 'clean'.

Substances that are of significant concern when discharged to surface or groundwater include:

Organohalogen compounds and substances which may form such compounds in the aquatic environment (e.g. dichloromethane, a paint remover also found in plastics and ink)
Phosphates lead to eutrophication of water, only a small fraction is emitted from MSW treatment, 50% of phosphate in water comes from agriculture and about 30% from sewage.
Nitrates also lead to eutrophication, again only a tiny fraction derives from MSW treatment.

Ammonia high levels can result in visible contamination in wastewater. The potential ecological impacts include excessive algae growth, sludge generation, poor water quality for the support of aquatic life.
Organo-tin compounds (e.g. tributyl tin) occurs in landfill leachate and emissions to sewer, there is no information on emissions from other MSW treatment processes.
Persistent hydrocarbons and organic toxic substances (e.g. PCP-pentachlorophenol, naphthalene, etc.) principally from landfills.
Cyanides from composting and landfill.
Metals and their compounds, principally from composting incineration and landfill.
Arsenic and its compounds, principally from incineration and landfill.
Suspended material leading to increased turbidity ('cloudiness'), which can effect aquatic life, can occur in all water emissions.
Oxygen using substances which have an unfavourable influence on the oxygen balance, measured using parameters such as biological oxygen demand (BOD) and chemical oxygen demand (COD).

These pollutants may undergo physical, chemical and biological changes, during and after emission from a MSW treatment facility that may markedly affect their impact on the receiving water.

4.1.7 Impact of noise and vibration

(a) Exposure to noise from various sources is most commonly expressed as the average sound pressure level over a specific time period, such as 24 hours. This means that identical average sound levels for a given time period could be derived from either a large number of sound events with relatively low, almost inaudible levels, or from a few events with high sound levels. This does not fully equate with the way in which humans experience environmental noise, or with the characteristics of human hearing.

Health effects from noise will include 'annoyance' effects (see above) and also effects from disturbed sleep patterns.

A majority of the population belongs to groups sensitive to interference with speech perception. Most sensitive are the elderly and persons with impaired hearing. Even slight hearing impairments in the high-frequency range may cause problems with speech perception in a noisy environment. From about 40 years of age, people demonstrate impaired ability to interpret difficult, spoken messages when compared to people aged 20–30 years. It has also been shown that children, before language acquisition has been completed, have more adverse effects than young adults to high noise levels and long reverberation times.

(b) Cardiovascular and psychophysiological effects of noise: epidemiological studies show that cardiovascular effects occur after long-term exposure to noise (particularly aircraft and road traffic) with LAeq, 24h values of 65–70 dB. However, the associations are weak. The association is somewhat stronger for ischaemic heart disease than for hypertension. Such small risks are important, however, because a large number of persons are currently exposed to these noise levels, or are likely to be exposed in the future. Other possible effects, such as changes in stress hormone levels and blood magnesium levels, and changes in the immune system and gastro-intestinal tract, are too inconsistent to draw conclusions. Thus, more research is required to estimate the long-term cardiovascular and psychophysiological risks due to noise.

(c) Mental health effects of noise: studies that have examined the effects of noise on mental health are inconclusive and no guideline values can be given. However, in noisy areas, it has been observed that there is an increased use of prescription drugs such as tranquillisers and sleeping pills, and an increased frequency of psychiatric symptoms and mental hospital admissions. This suggests that adverse mental health effects may be associated with community noise.

(d) Environmental noise effects may be evaluated by assessing the extent to which it interferes with different activities. Noise interference with rest, recreation and watching television seem to be the most important issues to most people. However, there is evidence that noise has other effects on social behaviour: 'helping behaviour' is reduced by noise in excess of 80 dBA (equivalent to very heavy traffic noise); and loud noise increases aggressive behaviour in individuals predisposed to aggressiveness. There is concern that schoolchildren exposed to high levels of chronic noise could be more susceptible to helplessness. (After: Berglund, B. & Lindvall, T. 1999).

(e) Typical noise levels associated with common sources include:

The noise level associated with conversation at 1 metre is about a 20 dBA increment.
The noise level associated with office activity is of the order of a 25 dBA increment.
The noise level associated with a vacuum cleaner at 3 metres is around a 35 dBA increment.

There are quantitative data on recorded incremental noise levels close to waste management facilities. For example:

Composting facilities	7 to 32 dBA increment.
Materials recycling facility	15 to 20 dBA increment.
Landfill	5 to 10 dBA increment.
Gasification/ pyrolysis	5 dBA increment.

(Enviros *et al*. 2004)

These are not very great increases when considered in the context of the normal background noise in an urban area.

4.1.8 Impact of odour

Many authors consider odour as an environmental, rather than a health problem (e.g. Enviros *et al.* 2004); however, it can have a significant effect on health as is shown by annoyance responses associated with the reporting of various somatic and psychosomatic symptoms. The most prominent of these are vomiting, nausea, dizziness, headache and irritation to eyes, throat and nose. It has been suggested that somatic symptoms are usually not directly associated with odour exposure, but are caused by annoyance reaction to the odour. This may also be acting as a sensory cue for the manifestation of stress related illness, particularly amongst individuals who are concerned about the quality of their environment. It is thought that only at extreme odour exposure are there direct links with health related symptoms such as vomiting (Steinheider *et al.* 1998).

4.1.9 Ozone creation potential

Although there is general concern about the loss of stratospheric ozone (O_3), presence of ozone close to ground level is problematic. Ozone can irritate the eyes and air passages causing breathing difficulties and may increase susceptibility to infection. It is a highly reactive chemical, capable of attacking surfaces, fabrics and rubber materials. Ozone is also toxic to some crops, vegetation and trees.
It is usually a secondary pollutant formed from the interactions of sunlight with VOCs and NO_x with atmospheric oxygen, and is therefore of some minor relevance to emissions from waste management facilities. Although high ground-level concentrations inhibit photosynthesis, reduce growth and depress agricultural yields (e.g. Agrawal & Agrawal 1999), lower concentrations are less problematic and difficult to interpret. For example, low-level exposure to ozone (and SO_2 to a lesser extent) can ameliorate Cd or Ni toxicity in plants.

Whereas nitrogen dioxide (NO_2) participates in the formation of ozone, nitrogen oxide (NO) destroys ozone to form oxygen (O_2) and nitrogen dioxide (NO_2). For this reason, ozone levels are not as high in urban areas (where high levels of NO are emitted from vehicles) as in rural areas. As the nitrogen oxides and hydrocarbons are transported out of urban areas, the ozone-destroying NO is oxidised to NO_2, which participates in ozone formation.

Sunlight provides the energy to initiate ozone formation; near-ultra-violet radiation dissociates stable molecules to form reactive species known as free radicals. In the presence of nitrogen oxides these free radicals catalyse the oxidation of hydrocarbons to carbon dioxide and water vapour. Partially oxidised organic species such as aldehydes, ketones and carbon monoxide are intermediate products, with ozone being generated as a by-product.

Since ozone itself is photodissociated (split up by sunlight) to form free radicals, it promotes the oxidation chemistry, and so catalyses its own formation (i.e. it is an autocatalyst). Consequently, high levels of ozone are generally observed during hot, still sunny, summertime weather in locations where the airmass has previously collected emissions of hydrocarbons and nitrogen oxides (e.g. urban areas with traffic). Because of the time required for chemical processing, ozone formation tends to be downwind of pollution centres. The resulting ozone pollution or “summertime smog” may persist for several days and be transported over long distances

However, MSW management only produces a small fraction of the national emissions of those chemicals that both form and destroy ozone. Thus we can conclude that although it makes sense to reduce such emissions to a minimum it is a higher priority to reduce such emissions from the major sources rather then MSW treatment.

4.1.10 Potential impact on global warming

The release of “greenhouse” gases, such as carbon dioxide, methane, nitrous oxide, chlorofluorocarbons (CFCs), and other halocarbons may lead to global warming. With regard to MSW treatment the most significant source of ‘greenhouse gases’ is from landfill sites. The ‘global warming potential’ (GWP) of MSW is estimated to be equivalent to 2.32 tons of carbon dioxide per ton of landfilled waste. One ton of methane is equivalent to 25 tons of carbon dioxide from a greenhouse gas potential. It is estimated that methane contributes around 18% of the UK global warming budget. The total UK annual emissions are estimated as 500 million tons methane, of which 40-75 million tons are due to emissions from landfills. Emissions of the other ‘greenhouse gases’ from MSW management are a minor proportion of the total national emissions of these gases. Thus when considering options for MSW management the emissions of methane from landfills is an important issue in the context of global warming.

All landfill sites taking MSW produce methane from the biodegradable portions of the waste and this accounts for a significant proportion of national emissions of methane (Table 4.2). The collection and combustion of landfill gas can reduce the amount of methane emitted from landfills, but a significant proportion of the methane will always escape as ‘fugitive’ emissions.

Although emissions of methane are greatest from the landfill options for dealing with MSW, emissions from home composting and poorly run central composting operations (where part of the degradation takes place under anaerobic conditions possibly due to lack of adequate turning of the waste) may also be significant. There is a paucity of information about such emissions. However, we can conclude that in terms of global warming potential, incineration of MSW is preferable to landfill, as there are practically no methane emissions from incineration.

One aspect of MSW management, which is relevant to global warming potential, is the indirect release of ‘greenhouse gases’ due to the expenditure of energy used as part of the MSW treatment. All forms of energy generation involve the release of ‘greenhouse gases’ in one shape or form, such releases may be obvious (e.g. burning oil) or less obvious (e.g. construction of ‘wind farms’). Part of the energy usage in MSW management will be due to the use of pollution control techniques. There is a trade off between the benefit of reducing certain emissions (e.g. metals) and the disbenefit of the energy used generating ‘greenhouse gas’, and other, emissions. It is extremely difficult to compare such potential environmental effects against the potential health effects of pollution control techniques. However, there has to come a point at which the gains for other pollutants are so small compared with the generation of ‘greenhouse gases’ such as CO_2 that global warming becomes the more important effect.

4.1.11 Impacts from accidents

Accidents are an inevitable accompaniment of any human endeavour. Within the area of MSW management there will be two main sources of accidents:

(a) Process accidents to parts of the management process, e.g. failure of pollution abatement equipment; failure of containment due to corrosion or pipe breakage, vandalism of equipment etc. The impact can be minimised by good design and management of the facility. The likelihood of each type of accident can be categorised and a prioritised emergency response plan drawn up. In terms of health and environmental impacts, accidents that lead to loss of control of emissions, e.g. damage to air pollution abatement equipment, require a rapid emergency response.

(b) Traffic accidents (i) during transport of MSW to the site; (ii) transport of materials away from the site; (iii) to workers travelling to the site; (iv) to members of the public travelling to and from the site (especially Civic Amenity Sites/Community Recycling Centres). This category of ‘health impact’ is by far the largest impact that any MSW facility will have on the human population.

For example recent research by McCarthy *et al.* (2005, pers com), on quantifying the potential health impacts for a proposed new waste incinerator calculated the excess mortality that would be caused by construction and use of the facility over period of 30 years. This showed that about 90% of the calculated excess mortality (total just under 0.15 deaths in 30 years) would be due to accidents in traffic associated with the facility.

4.2 Emissions from specific techniques

Table 4.2 Emissions to air from specific techniques
in weight per tonne MSW treated
(grammes except where indicated otherwise)

	Cm	AD	In	TT	MB	Lf	Tr
Methane (CH_4)	Y	Y	19	Y	411	20kg	N
Carbon dioxide (CO_2)	0.3 Mg	N	1 Mg	N	0.2 Mg	0.3 Mg	Y
Nitrogen oxides (NO_x)	N	188	1.6 kg	780	72	680	31
Sulphur oxides (SO_x)	N	3	42	52	28	53	0.11
Halides of hydrogen (HCl, HF)	N	<0.02	59	32.3	1.6	6	N
Non-methane VOCs	Y	Y	8	11	36	23	5.1
Dioxins & furans (ng TEQ)	N	N	400	48	40	140	0.04
Arsenic (As) mg	N	<0.5	5	60	?	1.2	?
Cadmium (Cd) mg	N	<0.1	5	6.9	?	71	?
Mercury (Hg) mg	N	<0.6	50	6.9	?	1.2	?
Nickel (Ni) mg	N	<0.3	50	40	?	9.5	?
Particulate matter PM	175	Y	38	12	Y	5.3	1.3
Polycyclic aromatic hydrocarbons	?	?	N	?	?	?	Y
Bioaerosols	Y	Y	N	N	Y	Y	N

Cm Windrow composting; **AD** Anaerobic Digestion; **In** Incineration; **TT** Advanced Thermal Treatment (pyrolysis/gasification); **MB** Mechanical Biological Treatment; **Lf** Landfill 25% of emissions as fugitive gases 75% from gas engines; **Tr** Waste related transport.
VOC volatile organic compounds; **?** no data; **N** not likely to be emitted in significant amounts; **Y** likely to be emitted unquantified. **Mg** megagramme, 1 million grammes; **kg** kilogramme, one thousand grammes; **mg** milligramme one thousandth of a gramme; **ng** nanogramme one thousandth of one millionth of a gramme. **TEQ** expressed as a concentration equivalent to the most toxic dioxin – 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD).

This section uses information mainly derived from Enviros *et al.* (2004).

4.2.1 Materials recycling/recovery facilities (MRFs)

See Section 2.2.1 for an outline of the processes undertaken in these facilities.

The main emissions from these facilities will be fugitive emissions to air from waste handling and sorting (Table 4.2). Emissions to land will come from the reject fraction from the sorting process, which will normally go to landfill or incineration. Leachate and emissions to water are not usually an issue at UK 'clean' MRFs.

Typically, reject fractions are in the order of 5 to15% of the input material comprising the fine size fraction and 'contraries' e.g. bottle tops, contaminated recyclables, or products where no market may be available for a particular facility such as carrier bags and yoghurt pots. Materials Recovery Facilities may handle a variety of sources of recyclables from co-mingled kerbside collected materials, to source segregated, material from civic amenity sites or commercial and industrial wastes. The nature and proportion of these different sources, together with the manner of operation of the facility, will determine the composition and the proportion of residual fines to incoming waste at the end of the process.

The incoming waste stream normally undergoes some form of pre-sorting, the precise process varies from facility to facility. A key issue is maintaining the rate of throughput. If waste remains in the facility for extended time periods then this may result in increased emissions particularly of bioaerosols and odours.

The principal raison d'être of a MRF is to extract recyclable materials from the waste stream which results in a concomitant reduction in the use of raw materials. This type of recycling and reprocessing could result in an overall reduction in emissions, or an overall increase in emissions from reprocessing, often at locations far removed from the MRF itself.

The reprocessing of recycled materials generates significant quantities of emissions, for example from transport, or in some cases more energy is needed for the recycled material than for the equivalent raw materials in a process. In other cases recycling can result in lower emissions. Perhaps the best example of this is the use of recycled glass 'cullet' in glass manufacture.

The negative and positive aspects of overall emissions associated with MRFs and reprocessing are complex and require further research and investigation before they can be adequately quantified. Thus any emissions referred to here, and any conclusions draw, refer to emissions from MRFs themselves and not the overall emissions associated with recycling and reprocessing.

It is the tipping and sorting processes that are responsible for most of the fugitive emissions from MRFs. However, this normally takes place in an enclosed facility, which allows a variety of control measures to be utilised. One of the most common and effective is to operate the facility under negative pressure with the air emitted from the facility being cleaned in a series of filters or other control techniques.

There is a lack of quantified data on emissions from MRFs. Due to this lack of data it is impossible to give any overall figure for emissions from the 90 or so MRFs operating in the UK.

In one study in the USA (EPA 1995) a series of monitoring points around various sites were used to measure particulates (total particles and PM_{10}), Pb, Hg, VOCs, bioaerosols, PCBs etc. However the study did not result in any useful conclusions as the emissions were very variable and only poorly quantified. The study did show that emissions to water (from surface rain run-off and such things as washing of vehicles and equipment) were well below the relevant environmental control limits.

Table 4.3 Composition of solid residues from specific techniques
in weight per tonne MSW treated
(grammes except where indicated otherwise)

	Cm	MB	AD	TT	InB	InA	InR
Destination of residue	R/L	R/L	R/L	R/L	L	L	R
Mass of solid residue kg/tonne	500	605	?	120	180	30	92
Dioxins & furans (ng TEQ)	7.2	?	?	?	9700	26600	2300
Antimony (Sb)	?	?	?	?	30	10	8
Arsenic (As)	1.75	?	?	?	4.8	1.1	1
Cadmium (Cd)	0.65	?	1.7	4	7.6	2.8	2
Chromium (Cr)	28	?	95	266	56	2.2	14
Lead (Pb)	70	?	290	670	480	65	124
Mercury (Hg)	0.25	?	1	?	0.07	0.25	<0.1
Nickel (Ni)	6.8	?	27	36	14	0.81	4
Sulphate kg	?	?	?	5.09	4.2	?	1.07
Tin (Sn)	?	?	?	?	320	19	81

Cm Windrow composting; **MB** Mechanical Biological Treatment; **AD** Anaerobic Digestion; **TT** Advanced Thermal Treatment (pyrolysis/gasification); **In** Incineration Bottom Ash; **InA** Incineration Air Pollution Control Residue; **InR** Incineration re-used Bottom Ash. **R** Re-use; **L** Landfill.
? no data; **kg** kilogramme, one thousand grammes; **ng** nanogramme one thousandth of one millionth of a gramme. **TEQ** expressed as a concentration equivalent to the most toxic dioxin – 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD).

4.2.2 Windrow Composting

This comprises the aerobic decomposition of rows of organic waste which are either periodically turned or have air forced through the rows to promote microbial degradation. It can be done outdoors or in enclosed buildings. The process can now only be used for green waste, rather than food waste, since it cannot be sufficiently controlled to meet the needs of the Animal By-Products Regulations.

(a) Emissions to air (Table 4.2)

There is a lack of accurate data on emissions to air from composting. Because the emissions are mainly fugitive there will be a wide margin of error in any measurements and available data vary widely. Thus the recent DEFRA report (Enviros et al 2004) was unable to give an accurate numerical summary of emissions. They give indicative figures for emissions to air, which are summarised in Table 4.2. They were unable to give any indication of the amounts of methane, non-methane VOCs, hydrogen sulphide, carbon monoxide and most significantly bioaerosols.

(b) Emissions to land (Table 4.3)

Clearly there are significant emissions to land as the material produced by the process, 'compost', is intended to be used as a soil improver. However, the composition of the 'compost' will be variable and dependent on the composition of the feedstock, which is also variable. For example source material from rural as opposed to urban areas will have different compositions which will affect levels of PAHs and 'dioxins' in the compost. Only the best composts will comply with the standard specification for compost (BS PAS 100), these will be suitable for agricultural or horticultural use. Lower quality composts may find a use in land restoration projects or as 'daily cover' on landfill sites. However, any compost used on a landfill site will contribute to the emissions from that landfill. A European Commission study indicated that about 6% of compost derived from MSW was sent directly to landfill because of issues with contamination and 'contraries' (contamination e.g. glass, plastics).

(c) Emissions to water (Table 4.4)

These include leachate in the range of 14 to 34 litres per tonne of waste composted (CIWM 2003) and there will also be run-off from hard-standing areas. Research indicates that leachate releases are most likely in the first two weeks of composting as the compost loses water. A reduction in mass of about 40% can be expected from water loss.

(d) Operation under abnormal conditions

A critical factor, which can markedly effect emissions from composting facilities, is the need to ensure that aerobic (oxygenating) conditions are maintained throughout the waste pile. With windrow composting this requires careful management, whereas in-vessel systems normally have semi-automatic systems to maintain aerobic conditions.

If good mixing is not maintained, for example due to insufficient turning of the windrow, then anaerobic (oxygen-free) conditions may ensue. This may cause increased emissions, for example of odours, methane and other VOCs and bioaerosols. With in-vessel systems the emissions can be controlled by passing the exhaust air through an abatement system (e.g. biofilter or by passing the air through a combustion facility located on the same site).

Emissions from windrow composting sites, particularly if abnormal operating conditions ensue, are capable of causing acute health effects in people living or working close to the site (within about 250 metres Sections 5.2, 6.2, 6.3).

4.2.3 In Vessel Composting

(a) The IVC technique. There is a wide range of techniques for in vessel composting. They all have in common that the waste is enclosed as it undergoes microbial degradation. Because the conditions can be closely controlled it is also suitable for composting food and catering waste. It enables the temperature to be maintained at a high enough level throughout the vessel to destroy pathogenic materials (capable of causing disease). Controls under the Animal By Products Regulations ABPR (EC 1774/2002) require that any food waste, including that from domestic premises, can only be composted in in-vessel systems.

This technology is not yet in widespread use but the demands of the ABPR are acting as a spur to its further development. In-vessel composting of source-segregated organics is an attractive option to waste disposal authorities in meeting the requirements of the biodegradable landfill diversion targets of the EC Directive on landfilling of waste.

(b) Emissions data

Emissions to air are mainly carbon dioxide, water vapour, possibly some ammonia and volatile organic compounds, particulates and bioaerosols. There will also be some emission of methane as in any composting system it is impossible to ensure aerobic conditions are maintained throughout the waste at all times.

Emissions will vary depending on the type of waste fed into the system and the particular procedures used at the facility such as addition of water, type of shredding used, residence time of the waste in the facility etc. The data on emissions from these systems is very sparse. The majority of the work that has been undertaken concentrates on ambient conditions (i.e. inside the facility) and there is a lack of data on emissions out of the facilities.

Because of this lack of information the Environment Agency commissioned a study of three composting facilities (Environment Agency 2001), one of which was an in-vessel system which processed mixed green waste, source segregated household organic waste and refuse derived fuel production fines.

(c) Emissions to air (Table 4.2)

In-vessel systems, unlike windrow composting, can control their emissions to air. For example they may control bioaerosols by using a liquid spray or by using a carbon filter or bio-filtration system. The latter will also control VOC emissions.

The Environment Agency study measured levels of bacteria in the vicinity of the in-vessel composting system as greater than 10^7 cfu/m^3 of air (cfu – colony-forming units, the number of bacteria that will grow on nutrient plates and form colonies). This should be compared with measurements of bacteria in the absence of any significant bioaerosol sources. Swan *et al.* (2002) concluded that such ambient levels of bacteria are between ten and one million times lower than those recorded during the handling of compost.

The Environment Agency (2001) concluded that appropriate ambient levels to reduce the possibility of health effects were in the range of 300 to 1000 cfu/m^3, i.e. of the order of ten to thirty-five thousand times **lower** than those measured in the vicinity of the in-vessel composting operation.

The Agency also measured concentrations of inhalable dust up to almost 10 mg/m^3. For many nuisance type dusts the occupational limits are around 10mg/m^3 for total dusts and 5 mg/m^3 for respirable or PM_{10} dusts. The Control of Substances Hazardous to Health Regulations 1999 (COSHH Regulations) specify that a Substance Hazardous to Health includes “a dust of any kind” present in concentrations of over 10 mg/m^3 total inhalable dust.

(d) Emissions to land (Table 4.3)

The use of the ‘compost’ output from in-vessel composting systems represents the main impact to land. Unfortunately there is no data specifically on the composition of composts from in-vessel systems, which allows a quantitative estimate of emissions to land to be made. We can only assume that the emissions are similar to those from windrow composting (Table 4.3).

Table 4.4 Emissions to water (sewer) from specific techniques
in weight per tonne MSW treated

	IC	MB	AD	In	Lf
Suspended solids g	23	?	?	?	?
Nitrogen (Total) g	?	134	1	?	39
Arsenic (As) mg	?	?	?	<6	0.7
Cadmium (Cd) mg	4.5	?	?	<3	?
Chromium (Cr) mg	23	?	?	<40	5
Cyanides (as CN) mg	0.75	?	?	?	<5
Lead (Pb) mg	33	?	?	<50	<5
Mercury (Hg) mg	26	?	?	<0.3	?
Nickel (Ni) mg	?	?	?	<40	6
Polycyclic aromatic hydrocarbons mg	?	?	?	?	<0.48
Sulphate g	?	5	?	?	?
Tin (organo-tin compounds) mg	?	?	?	?	0.022

IC In-vessel composting; **MB** Mechanical Biological Treatment; **AD** Anaerobic Digestion; **In** Incineration (mass burn); **Lf** Landfill; **?** no data; **g** grammes; **mg** milligramme.

(e) Emissions to water (Table 4.4)

All composting processes will produce some liquid residue as a result of decomposition of the waste. There will also be rainfall run-off from the site. Some in-vessel systems re-circulate liquid leachate, others discharge the liquid to sewer, with or without pre-treatment as appropriate. Using an assumption that 150 L of liquid leachate are generated per tonne of input waste the authors of the DEFRA report (Enviros *et al.* 2004) calculated a 'best-estimate' of the emissions to water released to sewer from in-vessel composting (these values are used in Table 4.4).

4.2.4 Mechanical Biological Treatment (MBT)

(a) The MBT technique

This is an industry term for the integration of several waste treatment processes in a single facility. These facilities are usually designed to deal with a residual waste stream after initial recyclables and compostables are removed and may include the preparation of a refuse derived fuel for a thermal treatment process. Usually the non-compostable part of the waste is put through a sorting system. This removes metals, including the magnetic separation of ferrous metals, and screens the output material into a reject fraction comprising some textiles, plastics and metals with a minor organic component.

The remaining organic fraction may then be composted or fed into an anaerobic digester. The 'compost' resulting from this process will probably require further treatment and sorting dependant on its ultimate destination. This may be as a soil conditioner, if of the highest quality, but is more likely to be used as daily cover on a landfill site or fed into another process such as incineration as a refuse derived fuel, or advanced thermal treatment.

Although there are currently no full-scale MBT systems in operation in the UK it is likely that this will be an area of development in the short to medium term as waste authorities develop integrated waste systems to meet the targets for diversion of biodegradable waste from landfill.

(b) Emissions data

Emissions will be strongly dependent on the composition of the waste input stream, weather conditions and the design and operation of the facility. There is a lack of quantitative data for MBT facilities; the best estimates (derived from Enviros *et al.* 2004) are listed in Tables 4.1 to 4.3.

(c) Emissions to air (Table 4.2)

These include fugitive emissions of bioaerosols, particulates, VOCs and odour. The available data is very limited but they are likely to be similar to such emissions from MRFs or windrow composting facilities. The data in Table 4.2 represents the 'best estimates' for MBT emissions taken from a European Commission (2003) draft document cited in Enviros *et al.* (2004).

Depending on the precise configuration of the system MBT processing can generate similar amounts of carbon dioxide and water vapour emissions to composting. The EcoDeco (industry trade name) process is cited as generating 200 to 250 kg of water vapour per tonne of waste processed. A European Commission study states that about 22 kg of CO_2 equivalent is generated per tonne of waste processed by MBT (Smith *et al.* 2001). This would be mainly as CO_2 gaseous emissions.

Bioaerosols will also be emitted from MBT facilities, unfortunately again there is a lack of useful data. In addition any residues which are sent to a combustion process will also result in emissions to air. Any comparison of emissions from different treatment techniques would need to take this into account.

(d) Emissions to land (Tables 4.3, 4.5)

These will be strongly influenced by the amount of processing of the residual material and its ultimate destination. MBT is an intermediate process, rather than a final treatment process, as the output streams are mostly sent for further processing.

Thus the total emissions and potential impacts from MBT treatment will depend on the exact combination of techniques used. The main emissions to land comprise the reject fraction from the process, which is normally sent to landfill, and the primary solid residue that makes up the bulk of the process. A stabilised residue sent to landfill from MBT processing has about 90% less landfill gas generation potential than raw MSW.

Some MBT systems are designed to act as a pre-treatment stage for refuse derived fuel incineration, ATT pyrolysis and/or gasification, or anaerobic digestion techniques.

Industry data on the EcoDeco technique suggests about 17% of the input waste goes into the reject fraction as fine material. The ‘best estimates’ of solid residues from this process are listed in Table 4.5.

Table 4.5	**Solid residues from an MBT process** (kg/tonne MSW input)	
Residue type	**‘Best estimate’**	**Destination**
Refuse derived fuel	**376**	**Incineration process**
Residue from fines treatment	**92**	**Landfill**
Low quality aggregate (mainly glass & miscellaneous non-combustible materials)	**82**	**Can be reused as building material** (if process is optimised for this)
Ferrous metals	**50**	**Recycled**
Non-ferrous metals	**5**	**Recycled**

(e) Emissions to water (Tables 4.4, 4.6)

Most systems use water in the initial process, which is partially evaporated in the composting process. In some systems leachate from the composting/biological drying process is re-circulated leading to no overall water emission.

In addition to the figures reproduced in Table 4.4, Enviros *et al.* (2004) give some best estimate figures for ammonia, nitrates and COD (chemical oxygen demand, the amount of oxygen consumed to completely chemically oxidise the organic water constituents to inorganic end products) for waste water output from one MBT process (where 261 L are produced per tonne of MSW input) and treated waste water output from another waste process (Table 4.6).

As shown by the example in Table 4.6 treatment of the wastewater substantially reduces the pollution load.

Table 4.6 Examples of emissions to water from MBT processes
(g/tonne MSW input except COD)

Emission	Waste water	Treated water
Ammonia (NH_3)	**160**	**20**
Nitrates	**10**	**1**
Sulphates	**5**	**1**
COD mg/L	**530**	**1**

(data from European Commission 2003; quoted in Enviros *et al.* 2004)

(f) Operation under abnormal conditions
Because MBT systems are so variable the possibility of abnormal operation depends on the design of the particular facility. Possible situations include anaerobic conditions developing in the waste, in a similar way to composting, if insufficient air is available. This will lead to the generation of VOCs, including methane, and increase the possibility of an odour nuisance being caused. Where the system includes a biogas combustion plant a failure of the combustion system might lead to emissions of unburned gas. However, in all cases good plant design and good management will reduce the chances of such events and minimise their impact by initiating prompt action.

4.2.5 Anaerobic Digestion

(a) The AD technique. Although AD is currently used in the UK for treatment of sewage sludge and some agricultural and industrial wastes it is not yet in common use for MSW. One of the first AD plants to be built is the Biffa facility in the City of Leicester due to be operational in 2005.

A typical process stream utilising AD would be along these lines:

- Compostable materials and recyclables extracted at source, leaving residual MSW;
- Metals, paper and plastics removed by pre-treatment;
- Remaining waste fed into the anaerobic digester;
- Biogas produced from digester fed into combustion plant to generate energy;
- Heavy particulate sediment from digester sent to landfill;

- Digestate residue is further treated by oxidation, prior to landfilling or incineration.

(b) Emissions data. Published data for emissions from AD processes is very limited and mainly derived from a single source (Enviros Aspinwall 2002). Because of this the figures may not be a good representation of emissions from all AD facilities.

(c) Emissions to air (Table 4.2)

In order to ensure anaerobic conditions the 'digester' within which the process occurs is completely sealed. The composition of a typical biogas produced is well known, but this gas is not released to air under normal operating conditions. Thus the main emissions to air will be from the associated energy generating plant which burns the biogas. The main emissions generated in this way are listed in Table 4.2 (data source Enviros Aspinwall 2002).

According to Enviros *et al.* (2004) the process of energy generation associated with the AD biogas results in a net reduction in emissions to air of SO_2, HCl and metals compared to emissions from UK power generation. However, the relative emissions of NO_x for AD are similar to those from power generation (using figures for 2001).

(d) Emissions to land (Table 4.3)

Outputs to land from AD processes are the use of digestate as a soil conditioner, as landfill cover or restoration medium, or possibly through spreading to land (normally used for sewage and agricultural waste products).

The composition and quality of the digestate will be strongly dependent on the input material. Where the input is mixed MSW the most likely destination is as a stabilised material to landfill or another treatment/disposal option. Where the input is source separated household organic waste the output may be suitable for some agricultural or soil conditioning purposes.

The 'best estimates' for amounts of certain chemicals in AD materials emitted to land, in terms of weight per tonne MSW treated, are given in Table 4.3.

(e) Emissions to water (Tables 4.4, 4.7)

According to the Environment Agency (2002b) AD processes give rise to between 100 and 330 kg of liquid per tonne of waste input. This wide range is because of the variable nature of different AD processes. Some processes need to input significant amounts of water to dilute the high solids content of the waste and to recycle the bacteria used in the process. If stored in the open and allowed to deteriorate these liquids can become noxious. The liquids may be recirculated or removed, treated and discharged to sewer as appropriate. Some of these liquids may be of a suitable quality to be used as fertilisers. In some cases the waste waters are denitrified prior to release.

(f) Operation under abnormal conditions

If the operation is not appropriately controlled then the waste may not be completely digested and will probably not be of high enough quality fr spreading on land. In this case the material will be strongly odorous and will probably have to be sent to landfill.

If the biogas is not completely combusted it may escape to air when the emissions would be similar to those from landfill (Table 4.2). However, AD facilities are normally fitted with containment systems, which would allow the gas to be stored if the combustion plant were undergoing servicing or repair.

Table 4.7 Emissions to water from AD processes
(g/tonne MSW input except COD)

Emission	'Best estimate'
Ammoniacal nitrogen	7.3
Total nitrogen	10
Dissolved solids	80
COD mg/L	100

(data from Environment Agency 2000a; quoted in Enviros *et al.* 2004)

4.2.6 Advanced Thermal Treatment (ATT) – Pyrolysis and Gasification

(a) The ATT techniques. Pyrolysis involves the thermal degradation, at temperatures in the range of 400 to 1,000 ^{o}C of waste in the near absence of air to produce gas ('syngas'), liquid (pyrolysis 'oil') or solid ('char' mainly ash and carbon).

Gasification takes place between 1,000 and 1,400 ^{o}C using a controlled amount of oxygen. Here the majority of the carbon in the waste is converted into 'syngas'. In most cases this gas will contain toxic and corrosive chemicals and may require cleaning prior to combustion and a post combustion flue gas treatment process.

In both cases the gases are normally burnt to produce electricity. The char from either system can be further reacted with steam, to produce syngas, with any residual ash going to landfill.

ATT systems usually require pre-treatment of MSW prior to processing in the pyrolysis/gasification plant. This is an extra complication compared to the moving grate incineration, energy from waste process, which can handle untreated MSW.

Some ATT processes have been suggested as being suitable for processing refuse derived fuel (RDF), or the residues from MBT processes, which are more homogeneous than raw MSW.

(b) Emissions data

The Environment Agency have produced a review of ATT pyrolysis and gasification (Environment Agency 2001b) which summarises emissions from these processes. However, the available data is very limited and in some cases is the result of a single test on a pilot or demonstration plant and there are various other difficulties with the data. However, in the recent DEFRA report (Enviros *et al.* 2004) data from industrial sources using operational equipment has been used to 'fill in the gaps'.

(c) Emissions to air (Table 4.2)

The 'best estimates' of emissions to air from two pyrolysis/gasification plants are listed in Table 4.2 (data from Enviros Aspinwall 2002). Emissions from ATT processes will vary according to the type of combustion plant used for the syngas.

The recovered energy when used to generate electricity will result in an offset of emissions, which would otherwise have been generated by power plants. Enviros *et al.* (2004) suggests this will result in a net reduction in emissions to air of SO_2 and particulates, whereas emissions of NO_x, VOCs and dioxins will be similar to those from electricity power plants. Emissions of metals may be higher than those from electricity power plants.

(d) Emissions to land (Table 4.3)

Some ATT systems are said, by their manufacturers, to produce residues that are usable in their entirety. If this were to be believed in theory such systems would have almost no emissions to land, always providing there are markets for the output residues and that any reused/recycled materials had no impact on land. However, in reality there are always potential impacts, for example from chemicals leached out of reused building materials etc. The lack of full-scale systems operating on MSW makes it impossible to give definitive figures.

Both pyrolysis and gasification will produce a slag or char residue, which may be disposed of by way of landfill. The overall quantity of residues varies according to precisely what type of process is used, and the composition of the feed stock. Each process is supposed to allow the reuse of at least part of the residue. For example, carbon black from gasification, 'inert' materials used as construction aggregate, air pollution control residues treated and reused in chemical applications.

Plasma pyrolysis vitrifies the solid residues. Whilst this requires an 'extra' input of energy such material is less likely to allow chemicals to be leached out resulting in a lower level of potential hazard. It may also allow the residue to be used, rather than landfilled, for example as a construction material.

Residues from the air pollution control (APC) system will require further processing or disposal to a landfill as hazardous waste. Again the type and quantities of APC residue will vary dependant on the type of treatment and the composition of the incoming waste stream.

(e) Emissions to water (Table 4.4)

Many ATT systems do not produce any emissions to water as the effluent generated by the process is recycled for reuse in the process. There is a lack of data on emissions to water, partly due to the variety of possible systems and configurations, and partly due to a lack of commercial full-scale systems utilising MSW.

Any liquid residues from the primary reactor or fuel gas cleansing systems will have a high organic loading, particularly of PAHs and phenols. Some APC systems use a wet scrubbing technique outputting some 6 litres of waste water per tonne of waste input. This effluent has high levels of alkali salts, particularly ammonium chloride (NH_4Cl), requiring further treatment prior to disposal.

4.2.7 Incineration of unsorted waste with energy recovery

(a) Controlled burning of MSW. This takes place at temperatures over 850 °C. Traditional fuel, oil or gas, is used at start-up of the process but the overwhelming majority of emissions are from the waste combustion. The concentration of many pollutants in emissions to air from incinerators has been drastically reduced in recent years in response to European Union Directives. As recently as 2000 the Waste Incineration Directive imposed even stricter emission limits. Newly constructed plant has to comply with these limits immediately whilst existing facilities have to comply by 2007. However, for most emissions MSW incinerators already comply with these limits.

Emissions from MSW incineration are similar throughout the European Union, due to EU-wide legislation. The USA and Canada have similar legislation and their emissions and technology are similar those of Europe. There are widely different percentages of MSW incinerated in different countries. In Denmark 52% of MSW is incinerated, In France 33%, Germany 23%, the UK 9%, in Ireland none is incinerated. Outside Europe Japan incinerates 21% of MSW, the USA 15%.

(b) Emissions data

These emissions are those which go to air through the incinerator chimneystack. No allowance is made for emissions from the storage and processing of waste prior to incineration. Emissions to water, disposal to landfill and reused materials are all based on calculations using Environment Agency Pollution Inventory data (Enviros *et al.* 2004). Measurement uncertainty in the values given for emissions from incinerators is in the range of plus or minus 10 to 50%, sometimes significantly less. One of the problems is that MSW is strongly heterogeneous and so 'spot' measurements (short timescale) need to be treated with caution as they may not give data which are representative of long-tem emissions.

There is also uncertainty in the data on the amount of waste put through the incineration process. Emission measurements are normally taken when the plant is operating at near maximum capacity and information on process throughputs is not routinely recorded. Therefore some assumptions have to be made regarding waste inputs which could introduce an uncertainty of the order of 25%. However, there is a great deal of data available for incineration emissions, which helps to increase the confidence that representative results can be obtained.

In order to allow for these uncertainties the authors of the DEFRA report (Enviros *et al.* 2004) derived a variability range which allowed for these uncertainties. Their 'best estimates' are the values reproduced in the tables in this report.

(c) Emissions to air (Tables 4.2, 4.8)

The values for incineration given in Table 4.2 are the best estimates of rates of emission to air based on data from operational incinerators. Incineration of MSW is normally part of the process of 'energy from waste' whereby the energy released by combustion is used to generate electricity for export to the National Grid. This will result in a reduced need to generate electricity by other means, such as the burning of fossil fuel, with a concomitant reduction in emissions from these sources (note that there is some controversy about how these reductions are calculated often they are assumed to displace coal-fired power generation when this may not always be the case, see for example FoE 2003). According to Enviros *et al.* (2004) this results in a net reduction in emissions of SO_2 and particulates, but an increase in emissions of other chemicals compared to power generation (2001 figures).

Emissions have declined substantially over a twenty-year period. Table 4.8 lists the emissions for 1980, 1990 and 2000 for MSW incineration in the UK as calculated by Enviros *et al.* (2004). Emissions to air of dioxins, furans and PCBs, and trace metals have decreased markedly since 1990. This is because in the late 1990's MSW incinerators were either shut down or upgraded to meet the emission limits in European Directives.

To meet these limits most MSW incinerators now include air pollution control (APC) systems that inject materials (such as activated carbon) into the exhaust gas flow to absorb the contaminants. These materials and the absorbed pollutants are then removed via filtration systems and disposed of as APC residues to landfill.

Table 4.8 Historical emissions to air from incineration

in weight per tonne MSW treated

Emission	1980	1990	2000
Nitrogen oxides (NO_x) kg	1.9	1.6	1.6
Sulphur oxides (SO_x) kg	1.4	1.2	0.04
Halides of hydrogen (HCl, HF) kg	3.8	0.02	0.06
Volatile organic compounds VOCs g	25	20	8
Dioxins & furans (ng TEQ)	?	180,000	400
Arsenic (As) mg	400	330	5
Cadmium (Cd) mg	2,600	16,000	5
Mercury (Hg) mg	1,800	2,200	50
Nickel (Ni) mg	2,800	28,000	50
Particulate matter PM g	313	264	38
Dioxin-like polychlorinated biphenyls mg TEQ	?	3.5	0.1

? no data; **kg** kilogramme, one thousand grammes; **g** grammes; **mg** milligramme one thousandth of a gramme **ng** nanogramme one thousandth of one millionth of a gramme. **TEQ** expressed as a concentration equivalent to the most toxic dioxin – 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD).

(d) Emissions to land (Table 4.3)

There are several types of solid residue arising from the present designs of municipal waste incinerators:

- Bottom ash - the bulk of the ash collected at the first stage of the combustion process from the grate. This can comprise some 20-30% of the weight of the feedstock
- Grate siftings - the portion of the waste and grate ash that passes through gaps in the grate and is characterised by the finer particles of the grate ash. It is typically 0.5% of the feedstock.
- Boiler ash - the ash that is collected from the energy recovery boiler. It is characterised by finer particles due to entrainment and condensed alkali metal salts. It is typically only 0.5% of the feedstock.
- Fly ash - the ash removed prior to the pollution abatement system. It consists of entrained ash particles and thus is of a fine particle size and contains high levels of metals and other pollutants. It is removed from the flue gas by the use of cyclones, electrostatic precipitators or fabric filters either singly or in combination. It is typically 2% of the feedstock mass.
- Air pollution control (APC) residues - These wastes are the residue from the systems to remove the acid gases, micro-organic pollutants, mercury and NO_x and consists of unspent reagent (lime, NaOH or activated carbon depending on the pollution abatement system) and the entrained pollutants or the reaction products. Typically the mass of this fraction is about 2% of the feedstock mass.

Whilst these ashes and residues are described separately their collection is controlled by the design of the incineration plant. Often bottom ash, grate siftings and boiler ash are collected together (and described as 'bottom ash') and the fly ash and APC residues are also combined (may be referred to as 'fly ash').

Mixing of the fly ash/ APC residues with the grate ash was carried out at some plants. In many countries, including the UK, this practice is now prohibited. This report does not deal with risks associated with the use of the mixed fly ash and bottom ash. (After Abbot *et al.* 2003)..

In summary, there are two main forms of solid product, which are either reused or disposed of to landfill, air pollution control (APC) residues ('fly ash') and boiler bottom ash (see also Section 2.2.3). Bottom ash may be re-used or sent to landfill as non-special waste, whereas APC residues are normally landfilled as special waste. See Table 4.3 for 'best estimates' of the composition of these solid residues.

The figures given by Enviros et al (2004) for the proportion of bottom ash reused are contradictory. On page 257 they state that about one third of bottom ash is re-used, but their Table 2.24 on page 74 suggests that only just over 27% is re-used i.e. about a quarter. The ash is used in aggregate e.g. in road construction; as bulk fill e.g. in road embankments and in building materials such as concrete blocks.

This use could be considered as having a positive environmental impact as it is replacing aggregate materials that would otherwise have to be extracted from geological sand and gravel deposits. This occurs largely in rural areas with the concomitant environmental impacts of heavy goods vehicle traffic, noise, dust and loss of visual amenity.

(e) Emissions to water (Table 4.4)

Most incinerators now use dry or semi-dry flue gas cleaning systems for air pollution control, which do not produce any emissions of water. Water is used in the ash pits for quenching. Of the ten incinerators assessed by Enviros *et al.* (2004) nine reported emissions to sewer. The emissions to water listed in Table 4.4 are for mass burn incineration emissions to sewer.

(f) Operation under abnormal conditions

MSW incinerators operate under increasingly stringent conditions according to licences or permits issued under the Integrated Pollution Control or the Integrated Pollution Prevention and Control regime (see Section 4.4). However from time to time their emissions may exceed the permitted limits.

This can occur when starting up or shutting down the process, but this may be allowed under the licence terms. Short-term fluctuations in emissions may exceed the operating limits but this can be minimised by ensuring the waste is well mixed. They can also be prevented or controlled by adjusting the PC system.

Environment Agency records show that there were 54 incidents of emissions outside permitted limits at the 14 MSW incinerators in 2003. The highest number occurred a anew incinerator which was being commissioned. Some 75% of the incidents related to increased emissions of carbon monoxide and hydrogen chloride, which would not result in any significant environmental effects. There were four incidents of dioxins and furans above permitted levels and one of cadmium.

All such incidents are of concern and action is taken to prevent their reoccurrence where necessary. However, the low frequency of such events, the minor contribution of emissions from incinerators to the national output of pollutants (Table 4.1) and the lack of any consistent evidence for health effects in populations living near incinerators (Chapter 5) suggests that emissions above consent limits are not a major problem for MSW incinerators.

4.2.8 Small-scale incineration of pre-sorted wastes with energy recovery

This takes place on one site in the UK, but it is possible that this type of incineration will become more common as part of integrated waste management solutions. Further facilities are planned and being constructed (Enviros *et al.* 2004).

Pre-sorting of waste takes place on site and emissions from this stage would be similar to those shown in Table 4.2 from MBT facilities.

Emissions to air from the single small-scale process in operation are lower than mass burn incineration for SO_2 and particulates, whereas emissions of VOCs, dioxins and furans and hydrogen chloride (HCl) are higher.

Because the waste is pre-sorted, with removal of plastics etc., it might have been expected that the emissions of HCl and dioxins and furans would have been lower. In fact since dioxins contain chlorine, a great deal of debate has revolved around the issue of how effective the removal of chlorine-containing materials (such as PVC) from the waste stream would be in reducing their formation. The problem is that chlorine is present in one form or another in virtually all materials and so there will always be a large excess available compared with the tiny amounts that may become incorporated into dioxin. Trials on laboratory, pilot and full-scale plant have all confirmed the lack of beneficial effects on dioxin emissions, and therefore this cannot be used as a strategy for controlling dioxin emissions.

Therefore it is likely that it is the design of the abatement system on this small-scale incinerator. It should also be emphasised that emissions from this incinerator have not exceeded the relevant regulatory limits as laid down in its authorisation, neither is there considered to be any significant risk to health from these emissions Enviros *et al.* 2004). There is absolutely no reason why emissions from small-scale incinerators using pre-sorted waste could not be reduced to match or exceed the performance of the best mass burn incinerators with appropriate pollution control equipment.

4.2.9 Landfill

(a) Landfilling as a process. Currently the vast majority of MSW is disposed of to landfill. However, new regulations (The Landfill Regulations 2002) implementing the European Landfill Directive will have a major impact on waste management. One of the principal effects will be to reduce the amount of biodegradable waste going to landfill progressively over a period up to 2020. Currently about 68% of MSW is biodegradable and the disposal of this waste results in landfills being major contributors to the production of greenhouse gases, in particular methane. These changes will mean that the composition of emissions to air and leachate from landfill sites will change. The precise nature of such changes is difficult to predict.

Landfilling differs from other MSW treatment processes in terms of the timescale over which emissions are emitted. Emissions from the other processes are effectively immediate whereas the production of landfill gas and leachate takes place over a period of years extending to several decades. Thus any measurement of current emissions from landfills is measuring emissions from waste deposited over a period extending up to something like thirty years ago. Similarly waste being deposited now will continue to produce emissions into the future.

Landfill also differs from other MSW treatment processes in that in one sense there are no emissions to land, whereas in another sense landfill is creating land that is very likely to contain greater amounts of potentially hazardous chemicals than natural land. Closed landfills are eventually used for other purposes including leisure park area or redeveloped for commercial or even housing purposes. One of the functions of the planning regime (Section 4.3.1) is to ensure that all development sites, including redeveloped landfills, are suitable for the intended purpose.

(b) Emissions to air (Table 4.2)

The principal emission is landfill gas (LFG) and the combustion products arising from burning that gas. This burning may be in engines generating electricity or via flare-stacks which simply burn the gas as a crude means of control. Flaring gas is now much less common than in the past.

Landfill gas is approximately two thirds methane and one third carbon dioxide with small amounts, typically around 1%, of other components. These other components may be highly odorous, e.g. sulphurous mercaptan compounds, and/or potentially harmful to health, e.g. hydrogen sulphide (H_2S), VOCs etc.

The emissions are principally from:

- LFG escaping to air through purpose built vents or cracks in the capping layer over previously deposited waste.
- LFG escaping through uncapped areas of the site, e.g. where tipping is actively taking place.
- LFG diffusion through the capping layer (even clay is not impervious to gas).
- Combustion products from flaring of LFG collected using a gas extraction system.
- Combustion products from LFG collected and burnt to recover energy in a power plant.

Whereas combustion of LFG destroys flammable components and reduces some environmental impacts, it may cause others, e.g. by producing sulphur dioxide (SO_2) from H_2S and other sulphurous constituents. Combustion will also never achieve 100% destruction of flammable components so emissions from flares and power generators will be partly combustion products and partly unburned LFG.

There are a number of uncertainties in calculating landfill site emissions; for example the composition of the MSW deposited will vary, the amount of LFG recovered and burnt will vary, there will be some uncertainty inherent in measurements of emission composition.

The authors of the DEFRA report (Enviros *et al.* 2004) calculated best estimates of emissions to air from two case studies both of which had 25% fugitive emissions but one was based on 75% emissions from energy generation, the other 75% from gas flaring. The 'best estimates' for landfill emissions to air reproduced here in Table 4.2 represent 25% fugitive and 75% engine emissions as this best represents current landfill practice where collection and use of LFG for energy generation is preferred over flaring for LFG. In the future a greater proportion of LFG will be collected and burnt for energy generation thus the amount of fugitive emissions will decrease.

Energy generation from burning LFG can be considered as reducing the need to burn fossil fuels to generate electricity elsewhere. This probably reduces the overall emissions to air of SO2, benzene (VOC) and particulates compared to emissions from power stations, but there will be a net increase in other emissions (2001 figures, Enviros *et al.* 2004).

(c) Emissions to water (Table 4.4)

The production of leachate from rainwater and water in the MSW is responsible for emissions from landfill to sewer, groundwater and surface water. Control of landfill leachate has improved markedly since the 1980's. Landfills are now required by legislation to be engineered in such a way as to control leachate and reduce any potential harm to health and the environment.

The Landfill Regulations (2002) require all landfills receiving MSW (i.e. non-hazardous waste landfills) to have a barrier system to contain leachate. These have three layers: a drainage blanket which allows for the collection of leachate; a leachate sealing system including an artificial liner; a geological barrier of low permeability material (e.g. clay) which extends under the base and up the sides of the landfill.

No system, however sophisticated will be able to contain all the leachate. Thus risk assessments are carried out for landfills to ensure compliance with the European Groundwater Directive and Water Framework Directive. The Landfill Directive also requires that rainwater, and surface and groundwaters are prevented from entering the landfill. Thus when a landfill is complete it is covered by a cap comprising a sealing layer, normally including a geomembrane, a surface water drainage system and cover soil.

This will drastically reduce the production of leachate once the site is completed. Therefore it is during the operational phase that leachate will be mainly generated. Even this is minimised by progressively capping the site as filling progresses. Leachate, which is formed, will be removed for treatment and discharge either at an on-site plant or an off-site sewage treatment works.

Table 4.9 Emissions to water from landfill

'best estimates' in weight per tonne MSW treated

	Lfs	Lfw	Lfg
Suspended solids g	?	?	?
Nitrogen (Total) g	39	0.8	8.6
Arsenic (As) mg	0.7	0.005	0.06
Cadmium (Cd) mg	?	?	?
Chromium (Cr) mg	5	0.08	0.82
Cyanides (as CN) mg	<5	<0.01	<1.2
Lead (Pb) mg	<5	<0.11	<1.2
Mercury (Hg) mg	?	?	?
Nickel (Ni) mg	6	0.11	1.1
Polycyclic aromatic hydrocarbons mg	<0.48	<0.006	<0.06
Phosphorous mg	320	6	70
Tin (organo-tin compounds) mg	0.022	0.0004	0.005

Lfs Emissions to sewer; **LFw** Emissions to surface water; **Lfg** Emissions to groundwater; **?** no data; **g** grammes; **mg** milligramme. (Data from Enviros *et al.* 2004. Note there is an error in this report: the values listed in Table 2.48 for releases to surface water from landfill are the values given in Table 2.42 as releases to groundwater. On the basis that emissions to surface water would be lower than those to groundwater Table 2.42 has been taken as giving the correct values reproduced above).

Even though leachate is removed in this way there will always be a small amount that seeps through the liner in to the ground. However, the rate of this seepage is controlled by design, inspection and management to ensure that the surrounding environment is not compromised.

Natural attenuation of emissions into the groundwater will assist in reducing the potential impact and this will be taken into consideration during the risk assessment. Therefore, although there is the potential for a considerable quantity of leachate to seep out of the landfill during the long post closure period, modern landfills are engineered to ensure that the surrounding groundwater has the capacity to cope with these emissions.

Table 4.4 lists the 'best estimates' of emissions from landfill to sewer, for comparison with other processes. Table 4.9 lists the 'best estimates' of emissions to sewer surface and groundwater.

(d) Operation under abnormal conditions

Emissions to air are vulnerable to breakdowns in the landfill gas combustion systems. Most of the larger UK MSW landfill sites operate LFG engines to generate electricity. Usually flares are used to deal with any remaining LFG or in the event of breakdown of the energy generation plant. However interruptions to the operation of flares are more common than interruptions to the operation of generator engines.

Best practice is to install landfill gas collection systems within six months of the commencement of filling a new cell on a landfill site. At sites were this does not occur there would be relatively higher levels of emission of LFG.

In the control of LFG emissions it is important that an appropriate amount, and type, of material is used as 'daily cover' on the operational areas of the site and for capping completed parts of the site. If inappropriate materials are used, or they are spread too thinly, then LFG and odours may be released from the site. The waste in the landfill is continually decomposing and losing volume, thus the capping material may develop cracks or holes allowing the release of LFG. This can be minimised by careful management, including surface gas surveys using instruments to detect areas where LFG is being emitted and prompt attention to such areas.

LFG is flammable and has the potential to spontaneously combust under certain conditions. This could result in the emission of combustion products both from the LFG and the waste. This is less likely to occur at sites with well-engineered LFG collection systems. Most fires at UK landfill sites have been associated with tyres in the waste. Such fires are usually dealt with by increasing the load of soil on the surface of the landfill, which causes compression and starves the fire of oxygen.

One particular problem in the recent past has been a lack of appreciation of how some wastes will react upon disposal in a landfill. This was particularly the case with the disposal of waste containing a high proportion of calcium sulphate ($CaSO_4$, sometimes referred to as 'gypsum') at several landfill sites including the Bletchley/Newton Longville site in Milton Keynes. In spite of the fact that information about the degradation of sulphate by sulphur reducing bacteria under anaerobic (oxygen-free) conditions was widespread in the scientific literature no special precautions were taken during the landfilling of this waste. This resulted in the generation of large volumes of hydrogen sulphide (H_2S), which is both toxic and foul smelling. Because disposal of certain wastes, including liquids, is no longer permitted in landfill sites accepting MSW this problem should not arise again.

Emissions to water would be most compromised by a failure or fault in the landfill lining system allowing the increased discharge of leachate. Boreholes are emplaced at key points around landfill sites, which allow for the detection of any such leaks such that remedial action may be taken.

At sites where leachate is stored prior to treatment any reduction in oxygen levels in the liquid may lead to the generation of odours which if allowed to escape could cause a nuisance in surrounding areas. If on-site treatment works break down then leachate is normally tankered off-site for treatment elsewhere.

4.2.10 Emissions from MSW transport

Department for Transport information suggests that the mileage travelled by HGV during MSW management activities amounts to 0.49% of all such vehicle mileage. Thus compared to transport as a whole, emissions to air associated with MSW transport are only a tiny fraction. Nevertheless Table 4.2 includes the 'best estimates' of such emissions as calculated by Enviros *et al.* (2004).

Future developments in waste and resource management may mean that the mileage travelled in dealing with MSW will increase as multiple journeys are made, e.g. MSW to a recycling centre, products away from the centre, rather than a single journey to a landfill site.

4.3 The regulation of MSW management facilities

4.3.1 The Planning Regime

(a) Local Development Documents – The Milton Keynes Waste Local Plan

A Local Development Document (LDD) identifies acceptable sites for a particular land use, and allocates land within the local authority area for that use. A specific LDD is produced for waste. The current Waste Local Plan was adopted in 1997 by Buckinghamshire County Council, the Waste Planning Authority at that time (prior to Milton Keynes Council becoming a Unitary Authority and taking over this responsibility). This Plan provides the basis for waste planning decisions made by Milton Keynes Council, it identifies sites for waste management facilities to meet requirements and includes detailed policies for the treatment and disposal of waste. The existing plan expires in 2006 and a new plan will be produced and adopted by February 2008.

(For more information see:
http://www.mkweb.co.uk/local_plan_review/documents/Local_Development_Scheme_2005_-_2008__March_2005_.pdf.)

(b) The Planning Application Process

New developments such as waste management facilities require the granting of planning permission. The formation of a planning application includes the completion of formal application forms, supporting statements and plans detailing the siting and appearance of the proposal. Many applications for waste management facilities require the applicant to undertake an Environmental Impact Assessment EIA), the EIA consider the characteristics of the development, the environmental sensitivity of the location and the characteristics of the potential impact. The information gathered during the EIA, is used to produce an Environmental Statement, which forms part of the application, and should include a non-technical summary.

When an application has been submitted, a planning officer will consult with relevant local, regional, and in some cases national organisations who may have an interest in the application. In addition local residents and parish councils are consulted to obtain their views on the proposal.

A committee of elected members will decide a large-scale development or controversial application. In Milton Keynes this is the Development Control Committee (DCC). The case planning officer submits a report on the application to DCC, the report details the applications compatibility with planning policies, the LDD, the responses from consultees and other considerations such as regional self sufficiency and the proximity principle. The planning officer also has to determine whether the application represents the Best Practicable Environmental Option for the area. The report to DCC makes a recommendation to the committee, if the recommendation is for approval, the recommendation may suggest planning conditions that will be required if the proposal is approved. A condition of planning approval may also be the completion of a satisfactory legal agreement, which may include details of funds payable by the applicant to make improvements to local infrastructure and amenities.

If DCC decide to approve an application, the planning officer draws up the official decision notice, which details the conditions that have to be met as part of the planning permission.

4.3.2 The Integrated Pollution Prevention and Control Regime

(a) Integrated Pollution Prevention and Control (IPPC) applies an integrated environmental approach to the regulation of certain industrial activities including most waste management facilities. This means that emissions to air, water (including discharges to sewer) and land, plus a range of other environmental effects, must be considered together.

Operators of installations carrying out prescribed activities must apply to the regulator (either the Environment Agency or the Local Authority i.e. Milton Keynes Council) for a permit. The regulator sets permit conditions based on the use of "Best Available Techniques" (BAT), which balances the cost to the operator against the benefit to the environment.

(b) The Pollution Prevention and Control Regulations 2000 (‘the PPC regulations’) implement the European Union Directive 96/61/EC on Integrated Pollution Prevention and Control, in so far as it relates to installations in England and Wales (‘the IPPC Directive’). Prior to the PPC regulations coming into force, many industrial sectors covered by the IPPC Directive were regulated under Part 1 of the Environmental Protection Act 1990, which will be repealed following full implementation of IPPC.

Other industrial sectors new to integrated permitting, such as landfill sites, intensive farming and food and drink sectors were regulated, where appropriate, by separate waste management licences and/or water discharge consents. The Environment

Agency regulates Part A(1) installations and the local authority regulates Part A(2) and Part B installations. Part A installations are subject to the IPPC system and Part B installations are regulated for emissions to air only.

The PPC regulations have been amended to include all landfill sites. They are classified as Part A(1) installations and are permitted by the Environment Agency. The IPPC Directive only applies to landfill sites receiving 10 tonnes of waste in any day or with a total capacity of more than 25,000 tonnes (but excluding landfills taking only inert waste). All landfill sites have to meet the requirements of The Landfill Regulations 2002, which implement the European Union Directive 99/31/EC on the landfill of waste ('the Landfill Directive'). Before granting a permit, the Environment Agency classifies the landfill site as either a site for hazardous waste, non-hazardous waste or inert waste. The co-disposal of inert or non-hazardous waste at hazardous waste sites was banned from 16th July 2004.

A landfill permit must be obtained before operating a new landfill site, or making a "substantial" change to an existing site. Existing operational landfills not covered by the IPPC Directive will be required to apply for a permit in a phased programme to be completed by 31st March 2007. For existing sites covered by the Directive, the permit application period is specified by the Environment Agency on the basis of the "site conditioning plan" previously submitted by the landfill site operator.

(c) The Waste Incineration Regulations 2002 ('the WI regulations'), implement the requirements of the European Union Directive 2000/76/EC on the incineration of waste 'the Waste Incineration Directive' (WID). The WID entered into force on the 4th December 2000 and incorporates and extends the requirements of the 1989 Municipal Waste Incineration Directives (89/429/EEC and 89/369/EEC) and the Hazardous Waste Incineration Directive (94/67/EC), forming a single Directive on waste incineration. The WI regulations amended Section 5.1 of the PPC regulations, which now covers most waste incineration activities. New incineration activities were required to comply with the Directive from 28th December 2002 and existing plant must comply from 28th December 2005. The Environment Agency regulate all hazardous waste incinerators and others operating above 1 tonne per hour capacity.

There are also sections in the PPC regulations that require permitting of specific installations disposing of waste other than by incineration or landfill (section 5.3), the recovery of waste (section 5.4) and the production of fuel from waste (section 5.5).

4.4 Conclusions about emissions from MSW treatment

All forms of MSW treatment give off potentially harmful emissions. There are strict controls on such emissions, which must be maintained and fully enforced.

'Dioxin' emissions from MSW incinerators make up between 0.3 and 0.8% of national 'dioxin' emissions. Domestic cooking and heating produce 18% of UK 'dioxin' emissions. Bonfire night and fireworks amount for about 14% of national emissions (Source National Society for Clean Air, www.nsca.org.uk). Therefore, with respect to 'dioxins', it makes more sense to introduce strict controls on bonfires and fireworks than to ban MSW incinerators, which are already tightly controlled.

MSW treatment is responsible for less than 2% of national emissions of volatile organic compounds (VOCs excluding methane). The VOC benzene, a known carcinogen, is of particular concern but less than 0.02% of UK emissions are due to MSW treatment. The level of VOCs in domestic indoor air is ten times greater than outside (from furnishings, cleaners, etc.).

Nitrogen oxides (NO_x) are a significant harmful air pollutant but less than 1% of national emissions arise from MSW management. Road traffic is responsible for 42% and electricity generation for 24% of these emissions.

Metal emissions from MSW treatment (incineration and landfill sites) amount to about 0.1% for As, 10% for Cd, 1.65% for Hg and 0.2% for Ni as percentages of national annual emissions. Almost all the Cd comes from landfill sites. Crematoria give rise to just over 15% of national emissions of Hg.

Data in respect of PAH emissions to air is poor but MSW treatment probably accounts for less than 3% of total national emissions to air.

Bioaerosol emissions may be a concern with non-combustion waste treatment technologies, particularly at composting, MBT and anaerobic digestion sites and possibly at some materials recycling facilities.

Emissions of methane from landfill sites amount to about 27% of the national total emissions of methane. Agriculture accounts for about 40 % of the national emissions of this ‘greenhouse gas’.

MSW management emits about 2.4% of the national total emissions of carbon dioxide.

4.5 Other sources of emissions affecting Milton Keynes

4.5.1 Sources within Milton Keynes

(a) Road transport. The major source of emissions within Milton Keynes is from road transport. The M1 motorway, one of the busiest motorways in the country, passes through the middle of the borough. This 17 km stretch of motorway is used by approximately 100,000 vehicles per day and the A5 is the second busiest road in MK being used by around 40,000 vehicles per day (Milton Keynes Transport Monitoring Report 2003). The grid road system in the new part of Milton Keynes is also used by tens of thousands of vehicles per day.

Road transport contributes significantly to a number of air pollutants, including benzene, nitrogen dioxide, carbon monoxide, carbon dioxide, particulate matter and metals, including lead. Pollution from road transport is not limited to combustion products, it also arises from wear and tear of brake linings, tyres and other components of vehicles, from road surfacing materials, all contribute to pollutant levels. In fact, new European Union legislation requires tyre manufacturers to reformulate their products by 2010 in order to curb emissions of PAHs (see Royal Society of Chemistry website).

Using a middle of the range family car’s CO_2 emission data of 200 g/km (http://www.smmt.co.uk/co2/co2search.cfm), the traffic usage of the M1 in MK produces around 124,000 tonnes of CO_2 per year. In comparison, Environment Agency data from 2003 shows that the Coventry Waste to Energy Plant (Waste Incinerator) emitted 115,000 tonnes of CO_2 per year. Although a crude comparison, this calculation indicates that total annual road transport CO_2 emissions from the whole of the road network in Milton Keynes is substantially greater than emissions from a single incineration plant.

Despite advances in technology to reduce emissions, the number of vehicles on the roads and numbers of journeys made continues to rise every year. With the continued growth of Milton Keynes and plans for future expansion, as well as consideration being made to widening the M1 from the M25 up to junction 14, emissions from traffic in Milton Keynes will undoubtedly increase considerably in the next two decades.

(b) Permitted processes in Milton Keynes

As outlined earlier in the report (Section 4.3.2), the Pollution Prevention and Control (England and Wales) Regulations 2000 require operators of specified industrial and other installations to obtain a permit to operate. Depending on the type of operation, permit conditions are set by either the local authority or the Environment Agency to control emissions to air, land and water, so as to achieve a high level of protection to the environment. Consequently, with a few notable exceptions (e.g. landfill sites), emissions from these processes are negligible compared to those from traffic. Indeed, data obtainable from the Environment Agency's website 'What's in your backyard?' feature show that because modern emission control techniques are so efficient much of the recent reported data for these processes are below the limits required for reporting.

Examples of permitted operations within MK include:

- Bletchley/Newton Longville landfill site
- Cotton Valley Sewage Works
- Concrete processing plants
- Car respraying workshops
- Coating of wood and metal processes
- Inorganic and organic chemicals manufacture

(c) The crematorium incinerator

Milton Keynes Crematorium performs around 1700 cremations per year. This operation is regulated under the PPC regulations. Cremation is an incineration process and consequently the types of emissions are similar to those from MSW incineration (carbon dioxide, mercury, dioxins etc.). Emissions of mercury (Hg) from dental fillings have been a particular cause for concern. Each cremation produces something of the order of 3 g of Hg, based on an average human having 5 amalgam fillings, each containing an average of 0.6 g of Hg. This concern has led to new tighter emission limits for mercury, and dioxins, for new crematoria (DEFRA, Process Guidance Note 5/2, Issue 1, September 2004).

4.5.2 Sources outside Milton Keynes

(a) Stewartby Brickworks. Milton Keynes Council receives many odour complaints every year relating to the nearby Stewartby Brickworks (Section 1.3.1). The site is 'over the border' in Bedfordshire and is regulated by the Environment Agency. Table

4.10 records the Environment Agency data from 2003 for emissions to air from the brickworks.

(b) Didcot A Power Station in Oxfordshire is the nearest coal burning power station to MK. Again the site is regulated by the Environment Agency. Table 4.11 records the Environment Agency data from 2003 for emissions to air and controlled waters from the power station.

Whilst emissions from these two sources certainly significantly affect the air quality in Milton Keynes the extent of that effect is unquantified.

Table 4.10 Emissions to air from Stewartby Brickworks in 2003

Substance	Total Released (tonnes)
Carbon Monoxide	1148
Carbon Disulphide	7
Carbon Dioxide	63080
Hydrogen Fluoride	40
Particulate Matter - Total	153
Dioxins % Furans (TEQ)	<0 kg
Hydrogen Chloride	17
Particulate Matter - PM_{10}	115
Nitrogen Oxides (NO_x) as NO_2	<100
Chlorine	17
Volatile Organic Compounds (NMVOCs)	530
Methane	206
Sulphur Oxides (SO_x) as SO_2	8564

Table 4.11 Emissions to air from Didcot A Power Station in 2003	
Substance	Total Released
Carbon Dioxide	9026.6 kt
Carbon Monoxide	3710.7 t
Selenium	360.9 kg
Nickel	315.5 kg
Particulate Matter	1209.1 t
Hydrogen Chloride	1105.7 t
Zinc	252.8 kg
Dioxins And Furans (TEQ)	0 kg
Particulate Matter - PM_{10}	967.2 t
Chlorine	1442.7 t
Fluorine	531.4 t
Polychlorinated Biphenyls (PCBs)	0.1 g
Volatile Organic Compounds (NMVOCs)	117.5 t
Cadmium	21 kg
Antimony	29.6 kg
Beryllium	7.9 kg
Arsenic	78.6 kg
Chromium	320.7 kg
Copper	185.3 kg
Methane	75.7 t
Lead	<100 kg
Manganese	540.2 kg
Mercury	69.6 kg
Sulphur Oxides (SO2 and SO3) as SO2	42 kt
Boron	31891 kg
Vanadium	261.6 kg
Nitrogen Oxides (NO and NO2) as NO2	24.7 kt
Benzo[a]pyrene	1.06 kg
Polycyclic Aromatic Hydrocarbons (PAHs)	<50 kg

Table 4.11 clearly shows that emissions, especially of metals, from Didcot A Power Station are significantly greater than those reported for any thermal treatment facility.

Part C: Potential Health and Environmental Effects and Impacts

5. Results of research on potential health effects

5.1 Epidemiological research

5.1.1 Types of epidemiological study

(a) Epidemiology is the study of disease in populations as opposed to the study of an individual (Sections 3.2.8 and 3.3.5). Where epidemiology studies the relationship between exposure to a hazard and its relationship to disease in a population it can be regarded as 'human environmental risk assessment'. There are various types of epidemiological study referred to in the literature:

(b) Ecological epidemiological studies are characterised by measuring exposure in geographical terms, for example distance from a waste site, usually by recording the home addresses of the exposed population. Although this is far from ideal because of the difficulties in actually measuring personal exposure to chemicals outside waste sites, this method of exposure estimation is often the best available. While ecological studies have significant limits, they are the only method commonly available for measuring the actual health effects of living near waste sites.

(c) Case-control epidemiological studies compare two groups of people. The first group comprises people affected by a specific disease. The second group comprises people without this disease. Both groups are studied, and their characteristics compared. Typically, subjects are given questionnaires to complete, but it is increasingly common to take blood samples or other biological samples to assess exposure. The principle underlying this type of study is that, if a particular factor causes disease (for example living near a landfill site), it should be more common in the group with the disease than in the group without the disease. The main practical difficulty in the conduct of case-control studies is the selection of the control population. This group should represent people, who would have been identified as cases by the study, had they developed the disease under consideration. In practice this requirement can be hard to meet.

The main issue in the interpretation of case-control studies is known as recall bias. Participants in a case-control study usually have their past exposures estimated. As a result, any factor that affects the recollection of cases and controls can affect the results of this type of study. Unfortunately, people with serious chronic illnesses, the type most commonly studied using these techniques, frequently spend time wondering why they have fallen ill. Control subjects seldom do this.

(d) Cohort epidemiological studies involve a single group of people. They are identified and followed over a period of time and their health outcomes are recorded. Common types of cohort study include the occupational cohort, where the cohort is defined to include employees of a particular factory. In this situation, the occurrence of disease is often detected using occupational health records of some kind. Cohort studies often depend on the existence of past records. These records were seldom collected with the needs of future epidemiologists in mind, and must be interpreted cautiously. Assessment of exposure based on past occupational records may be of limited reliability. (After Crowley et al. 2003).

(e) The concepts of exposure, effect estimate, and outcome are common to all types of environmental epidemiological study that attempt to establish a link between adverse health effects and exposure to hazardous emissions. The exposure is typically a measure of proximity to a waste site, or a set of exposure estimates for a specific chemical. Effect estimates are quantitative, numerical estimates of the impact of exposure on disease occurrence. These might be measures such as the difference in incidence between exposed and unexposed people, or the ratio of the incidence of disease in the exposed group to that in the unexposed group. The outcome is the result of the exposure under investigation. Common health outcomes studied in relation to exposures related to waste sites have included cancers, congenital malformations, and stillbirths.

5.1.2 Assessment of exposure

A problem common to epidemiological studies of MSW facilities is the lack of information relating to human exposure. In fact few studies have carried out actual measurements of exposure to specific pollutants. Transport mechanisms and pathways that strongly influence the risk of exposure off-site, including that most basic effect the heterogeneous distribution of wind directions around the site, have generally not been taken into account in epidemiological studies. In the slightly more sophisticated studies, concentric circles have been constructed around a point source of emissions, such as an incinerator, and a gradient in exposure assumed between the innermost and outermost circles.

The effect of uncertainties such as these is to cause misclassification of exposure, where some people with low exposure are classified as high exposure and vice versa, which leads to a biased estimation of effects.

The US National Research Council (1983) provides a guideline of the relative reliability of methods of estimating population exposure. In their hierarchy, the most desirable option for exposure assessment is biomonitoring, whereas data on residence or employment in a geographical area are regarded as least reliable:

Table 5.1 Hierarchy of exposure assessment data

Most reliable

1. **Quantified individual measurements (biomonitoring)**
2. **Quantified ambient measurements**
3. **Quantified surrogates**
4. **Distance and duration**
5. **Distance or duration**
6. **Residence or employment proximity**
7. **Residence or employment in a geographical area**

Least reliable

Unfortunately it is the least reliable estimate of exposure, residence in a geographical area, which is most often used in epidemiological studies. Although one of the strengths of geographical population studies is the ability to detect small differences in measured health between exposed and unexposed populations; this measurement is very sensitive to other influences, such as lifestyle factors and other environmental exposures.

However, given the complexity of emissions from MSW management sites, their very low concentrations, the possibility of exposure to the same pollutant from multiple sources and via multiple pathways and the generally non-specific health outcomes which could be attributed to more than one pollutant, it is quite likely that little would be gained by attempting to directly measure the population exposure.

5.1.3 Measuring health outcomes

Evaluating health outcomes is usually most straightforward in regard of cancers, since the cancer registration process in the UK (and in many other countries) records the point of residence of those recorded as contracting the disease. Therefore it is possible to retrospectively analyse the incidence of cancer in relation to some surrogate for pollutant exposure. In the case of most other illnesses, such as respiratory disease, there is no comparable registration process and routine health service data such as hospital admissions cannot be disaggregated according to location of residence. Epidemiological studies of these outcomes must depend upon self-reported symptoms, which are recognised to be frequently unreliable, or upon objective measures such as lung function which cannot be measured on large numbers of people. This consequently reduces the power of the study to identify an effect. (After Enviros et al.2004).

5.1.4 Statistical associations in epidemiological studies

(a) Statistical power. A primary consideration in any study of the health effects of an exposure is the ‘statistical power’ of the study. This is simply the chance that a particular study will detect a real increase (or decrease) in risk. This is influenced by two main factors. The first is the size of the risk. The higher the risk, the more likely any given study is to detect that risk. The second is the size of the study, in this context the number of people exposed. The larger this number, the more likely a study is to detect any given level of increased risk. (After Crowley et al. 2003).

(b) The concept of causality. Another important question is whether a statistical association, which is calculated to occur between exposure to a hazard and an adverse health outcome, is a ‘causal connection’. A statistically significant finding in a study is only a demonstration of a statistical association. Just because there is statistical association between two factors does not imply that one causes the other. For example, just because most people injured by cricket balls are found to have been wearing white clothes does not mean that wearing white clothes increases your chances of injury from flying cricket balls.

Although there is no standard set of criteria for attempting to establish whether a statistical association, between such things as exposure to a pollutant and disease, is a result of causality, there are lists of criteria which have been proposed, for example by Hill (1965).

(c) Criteria for establishing causality. Factors that are often used to attempt to establish causality include:

- **Strength of association**: A large magnitude of effect and high statistical significance is likely to be far more convincing than a small effect of marginal statistical significance.
- **Time sequence**: The occurrence of the disease must follow the exposure in time. If the disease precedes the exposure, then causality is highly improbable.
- **Distribution of the disease**: If the disease varies in space and time in the same manner as the causal factor (allowing for possible latency periods), then causality is much more likely.
- **Exposure-response gradient:** It would be expected that large exposures are associated with more cases of consequent disease. Areas highly exposed to pollutants would be expected to show a greater prevalence of consequent disease than those with a low exposure.
- **Consistency and coherence:** If a number of studies, for example in different places, showed the same relationship between exposure and disease, this would be referred to as consistency and would add weight to arguments for causality. If evidence from different kinds of studies also shows the same kind of association between exposure and disease, this coherence would also be taken as evidence favouring causality.
- **Biological plausibility:** The association between the disease and exposure to the suspected causal agent should be consistent with the known biological activity of the suspected agent.
- **Experimental models:** There is a range of experimental models, such as laboratory animals, which can be used to evaluate the consequences of exposure to chemicals. If the results of such experiments are consistent with the statistical associations established through epidemiology, the case for causality is strengthened. (After Enviros et al. 2004).

Causality as a concept is fraught with difficulties, essentially it can be interpreted as meaning that there is a causal relationship if removing the ‘hazardous exposure’ would reduce the risk of ill health. Unfortunately, it can be very hard to establish causality from epidemiological studies. There is frequent disagreement about the most appropriate interpretation of the evidence, and in particular the question of the amount of evidence required to justify a particular action can be very divisive. No single study is sufficient to establish scientific causation, and good evidence for causation requires several large, well-conducted studies from different countries.

Scientific decisions on causation remain tentative and are liable to revision, as new evidence becomes available. Decisions on causation for policy purposes are governed by different priorities. Scientists try to estimate the size of an effect, as precisely as possible, but from a policy perspective the financial and political costs of missing a real hazard may be much greater than the costs of overstating an effect. (After Crowley et al. 2003).

5.1.5 The problems of chance and confounding in epidemiological studies

Probably the two main difficulties with establishing causality when an epidemiological study identifies a statistical relationship, or correlation, are ‘chance’ and ‘confounding’. A statistical correlation does not imply causation since it may arise simply by chance or because one or more further variables are correlated with both the exposure and the health outcome (a confounding factor).

(a) Chance in statistical correlations

Many epidemiological studies consider a wide range of adverse health outcomes and a small proportion of results will always be positive by chance. Even a relatively high confidence level of 95% means that on average 5% of results will be positive by chance. Therefore, if 20 adverse health outcomes were investigated, at the 95% confidence level on average one will have occurred purely by chance. In examining the outcomes of such studies, it is necessary to look for evidence of consistency between studies rather than taking a single statistically significant positive finding as necessarily indicative of an effect. The second very important point is that a statistically significant finding in a study is only a demonstration of a statistical association. To infer or reject causality between the correlated factors requires a number of criteria to be satisfied (5.1.4 above).

(b) Confounding factors

These represent sources of bias in the study. For example, the study may not fully allow for all the sources of exposure to substances contributing to causing a disease. It is now well know that smoking causes lung cancer. If a group of people living in a study area smoke more than the general population as a whole and this is not fully allowed for by the investigators, then they might make the incorrect conclusion that there is a higher level of lung cancer in the study population. If this population has been chosen because they live close to an MSW facility then the assumption may be made that there is a causal connection between the facility and the incidence of lung cancer.

The principal variable, which leads to confounding, is socio-economic status. People in higher socio-economic groups rarely choose to live close to waste management facilities. Therefore it is the poorer members of the community, who are also statistically more liable to contract most diseases for reasons unconnected with pollutant exposure and who tend to smoke more, that live in the areas closest to emissions from industry and waste management operations.

Thus, even in the absence of a pollutant effect, one might well expect to find a correlation between proximity to an incinerator, for example, and a range of diseases, including lung cancer. Therefore epidemiological statistical studies need to control for confounding effects. In other words they adjust the results to allow for effects such as socio-economic status. However, such adjustments will not be perfect and there will normally be some residual confounding. This could produce a statistical correlation but this will not be due to a real effect.

Whilst socio-economic status is often the most important confounding factor, there are many other sources of confounding such as age, gender, ethnicity, access to healthcare, smoking prevalence, occupation, etc.

Other confounding factors include such things as the industrial heritage of an area. MSW management facilities tend to be located in areas where former industrial operations may have left a local legacy of contamination. Thus allocating any statistical effects to a particular source may be even more problematic. Ideally, an epidemiological study will control for all of these variables, but in practice this is rarely practicable and it is unusual to control for anything other than socio-economic status. The consequence is that there may be residual confounding which could lead to a false result, either positive or negative.

5.2 The findings from epidemiological studies

5.2.1 The main areas of concern

Many studies have been carried out on possible health impacts from landfill sites and incinerators and there have been a few studies on materials recycling facilities and composting sites.

Particular concerns and investigations have focussed on three areas in connection with MSW:

- **Landfill sites** have been investigated as the possible cause of birth defects, cancers and respiratory illnesses including asthma;
- **Incinerators** have been investigated as to possible increases in cancer, birth defects and respiratory illnesses including asthma. Other studies have particularly concentrated on emissions of dioxins from incinerators;
- **Composting and materials recycling facilities** (MRFs) have been investigated for possible exposures to micro-organisms and odours, and lung diseases like bronchitis.

5.2.2 Studies on landfill sites

A recent study by the Small Area Health Statistics Unit is the only study that shows a consistent statistical relationship between living near MSW landfill sites and adverse health effects (Elliot et al. 2001). This study investigated the occurrence of birth defects in children born to families living within two kilometres of landfill sites in the UK. It included data on over eight million births in the UK between 1983 and 1999. The birth data were grouped into two categories: (i) where the mother lived within two kilometres of a landfill site; (ii) where the mother lived more than two kilometres from a landfill site.

The two categories were then compared to see if there was any statistical difference between the occurrence of birth defects in the two groups. The comparison showed slightly higher rates of birth defects in the group living closer to landfill sites. However, there are serious problems with interpreting the results of studies of this type including:

- the geographical location data was based on postcodes, which are broad indicators, this is the reason for using a 2 km distance cut-off point;
- the type of landfill site studied is unclear, it may be that it includes sites which have received hazardous waste in addition to MSW;
- even after attempting to allow for known ‘confounding factors’ it may be that the two groups differ due to residual confounding factors such as misclassification of socio-economic status, rather than a real difference in health (‘poor people’ have worse health than ‘rich people’);
- for some landfill sites which opened during the study, for some of the health effects studied, the group who lived nearer the landfill site suffered fewer birth defects than the group living further away (in other words living near the landfill site appeared beneficial to health). This indicates that factors other than residence near a landfill site may be the cause of the statistical differences;
- the very small scale of the incremental health risks identified in this study mean it is less likely that the reported effects are caused by any emissions from the landfill site.

The authors of this report are quite clear that there is no direct evidence of any cause and effect relationship between the identified health effects and living near a landfill site. In fact it is quite possible that if residence near municipal swimming pools were substituted for landfill sites then similar statistical differences might be found between the two populations due to residual confounding effects from socio-economic factors, such as the mother's diet, smoking and alcohol intake. Factors that include the mother's health and the child's genetic make-up are known to be causes of birth defects, but even so, the majority of birth defects are of unknown origin.

The independent expert Committee on the Toxicity of Chemicals in Food, Consumer Products and the Environment (COC) concluded "it is inappropriate to draw firm conclusions on the possible health effects of landfill sites from the results of this study".

There have been other studies on landfill sites, many of them on hazardous waste sites rather than sites for MSW. No study has shown unequivocal evidence that residence near a landfill site causes negative health impacts. In particular after an exhaustive investigation of the evidence the recent DEFRA report (Enviros et al. 2004) says, "we found that the weight of evidence is against any increased incidence of cancers in people living near to landfill sites".

5.2.3 Studies on Incinerators

Air pollution from all sources is known to have negative effects on the health of susceptible people, young children, the elderly and particularly people with pre-existing respiratory diseases. The UK Committee on the Medical Effects of Air Pollutants (COMEAP 1998) has shown that exposure to air pollution can bring forward death in a person with severe pre-existing disease, although the extent of life-shortening is of the order of a few weeks at most. However, there is little convincing evidence that current levels of air pollution in the UK cause adverse health effects on healthy individuals.

Most published studies of incinerators concentrate on the older generation of incinerators, which were phased out in the UK after the IPPC regime introduced stricter emission controls. The level of emissions from these incinerators was very much higher than from modern incinerators, which makes any conclusions from these studies not directly relevant to the current situation. Not withstanding this, most of the epidemiological studies of populations living near incinerators have not given clear indications of the presence, or absence, of negative health effects.

The fact that there is no good evidence of an association between living near an incinerator and adverse impacts on health could mean that incineration does not cause adverse health effects or it could mean that the health effects are not detectable using existing epidemiological methods and the available data. However, there is some research that showed that there is no difference in the amounts of dioxins and furans in blood samples from people living near to a modern incinerator and those living further away (Gonzalez et al. 2000).

Several studies have investigated possible associations between incinerators and the incidence of cancer. The most frequently studied cancers are those of the stomach, colorectal, liver, lung, larynx and non-Hodgkins lymphoma. Some studies have shown apparently significant correlations but the incinerators studied are often in areas close to other sources of potentially hazardous emissions, thus making it impossible to be certain of the source of any impact.

After considering all the available evidence the experts of the government's advisory COC came to the conclusion that "any potential risk of cancer due to residency (for periods in excess of ten years) near to municipal solid waste incinerators was exceedingly low and probably not measurable by the most modern techniques".

It has been often asserted that emissions from incinerators make respiratory problems worse. There is little evidence of this, in fact there is evidence to suggest the contrary, and it seems unlikely to be a major effect as in most cases the incinerator contributes only a small proportion of the local level of air pollutants.

5.2.4 Studies on composting sites

Hazards from bioaerosols have been shown to lead to a number of distinct health conditions such as allergic rhinitis and asthma, inflammatory diseases of the respiratory system, inflammation of the deep lung, and toxic pneumonitis (organic dust toxic syndrome). Studies have shown that levels of bioaerosols in a number of commercial scale composting facilities represent a distinct hazard, particularly to the on-site workers. However, there are insufficient studies to allow a quantification of these effects. In addition there are few studies of potential effects on residents near composting sites but they show that they could experience an increased rate of adverse health impacts such as bronchitis, coughing and eye irritation, but no link has been found with asthma.

In-vessel composting systems are capable of exerting a much greater degree of control on bioaerosol emissions and so are to be preferred to open 'windrow' composting operations but there is still a lack of information about these systems.

A few studies have examined the emission of VOCs from composting sites. One study has examined whether there is an increased risk of cancer due to exposure to emissions from these sites. No additional risk of cancer was found.

Further work is urgently needed to investigate, clarify and quantify the potential health impacts from composting sites of all types.

5.2.5 Studies on Materials Recycling Facilities

A few studies have been carried out on workers in these facilities. These show that the incidence of flu-like disease, eye and skin problems, fatigue and nausea are higher in these workers than in comparable groups. The most probable cause is exposure to high levels of bioaerosols. A significant problem is that there are no reported studies on the health of local populations living around MRFs.

In the absence of such studies we cannot assume that the impact of any emissions on local populations is negligible nor is it easy to use studies on worker's health as an indicator of possible effects on the local population both in respect of MRFs and composting sites.

This is because the general public is likely to include individuals of far greater susceptibility than the workforce. This is partly because of the well-known “healthy worker effect” which results in a workforce becoming a self-selecting population. Those who suffer ill health as a result of their work tend to leave for employment elsewhere, whilst those who are more resistant to the effects of occupational exposures are more likely to continue with that employment. This means that the workforce in MRFs, and composting sites, may be significantly more resistant to the negative effects of emissions such as bioaerosols than the general public. On the other hand they are exposed to much higher levels than the surrounding residents.

The conclusion must be that we cannot draw any useful conclusions about the potential for health effects on the population around MRFs, and composting sites, without further research.

6. Quantified risk assessment of potential health and environmental impacts from MSW facilities

6.1 The design of the quantitative investigation

The authors of the recent DEFRA report on Environmental & Health Effects of MSW treatment carried out an exercise to assess quantitatively the health effects of MSW treatment and disposal facilities on a nation-wide basis. This is the most recent and wide-ranging study of its type carried out to date. This chapter is an outline of their findings, for further details, especially a more thorough treatment of the sources and the uncertainties in the data; the full report should be read (Enviros et al. 2004)

The assessment was restricted to emissions to air. Potential exposure to substances emitted to water or land is affected to a much greater extent by site-specific circumstances and by an individual's diet and lifestyle (we all have to breathe air, we don't all eat meat, smoke or drink alcohol etc.) and also by controls on water and food quality.

The results of their study on health effects from MSW management, on a national scale as a whole, are reviewed in Section 6.2. The results from their study relating to individual MS management techniques are reviewed in Section 6.3.

6.1.1 The health effects studied

The health effects they considered were:

- 'Deaths brought forward', i.e. deaths occurring sooner than would otherwise have happened of vulnerable people such as the sick and elderly. This effect is a known result of elevated levels of air pollutants, it does not include deaths due to cancer caused by airborne carcinogens;
- Respiratory hospital admissions;
- Cardiovascular hospital admissions;
- Additional cases of cancer.

6.1.2 The MSW management facilities studied

The waste management facilities they considered were ten conceptual MSW facilities and results from a previous study for incinerators:

- Incinerators, results from a previous study (Environment Agency 2003);
- Six different types of landfill site, the one most appropriate to Milton Keynes is a site accepting 75,000 tonnes of waste per year with 75% of landfill gas captured and burnt in energy generation engines with 25% fugitive emissions and the results for this site are included here;
- A pyrolysis/gasification plant accepting 50,000 tonnes of waste per year;
- A composting plant accepting 50,000 tonnes of waste per year;
- An anaerobic digestion plant accepting 50,000 tonnes of waste per year;
- A mechanical biological treatment plant accepting 50,000 tonnes of waste per year.

6.1.3 Limitations of the study

As Enviros et al. point out, a number of assumptions had to be made in carrying out the evaluation due to lack of sufficient data. Potential effects due to exposure to emissions other than via the airborne pathway were not considered. Airborne exposure is the pathway of greatest concern particularly for combustion processes.

Emissions to land, such as compost, which might effect food crops, are now subject to controls which greatly reduces the significance of this pathway for human exposure. Similarly drinking water is treated prior to consumption and closely monitored by the water companies to ensure that its chemical composition is within agreed limits.

A previous Environment Agency study on emissions of dioxins and furans from modern incinerators has shown that they amount to only between 0.3% and 0.8% of the background exposure from other sources. On this basis they concluded, "the dioxin emission contribution to exposure of local populations is entirely negligible" (Environment Agency 2003).

They were unable to estimate the potential health effects from composting sites, and for some emissions from other processes, because of a lack of quantitative information.

6.1.4 The methodology of the study

The methodology used was essentially that used by Environment Agency (2003) in their study of incinerators. The available data on emissions, plus assumptions about the six model landfill sites, were used in a dispersion-modelling program, which produced a map of ground-level concentrations of the emissions in the vicinity of the modelled sites. These concentrations were then assessed in terms of their likely health impact on an assumed exposed population.

The methodology prepared by the Committee on the Medical Effects of Air Pollutants (COMEAP 1998), to estimate the incremental effect of emissions of SO_2, NO_x and particulates, was used to estimate the increase in mortality and hospital admissions using exposure-response coefficients derived from epidemiological studies. These coefficients represent the percentage increase in a baseline health rate in the population per unit rise in pollutant concentration. The COMEAP approach was used because it is the most up to date method available using UK-specific data.

World Health Organisation unit risk factors for exposure to chemical genotoxic carcinogens were also used in the study (WHO 2000). Both the WHO and the COMEAP unit risk factors relate to health effects with no 'threshold effect'. Thus the assumption is made that any exposure down to the cut-off level used (0.01 $\mu g/m^3$, see below) has some risk of harmful health effects. This assumption cannot be practically tested but it means that any calculated effect is likely to be over estimated rather than under estimated. Thus the health effects discussed in Sections 6.2 and 6.3 below can be considered to be 'worst-case scenarios' with any real effects likely to be significantly less.

6.1.5 The data used

As can be seen from Table 6.1 there is quantitative data available for most substances for most techniques, but there are some areas where data is not available.

Table 6.1 Available data on emissions used in quantitative study

	Composting	MBT	Anaerobic digestion	Pyrolysis Gasification	Incineration	Landfill
NO_x	----	Y	Y	Y	Y	Y
SO_2	----	Y	Y	Y	Y	Y
PM_{10}	N	Y	Y	Y	Y	Y
PAH	N	N	N	N	Y	N
'Dioxins'	N	N	Insig	Insig	Insig	Insig
Benzene	N	N	----	----	----	Y
Vinyl chloride	N	N	----	----	----	Y
Arsenic	N	N	Y	Y	Y	Y
Chromium ^{VI}	N	N	N	N	Y	N
Nickel	N	N	Y	Y	Y	Y
Bioaerosols	N	N	----	----	----	N

Y: quantitative data available and used; **N:** no data, potentially significant emission;
Insig: emissions assumed to be insignificant (Environment Agency 2003).

Incineration: A wide range of emissions data is available.

Landfill: A wide range of emissions data is available, although emissions of micro-organisms may be significant, together with exposure via other routes.

Pyrolysis/gasification: A range of emissions data is available, but this is based on a limited data set.

Anaerobic digestion: A range of emissions data is available, but this is based on a limited data set.

Composting: Emissions data are, in general, not available. A low or nil forecast impact should not be taken to demonstrate no effect.

MBT: Emissions data are in general not available. A low or nil forecast impact should not be taken to demonstrate no effect.

PAHs: Little data are available. The assessment of incineration indicates that these emissions are likely to be insignificant.

Bioaerosols (micro-organisms): No exposure-response functions are available for micro-organisms. There is no emissions data available, although some environmental measurements have been published. This is a potential issue for landfill, composting and MBT. (After Enviros et al. 2004)

6.1.6 Comparison of the emissions from MSW with other sources

The emissions from MSW treatment and any corresponding health impact, must be read in the context of MSW management being responsible for levels of emissions which, for most substances, are a tiny fraction of total national emissions (Table 6.2).

Based on the data in Table 6.6 the following conclusions can be drawn:

- The electricity supply industry is the major source of carbon dioxide emissions in the UK as it is the major consumer of fossil fuels. Total emissions from transport equate to around 24% of the total UK carbon dioxide emissions. Good quality information is available on these emissions

- The largest source of methane emissions is the agricultural sector. Emissions from landfill are estimated to account for approximately 27% of UK methane emissions in 2000, although this estimate is of poor quality. The value for waste management derived in this project is dependent on assumptions regarding the different types of landfill site in the UK and the variation in methane emissions during the lifetime of a landfill. These values are of moderate quality. Methane emissions are likely to decrease in the future as extraction and combustion of landfill gas increases, and the biodegradable content of landfilled material decreases.

- Emissions of benzene are dominated by transport, accounting for 47% of the 2000 estimate total. The estimate of emissions from traffic is of good quality, but estimated emissions from other sources are only considered to be of poor or moderate quality.

- PCBs have not been manufactured and used in the UK for many years, but it is estimated that 81% of PCB emissions are associated with PCB-containing equipment that still exists. Large quantities of PCBs are thought to have been disposed of to landfill in the past.

- The largest emission of arsenic arises from coal combustion with other sources being very small by comparison. Coal use has declined over the period considered, in favour of natural gas use. The emissions from the industrial sector are large compared with the emissions from public power generation; this is due to the different levels of abatement efficiency that are assumed. The estimated emissions of arsenic are of moderate quality.

- The main sources of cadmium are non-ferrous metal production and iron and steel manufacture.

- The largest source of lead is road transport, although the introduction of lead-free fuels has reduced emissions. Other major sources are industrial processes and iron and steel manufacture.

- The main emissions of mercury are from waste incineration, cremation, the manufacture of chlorine in mercury cells, non-ferrous metal production and coal combustion.

- Estimated emissions of dioxins and furans from management of MSW account for less than 1% of the UK total, shared approximately equally between incineration and landfill gas combustion. A number of sources contribute to emissions of dioxins and furans to a similar or greater extent including: accidental vehicle fires; small-scale waste burning (e.g. on building sites); incineration of other wastes; and the iron and steel industry. However, the most significant sources of dioxins and furans are domestic emissions and fireworks and bonfire night, both of which account for about a sixth of total emissions. Information on emissions of dioxins from waste management and power generation is of moderate quality; information on emissions from other sources is of poor quality.

- A different perspective can be gained by considering how much road traffic would give the same emissions as managing MSW. The national UK emissions of oxides of nitrogen from management of MSW are approximately equivalent to emissions of oxides of nitrogen from traffic using a motorway 200 km in length. Similarly, emissions of particulates from management of MSW are approximately equivalent to emissions from a motorway 120 km long, and emissions of carbon dioxide from management of MSW are approximately equivalent to emissions from a motorway 500 km long. (After Enviros et al. 2004).

  [Note: there are about 3,500 km of motorway in the UK]

Table 6.2 Comparison of emissions to air from MSW management and other activities

Substance	Total	MSW	MSW %total	Power	Road	Domestic	Agriculture	Other
Carbon dioxide (CO_2)	147,500	3,600	2.4%	42,000	31,500	23,400	200	
Methane (CH_4)	2,427	690	27%	28	16	29	969	
Benzene	16	0.002	0.0125%		7.71	3		
Nitrogen oxides (NO_x)	1,512	10	0.66%	358	629	72		
Sulphur oxides (SO_x)	1,165	2	0.17%	826	6	44		
Halides of hydrogen (HCl, HF)	88	0.47	0.53%	74.4		4.7		
Non-methane VOCs	1,676	0.2	0.01%	8	408	36		
Dioxins & furans (g TEQ)	360	2.9	0.81%	14	12	65		50 (1)
Polychlorinated biphenyls PCBs	1,706	0.24	0.014%	49		10		1,200 (2)
Arsenic (As) tonne/year	34.6	0.021	0.06%	4.3		7.3		
Cadmium (Cd) tonne/year	5.2	0.52	10%	0.4	0.4	0.3		
Lead (Pb) tonne/year	496			17.5	326	13.6		
Mercury (Hg) tonne/year	8.5	0.13	1.53%	1.4		0.5		1.3 (3)
Particulate matter PM10	172	0.2	0.12%	22	26	28	14	
Data quality	Poor to moderate	Moderate	Moderate	Good to moderate	Good to moderate	Poor	Poor	

Total: total national emissions; **MSW:** municipal solid waste management; **MSW** %total: MSW emissions as % national emissions; **Power:** energy generation;
Road: road transport; **Domestic:** emissions from households; **Agriculture:** emissions from farming etc. Data from National Atmospheric Emissions Inventory 2000).
Values in kilotonne per year, except: dioxins in gramme TEQ per year; PCBs in kilogramme per year; As, Cd, Pb, Hg in tonne per year.
(1) Fireworks estimate National Society for Clean Air; **(2)** Fluid in old electrical equipment; **(3)** Emitted from crematoria.

6.2 Results of the quantitative evaluation of health impacts

6.2.1 Overall health effects from UK MSW treatment

The results showed that on a national scale, allowing for the amount of waste currently managed by each process, emissions to air from MSW management are estimated to cause:

- Five hospital admissions for respiratory disease each year;
- less than one death brought forward per year;
- about one additional cancer case every seven hundred years.

The report says that more work on the possible health effects of composting is needed especially as there is some epidemiological evidence suggesting that health effects might occur in people living very close (within 250 metres) to MSW composting sites.

Table 6.3 Comparison of health effects

	Number per year in the UK due to:			
Health impact	**MSW management**	**Skin cancer (Mainly due to sunlight & sunbeds)**	**Lung cancer due to passive smoking**	**Health impacts due to overall air pollution**
Deaths brought forward	**0.55** (less than one nationally per year)			**11,600** (about one per small town per year)
Hospital admissions	**4.9** (about one per region per year)			**14,000** (about one per small town per year)
Cancers	**0.0014** (about one nationally every seven hundred years)	**6,000** (about one per small town per year)	**hundreds** (about one per large town per year)	
Data quality	**Poor**	**Moderate**	**Poor**	**Poor**

In terms of respiratory hospital admissions the available data does not definitely indicate that one option for managing MSW is better or worse than another. There is an indication that incineration may have a greater effect on health than landfill, in this regard, but the differences are very small.

6.2.2 Comparison of health effects from MSW management with other causes

The calculated total number of estimated extra hospital admissions at less than five per year is very small. This is especially the case when viewed in the context of the total number of admissions to hospital for respiratory disease caused by the action of two air pollutants (PM_{10} and SO_2, primarily produced by burning fossil fuel and transport) in urban areas of Great Britain. This was estimated by COMEAP, on behalf of the Department of Health, to be 14,000 per year (COMEAP, 1998). Other influences on health are much more important than the management of MSW, even for people living near to sites handling MSW. For example McCarthy et al. (2005, pers com), when considering the extra traffic generated by such a facility conclude (quote) “Traffic probably contributes to local air pollution more than the incinerator…”.

The DEFRA report (Enviros et al. 2004) concluded that the data does not allow them to say that one option for managing MSW is definitely better or worse than another in terms of deaths brought forward due to emissions to air. The estimate of less than one death brought forward pales into insignificance when compared to the COMEAP estimate of 11,600 deaths brought forward per year caused by overall PM_{10} and SO_2 air pollution alone in urban areas of Great Britain (COMEAP 1998). The estimated number of cancer cases caused by emissions to air from MSW management is so small that again it is impossible to say that one MSW management option is definitely better or worse than another.

Table 6.4 Health effects from other causes

	Number per year in the UK due to:					
Health impact	**Home accidents**	**Work accidents**	**Road traffic accidents**	**Natural or environmental factors** (e.g. excessive cold)	**Choking on food**	**Injury from fireworks**
Deaths brought forward	**4300** (1 per small town)	**736** (1 per large town)	**3,409** (1 per small town)	**191** (1 per large town)	**246** (1 per large town)	**2** (in year 2000)
Hospital admissions	**168,300** (1 per street or village)	**c. 500,000** (1 per street)	**320,000** (1 per street)			**1017** (year 2002)
Data quality	**Good**	**Good**	**Good**	**Good**	**Good**	**Good**

If a comparison is made between the hazards of MSW management and other health hazards it helps to put them even further into context.

For example, fireworks resulted in over 1000 hospital admissions in 2002 and two deaths in 2000; passive smoking (breathing in smoke from other people’s cigarettes) causes hundreds of people to get lung cancer each year. These health effects are easily avoidable by banning fireworks and taking drastic action against smoking, but as a society we choose not to take the necessary action. Traffic accidents result in over 3,000 deaths and over 300,000 hospital admissions every year, yet almost all of us venture into the traffic every day.

This compares with emissions to air from MSW management causing less than one death to be brought forward and five extra hospital admissions every year, to people who are already elderly and/or ill.

6.3 The results of the risk assessment for each type of facility

6.3.1 Estimated health impacts for each facility

Simplified versions of the heath impacts calculated by Enviros et al (2004) are set out in Tables 6.5 and 6.6. Note that in Table 6.5 the health impacts have been recalculated to represent impacts per facility per **100 years** (to simplify the numbers). In Table 6.6 the figures have been recalculated as impacts per **thousand tonne** of waste treated per facility. Figures 6.1 to 6.6 graphically illustrate the calculated impacts (after Enviros et al. 2004).

Figure 7.1 is a graphic representation of data from Entec (2005) in a report on MSW management options for Milton Keynes Council (see below).

The results of extensive research comparing potential impacts from various types of MSW management facilities was published in a report by the Community Recycling Network on behalf of Friends of the Earth (Hogg and Mansell 2002). Figure 7.2 is a simplified version of a figure from Hogg and Mansell).

6.3.2 Comparison of the results for the different facilities (Enviros et al. 2004)

(a) The results in tabular and graphical form. Tables 6.4 and 6.5 list the calculated impacts per facility. Figures 6.1 to 6.6 (reproduced from Enviros et al. 2004) plot the outcomes graphically showing the uncertainties (as error bars extending on either side of the plotted number).

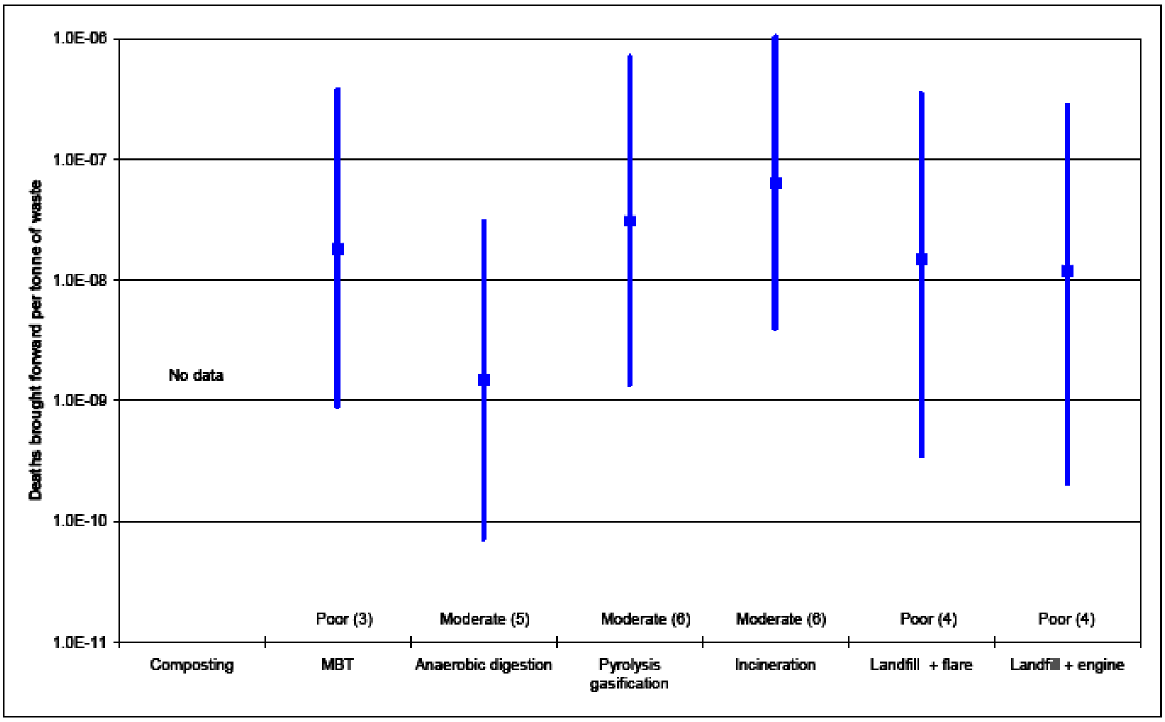


Figure 6.1 Estimated deaths brought forward per tonne of MSW processed

Table 6.5 Calculated health impacts per facility per 100 years due to emissions to air							
	Substance	**Composting**	**MBT**	**Anaerobic digestion**	**Pyrolysis Gasification**	**Incineration**	**Landfill**
Deaths brought forward	PM_{10}	No data	No data	No data	0.0347	<0.005	0.01
	SO_2	Not emitted	0.091	0.0074	0.1192	0.79	0.077
	Total	**No data**	**0.091**	**0.0074**	**0.154**	**0.79**	**0.087**
Respiratory admissions to hospital	PM_{10}	No data	No data	No data	0.033	<0.005	0.009
	SO_2	Not emitted	0.0680	0.005	0.09	0.57	0.058
	NO_x	Not emitted	0.179	0.35	1.34	18.6	0.752
	Total	**No data**	**0.25**	**0.36**	**1.47**	**19.2**	**0.82**
Cardio-vascular admissions	PM_{10}	No data	No data	No data	0.027	<0.005	0.008
Additional cancer cases	Arsenic	No data	No data	0.0000047	0.0000805	<0.00007	0.00000694
	$Chromium^{VI}$	No data	No data	No data	No data	<0.00007	No data
	Nickel	No data	No data	0.00000071	0.0000136	<0.00007	0.0000135
	Benzo[a]Pyrene	No data	No data	No data	No data	<0.00007	No data
	Vinyl chloride	No data	Not emitted	Not emitted	Not emitted	Not emitted	0.000155
	Benzene	No data	Not emitted	Not emitted	Not emitted	Not emitted	0.000202
	Total	**No data**	**No data**	**0.0000054**	**0.0000942**	**<0.0003**	**0.000378**

Table 6.6 Calculated health impacts per thousand tonnes of waste per facility due to emissions to air						
	Composting	MBT	Anaerobic digestion	Pyrolysis Gasification	Incineration	Landfill
Deaths brought forward per 1000 tonne waste	No data	0.0000182	0.00000148	0.0000308	0.000064	0.000012
Respiratory admissions to hospital per 1000 tonne of waste	No data	0.0000495	0.000072	0.000293	0.0015	0.00011
Cardio-vascular admissions per 1000 tonne of waste	No data	No data	No data	0.00000545	<0.00000041	0.000001
Additional cancer cases per 1000 tonne of waste	No data	No data	0.00000000108	0.000000019	<0.00000002	0.00000005
Data quality	n/a	Poor	Moderate	Moderate	Moderate	Poor

Note: Tables 6.5 and 6.6 are simplified from data in Enviros et al (2004). The landfill category is for a medium sized landfill with 75% of landfill gas captured and burnt in a generator, 25% of landfill gas escaping as fugitive emissions.

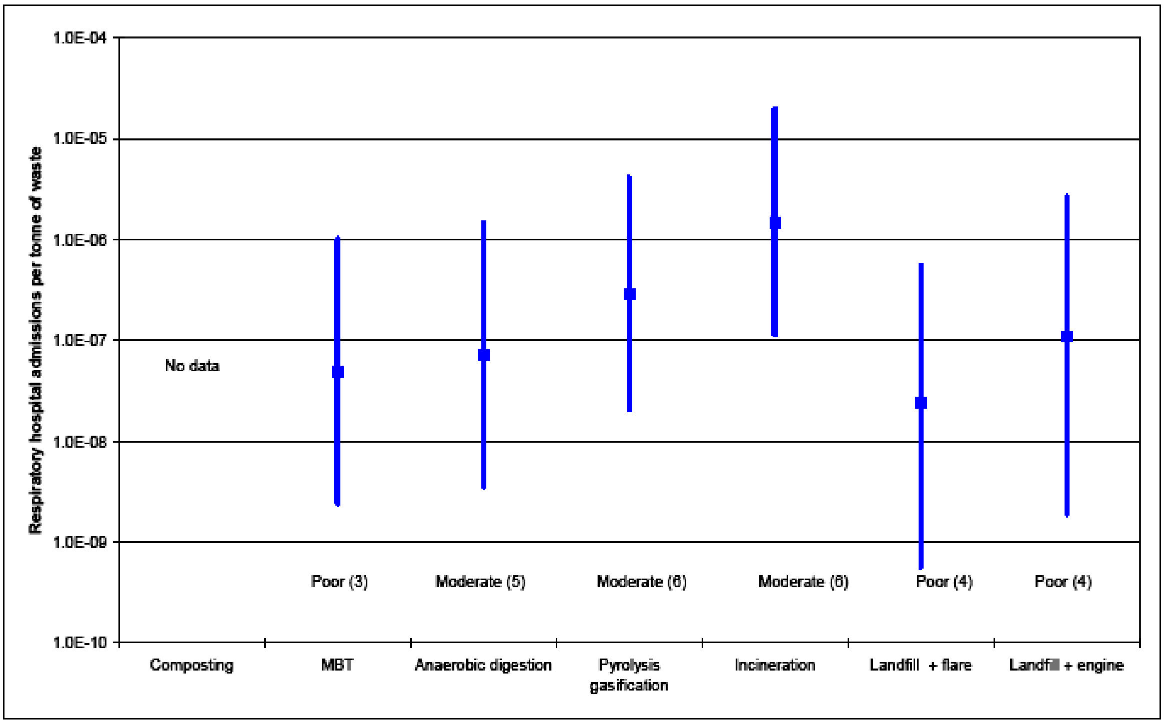


Figure 6.2 Estimated respiratory hospital admissions per tonne of MSW

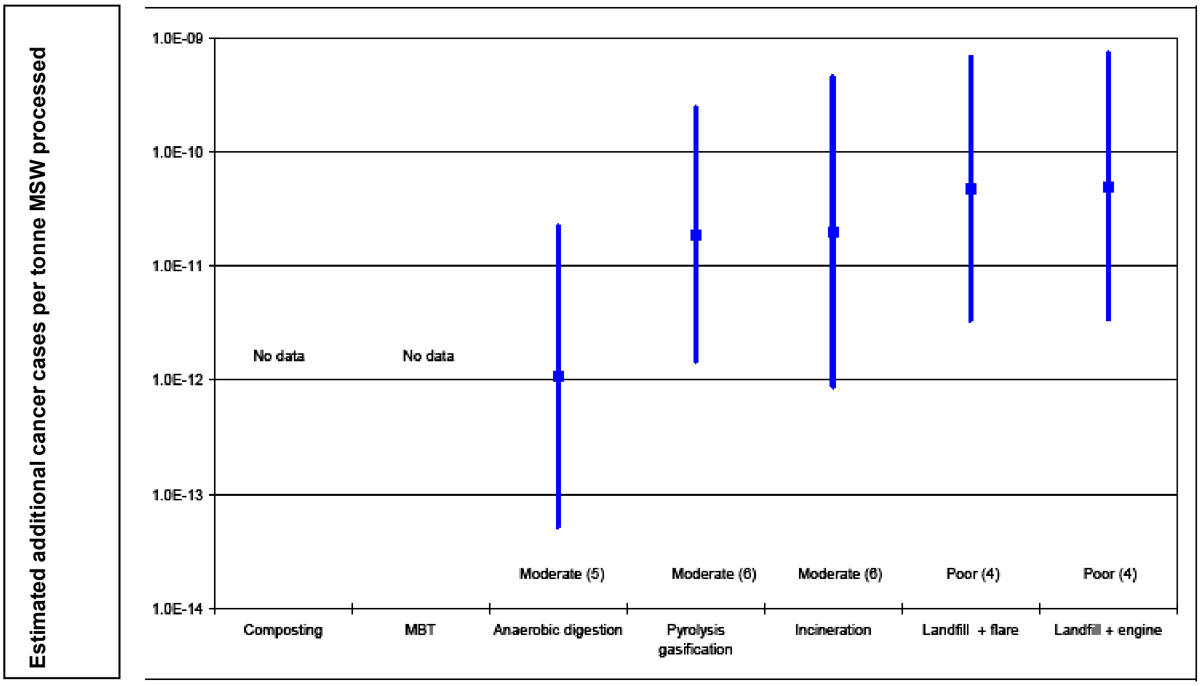


Figure 6.3 Estimated additional cancer cases per tonne of MSW

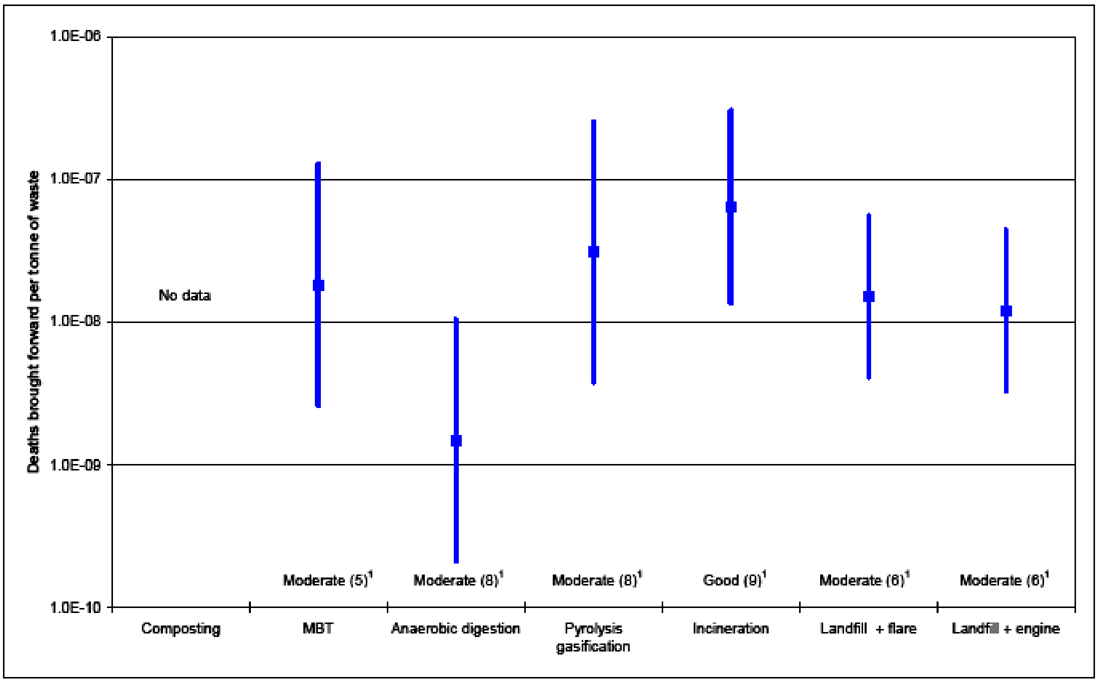


Figure 6.4 Estimated deaths brought forward per tonne of waste processed
Uncertainties common to each option removed. This allows a comparison of the extent to which the effects associated with each MSW management option vary.

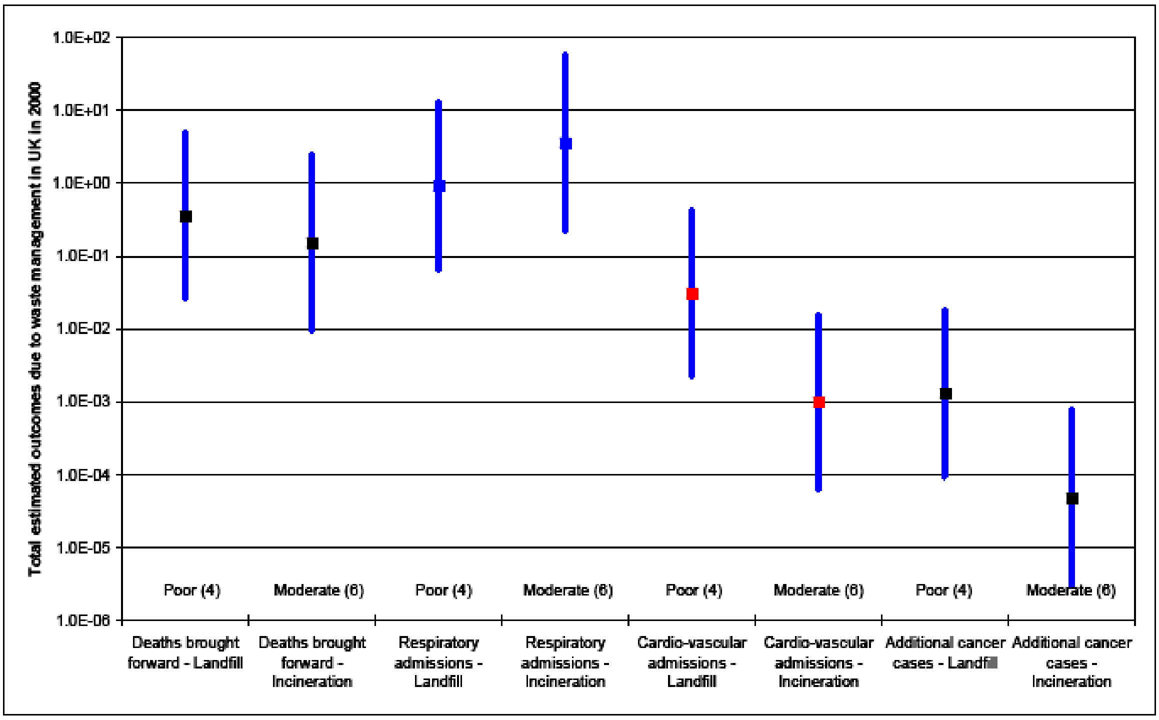


Figure 6.5 Estimated annual UK health consequences due to emissions to air from landfill and incineration.

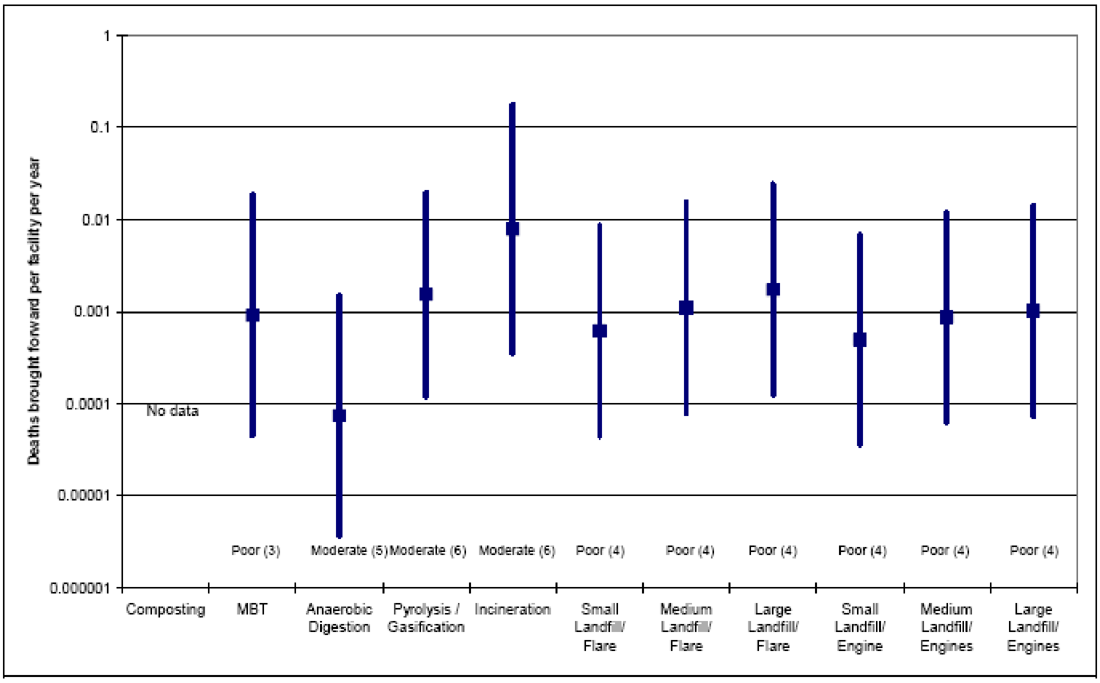


Figure 6.6 Comparison of the estimated numbers of deaths brought forward due to emissions from an individual facility

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(b) Uncertainties in the data

The data quality is variable and all the emissions data have ranges of uncertainty (see Enviros et al. 2004, Chapter 2). The dispersion modelling calculation also introduces further uncertainty. The assessment was carried out for typical facilities assuming inputs which are representative of the UK as a whole. This means that although the results are useful on a national basis their use for specific facilities in specific locations should be treated with caution.

For example, if the population surrounding a facility has a higher or lower density this will affect the calculated figures. In addition some areas have higher, or lower rates of hospital admissions or deaths than the national average and in such areas the proportion of effects due to MSW treatment would be proportionally more or less significant. Most significantly, different sites have different emission control systems and obviously the sites with the most effective control systems give out the least emissions per tonne of waste.

(c) Conclusions from the quantitative study

Taking these (and other) uncertainties into account, using the information presented above in Tables 6.1 to 6.6 and Figures 6.1 to 6.6, Enviros et al. (2004) reached the following conclusions (quoted verbatim):

- The more significant effects are associated with emissions of the "classical" pollutants; particulate matter (PM_{10}), sulphur dioxide and oxides of nitrogen. Emissions of carcinogens such as arsenic and nickel are less significant (Confidence level for this conclusion: Moderate).

- The effect of emissions from waste management on cardiovascular admissions is less significant than the effect on respiratory hospital admissions and deaths brought forward (Confidence level for this conclusion: Moderate).

- The most likely outcome identified in this study is approximately one additional respiratory hospital admission in five years as a result of emissions from an individual waste incinerator facility. On a national scale, this would currently correspond to approximately four respiratory hospital admissions per year. This level of effect would not be detectable by any practicable means. This forecast is reliable to within a factor of 30, with a moderate level of confidence.

- One death might be expected to be brought forward due to emissions from an individual incinerator approximately every 100 years. This forecast is reliable to within a factor of 30, with a moderate level of confidence. For other waste management facilities, one death brought forward might be expected to occur every 1000 years. For landfill, this forecast is reliable to within a factor of 30, but with a poor level of confidence. (Environment Agency, 2003 draft).

- Impacts per tonne of waste for landfill are forecast to be lower as the size of the facility increases. Again, it should be borne in mind that the health effects of landfill emissions will take place over a number of years. By the same token, any health effects taking place at present will be as a result of wastes landfilled over previous years.

- For the cancer outcomes assessed, the incremental risks of leukaemia and haemangiosarcoma were at a similar level, and more significant than the lung cancer outcomes (Confidence level for this conclusion: Moderate).

- The potential health effects of emissions to air from composting cannot be assessed because there are no emissions data. Of the substances assessed, composting facilities are most likely to emit significant quantities of particulates. This represents a key area of uncertainty, and future research should be focused in this area.

In order to assess the potential health effects of any individual facility, it would be necessary to consider the local conditions and sensitivity to air pollution – for example, the density of residential properties in the area around the waste management facility. (unquote).

6.4 Results of research on potential environmental impacts

6.4.1 The principal emissions and their potential environmental impacts

(a) Data regarding environmental impacts. Municipal waste management has a number of potential environmental impacts that would mainly occur in the area surrounding the facility. In comparison to the data available about the potential health impacts of MSW management there is only a limited amount of data available on potential environmental impacts of MSW management.

(b) Areas in need of further research. Enviros et al. (2004) identified the following areas where data is currently not available and where research could usefully be focussed:

- Assessment of the potential for bioaccumulation and biomagnification of released materials in flora, fauna, aquatic environments and soils.
- Assessment of chronic effects on flora and fauna of exposure to released materials.
- Quantification of the effects on global climate of emissions of carbon dioxide, methane and other ‘greenhouse’ gases.
- Quantification of acute and chronic contamination of surface and groundwater as a consequence of planned and unplanned releases.
- Assessing the accumulation of metals, hydrocarbons and other contaminants associated with the spreading of MSW derived compost.
- Assessment of the impacts of emissions on habitats and biodiversity, and the potential for loss of species.
- Assessment of the likely effect of changes in facility design.

As a result of these shortcomings in the research, there are many unknowns when assessing the potential environmental impacts of acute and chronic emissions associated with waste management options. Very little data exists to be able to quantify the point at which emission concentrations become harmful or of the ultimate environmental effects of released contaminants. As has been discussed previously, emissions data exist for most waste management operations. However, there are little field data on the fate of the emissions and the pathways by which emissions will disperse in the environment.

Nevertheless the available data is sufficient to draw some useful conclusions. If a specific facility were being considered then it would be important to take into account all the local circumstances and especially if there was any evidence of local sensitivity to the potential environmental impacts. For example, if a waste disposal facility was located next to a country park with extensive wildlife habitats.

(c) The most important environmental impacts
The two most important potential impacts are due to the emission of so-called ‘greenhouse gases’, with the potential to affect global climate, and the emission of acid gases which might contribute to acid rain (Table 6.7).

The most significant environmental impact from MSW management is emissions of ‘greenhouse gases’ from landfill sites. The contribution of methane, in particular, is very significant (Tables 4.1, 4.2, 6.2). Although this can be minimised by collecting and burning landfill gas, preferably in an energy generating engine, there is a practical limit to the proportion of landfill gas which can be collected. Something of the order of 25% or so will always escape as fugitive emissions. Because of this avoiding the landfilling of biodegradable waste will have a net positive impact on the environment.

Table 6.7 The main environmental impacts

Technique	'Greenhouse gas' emissions	Acid gas emissions
Materials recycling facilities	Slight overall benefit	Nil
Composting	Small effect due to CO_2 and possibly other emissions	Nil
Anaerobic digestion	Small effect due to CO_2	Minor adverse effect
Incineration	Small effect due to CO_2	Minor adverse effect
Advanced thermal treatment	Small effect due to CO_2	Minor adverse effect
Mechanical biological treatment	Small effect due to CO_2	Low or nil
Landfill	Large effect due to methane	Minor adverse effect
Transport & waste transfer stations	Minor benefit due to more efficient logistics	Minor adverse effect

6.4.2 Conclusions on environmental impacts

With the exception of methane emissions from landfill sites, properly designed and managed MSW facilities have minimal effects on the environment.

Although some processes do emit acid gases the amount and effect of these will be negligible compared to other sources of acid gases, such as combustion of fossil fuel and transport.

Many processes emit carbon dioxide, which will have a minor effect on global warming, but again MSW management is not a very significant source of CO_2. However, landfill is a major source of methane emissions, which do have a significant effect on global warming. Thus avoiding the landfilling of the organic fraction of MSW will have a positive benefit in terms of global warming.

7. Assessment of the implications of recent research for MSW management options in Milton Keynes

7.1 Life cycle assessment and comparing MSW treatment options

7.1.1 Recent reports on MSW management for Milton Keynes Council

Milton Keynes Council is currently engaged in the development and evaluation of long term options to treat and dispose of residual waste arisings. As part of this process, Milton Keynes Council engaged consultants to undertake a "Waste Management Technical Options Appraisal" to evaluate suitable treatment technologies for Municipal Solid Wastes in the medium to long term (Jacobs Babtie 2005). This report evaluated eleven possible options of combinations of techniques for managing MSW (Table 7.1).

Table 7.1 Options for managing MSW in Milton Keynes

1	Option 1a:	MBT+ATT+IVC
Mechanical Biological Treatment + Advanced Thermal Treatment of RDF + In-Vessel Composting of waste derived compost.		
2	Option 1b:	MBT+FBG+IVC
Mechanical Biological Treatment + Energy from Waste/ Fluidised Bed Gasifier + In-Vessel Composting of waste derived compost.		
3	Option 1c:	MBT+IVC+LF
Mechanical Biological Treatment + In-Vessel Composting of waste derived compost + Landfill		
4	Option 1d:	MBT+IVC+RDF
Mechanical Biological Treatment + In-Vessel Composting of waste derived compost + RDF treated in a third party thermal facility		
5	Option 2a:	MT+ATT+AD
Mechanical Treatment + Advanced Thermal Treatment of RDF + Anaerobic Digestion of waste derived compost + maturation of digested compost product		
6	Option 2b:	MT+AD+LF
Mechanical Treatment + Anaerobic Digestion of waste derived compost and kerbside organics + Landfill		
7	Option 2c:	MT+AD+RDF
Mechanical Treatment + Anaerobic Digestion of waste derived compost and kerbside organics + RDF treated in a third party thermal facility		
8	Option 3a:	ATT screened waste
Screening + Advanced Thermal Treatment		
9	Option 4:	EfW screened waste
Screening + Energy from Waste recovery by thermal treatment		
10	Option 5a:	AC+ATT
Autoclave + Advanced Thermal Treatment (pyrolysis and/or gasification)		
11	Option 5b:	AC+LF
Autoclave + Landfill		

The Council also engaged consultants to produce a "Best Practicable Environmental Option Report" (Entec 2005). This report used the life cycle assessment (LCA) software WISARD (Waste: Integrated Systems Analysis for Recovery and Disposal) to evaluate the potential environmental impacts associated with these waste management options.

7.1.2 Life-cycle assessment and the limitations of WISARD

Although useful for the purpose of informing decision-makers, the output from any life cycle assessment software has to be treated intelligently and with caution. All LCA software including WISARD is limited in scope, amongst other things it does not fully reflect the waste technologies employed. In common with other life cycle assessment tools, WISARD considers a set of environmental impacts, which are generally global in nature, because the sources of burdens considered are many and disparate. The WISARD Reference Guide notes that the software has limitations in its assessment of environmental impact. Specifically, it does not address "...human or environmental safety, legal compliance issues or nuisance issues (e.g. litter, dust and visual amenities)." The Guide clearly states that "...there are other tools such as risk assessment and environmental impact assessment, which should be used for other functions such as assessing the safety of particular processes or the siting of particular waste handling or treatment plants."

The Environment Agency's Strategic Waste Management Assessments, published in November 2000, used WISARD to investigate the environmental impacts associated with future waste management scenarios for the planning regions of England and Wales. The report is restricted to four environmental impacts: air acidification, depletion of non-renewable resources, greenhouse effect and photochemical oxidant formation, which are "...commonly associated with waste management systems", in order "...to highlight the differences that result from managing the same waste in different ways".

As explained in the Environment Agency WISARD report, the data used in the modelling is "associated with large uncertainty as a result of the complexity of the environment." Therefore a 'generic' environment was used as the basis of this aspect of the study. Also, there is considerable difficulty in modelling specific local habitats and ecosystems and the changes to be expected in future technology, vehicles and the economy.

Hogg and Mansell (2002) referring to WISARD say (quoted verbatim): [Life cycle analysis] "has become, quite quickly, a means to supposedly justify the choice of one or other waste management strategy in different local authorities. It has also assumed some significance in planning enquiries. We would argue that the significance given to the approach in such discussions is not justified by the limitations of the approach. This applies with special force since the tools currently being used in the UK context, notably the life-cycle tool WISARD, suffer from some shortcomings which deserve to be quite clearly highlighted – to planning inspectors, waste management professionals, local authority officers and citizens alike – in order that the limitations can be understood." (unquote).

The Entec (2005) report for Milton Keynes Council includes an indicator "Emissions injurious to public health" but gives little or no information about: the data used, any underlying assumptions, uncertainty, etc.

Thus it is very difficult to assess what reliance can be placed on the numerical output given in Table 5.2 of the Entec report against the heading "Emissions injurious to public health (g eq.1,4-DCB)", although there is no explanation given of this term, it is presumably ‘gramme equivalent 1,4-dichlorobenzene’ as a Human Toxicity Potential indicator (see Section 3.2.5).

Blindly relying on these figures to give a relative assessment of the potential for impact on human health of the different MSW management options could be very misleading without a thorough understanding of the uncertainties and assumptions inherent in the underlying data. This is illustrated in the next section.

7.1.3 Two different approaches to life-cycle assessment for MSW management

Figure 7.1 is a graphical representation of the figures derived by Entec (2005) for “emissions injurious to public health” in their life-cycle assessment of the MSW management options under consideration by Milton Keynes Council. It is instructive to compare this with Figure 7.2, which is a simplified plot of data output from similar life-cycle assessment for MSW management options produced for a Friends of the Earth sponsored report by Hogg and Mansell (2002).

Without going into exhaustive detail, it can be seen in the Entec report that options including thermal treatment (especially options 3a and 4) appear to have the most potential for adverse human health effects (Figure 7.1). This is in complete contrast to the results from the Hogg and Mansell report where the landfill option appears to be the worst performer and BMT (Biological Mechanical Treatment, i.e. simply a type of MBT where the biological treatment is carried out first) with residuals going to a fluidised bed incinerator the best performer (Figure 7.2).

How can this be? The same life-cycle assessment tool appears to be giving contradictory results. The answer is quite straightforward, WISARD and other LCA software, is simply a computer program and like any such program the results it outputs are critically dependant on the data which is input to the program.

A very useful feature of the Hogg and Mansell (2002) report is their detailed analysis of the data they use in their lifecycle assessment. In their summary report Hogg and Mansell sum up the shortcomings of life-cycle assessment as follows (quoted verbatim):

“The principle shortcomings of the life-cycle approach are:

- its difficulty addressing the issue of time, and a tendency to view the world as static;
- the lack of any location-dependent impact assessment (the environmental impacts of most emissions are highly dependent on location – greenhouse gases are a notable exception);
- the range of impact assessment approaches (which seek to aggregate the effects of different emissions on thematic lines, such as eutrophication, acidification, human toxicity, etc.) which exist weight emissions differently relative to one another;
- the data intense nature of the process leads to a tendency to use datasets of differing vintage and origin, potentially leading to bias in the analysis;

- the analysis is always incomplete, because assignment of chemicals to impact categories is hampered by a lack of knowledge about many of the chemicals concerned.

There are also several assumptions that underpin the comparative analysis of waste management options:

- The assumption concerning the emissions which are assumed to be avoided by the generation of electricity. The more damaging the source assumed to be displaced, the greater the implied benefit from energy generation. In WISARD the default assumption is that the displaced source is coal. We believe this assumption is unjustified and that analyses should use, as a default, electricity from gas burning power stations. Exceptions would be co-incineration options, for which the displacement effect is more direct (coal is displaced at coal-fired power stations);

- The treatment of greenhouse gases. Landfills act as sequesters of carbon. The approach adopted in WISARD ignores carbon dioxide emissions originating from carbon of biogenic origin and results in the incorrect modelling of landfills. We believe that it makes more sense, in a comparative analysis, to attribute all emissions as and when they occur – this is what we have done;

- The treatment of residues from the various treatment options when they are landfilled. What happens to the material in the landfill? The question relates to the issue of time. Some authors distinguish between surveyable time and all time. Emissions from landfill can be modelled over time, but they cannot be estimated from empirical evidence. Where emissions are accounted for, they become a dominant element in the analysis. For example, the impact of improvements in flue gas cleaning at incinerators is an increased transfer of heavy metals and other pollutants to residue streams. Some analyses suggest that treatment of residues will become the principal factor determining relative performance of thermal treatment options where incinerators are equipped with best practice flue gas cleaning mechanisms (no incinerator in the UK is so equipped).” (unquote).

Thus it is clear that Hogg and Mansell used rather different data and assumptions to those used by Entec (2005) in their report for Milton Keynes Council.

So which is right and which is wrong? The answer is both and neither; and it is certainly not a simple question or answer. In both cases the investigators have no doubt attempted to produce the most objective assessment possible within the limitations of the data and assumptions used to input to the LCA software. To their credit Hogg and Mansell go to great lengths to explain their assumptions, the type and source of their data, in their quite sophisticated analysis. This brief outline cannot do justice to the problem. You are recommended to read the full reports to appreciate the complexities involved.

Figure 7.1 Relative emissions injurious to health for the MKC management options

(Data from Entec 2005; emissions in kg equivalent 1,4-dichlorobenzene)

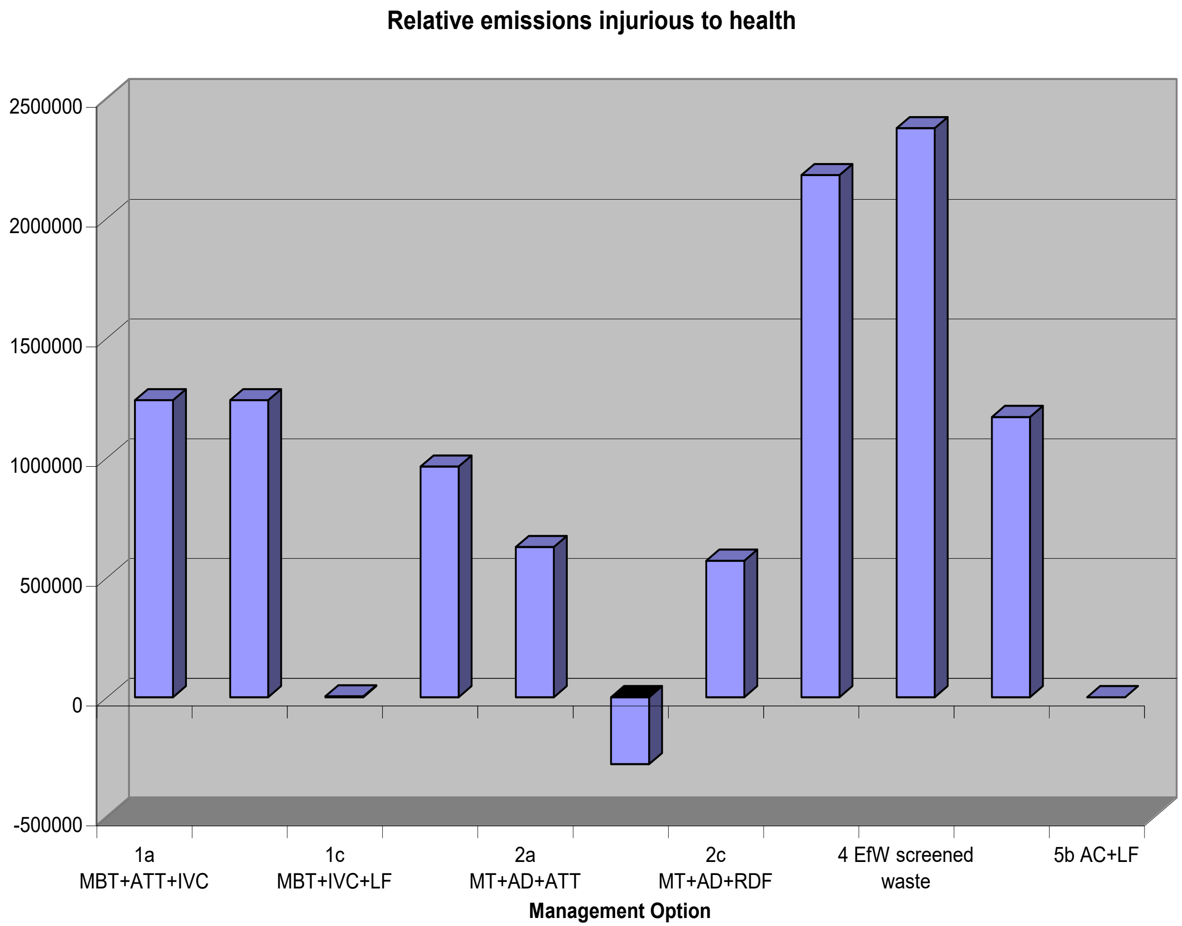
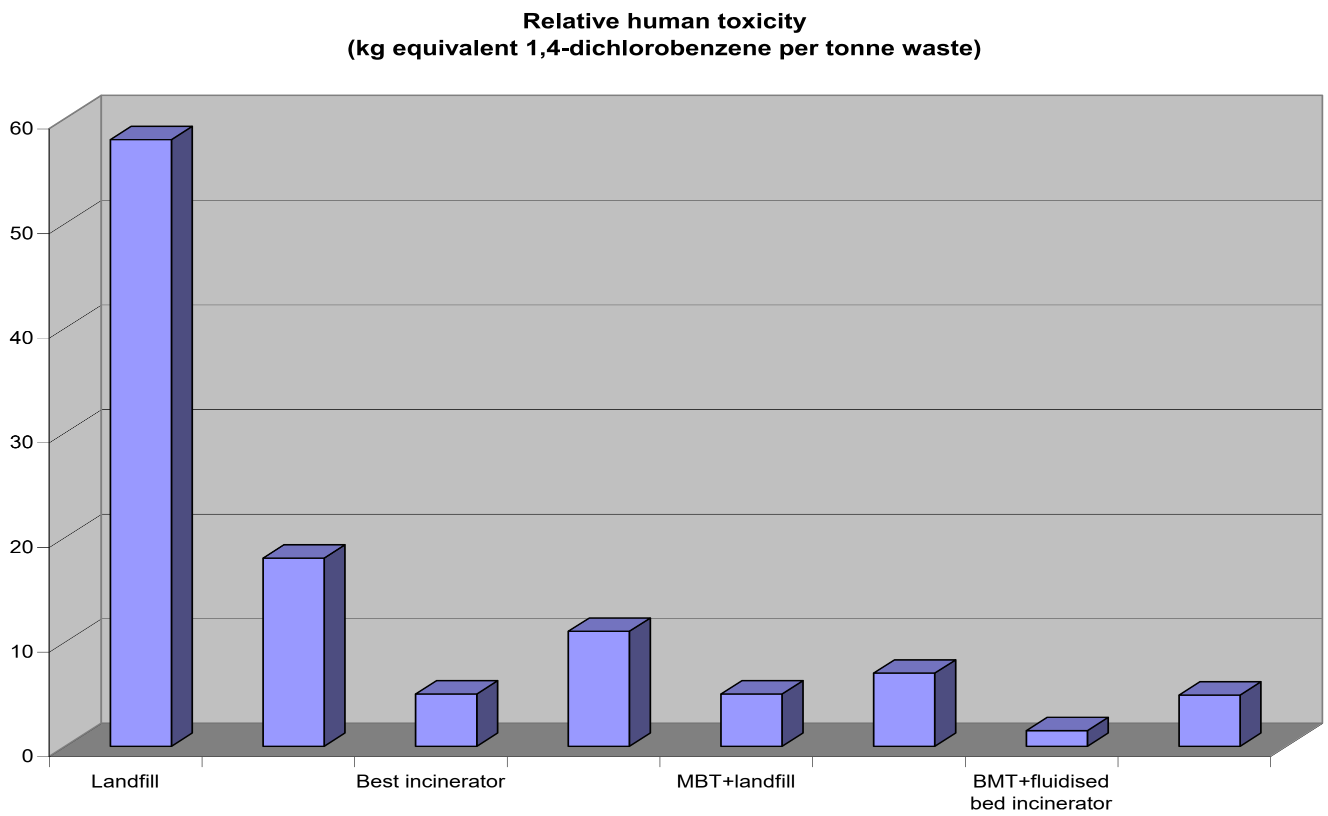


Figure 7.2 Relative human toxicity for MSW management techniques



(data simplified from Hogg and Mansell 2002)

7.1.4 The 'best available technology' and incinerator emissions

It is often pointed out, for example in the 'DEFRA report' (Enviros et al. 2004), that modern incinerators are much more efficient at controlling emissions than the previous generation of incinerators. However, one significant point brought out by Hogg and Mansell, which is rarely touched upon elsewhere, is that although all modern UK incinerators supposedly use BAT (the best available technology), according to Hogg and Mansell none of them actually do so.

They argue that there are more efficient techniques for controlling incinerator emissions than are currently used at all or most UK incinerators (for example NO_x see 7.1.3 in Hogg and Mansell 2002). In their assessment of emissions from MSW management they show that the emissions from modern incinerators which really do use the best available technology for controlling emissions are much lower than an 'average' modern UK incinerator (shown as 'Best incinerator' column in Figure 7.2).

7.2 Conclusions on MSW management options in Milton Keynes

In the context of health and environmental impacts life-cycle assessment will no doubt be developed in the near future with more accurate input emissions data and modelling of all modern treatment techniques. Even so life cycle assessment does not give definitive answers, it is only a tool to aid judgement. In terms of health and environmental impacts it only outputs calculated net emissions it does not give any actual data on real impacts.

Given the apparent contradictions, outlined above, in using life-cycle assessment software to attempt to quantitatively compare the potential health impacts of MSW management options, are there any useful conclusions to be drawn about such impacts?

It would seem a sensible approach to look at the best available data on potential health impacts from MSW management in comparison with the health impacts from other activities (Tables 6.3; 6.4). This should place the health risks from MSW management in context. Table 7.2 below uses calculated data about health impacts from various techniques (from Enviros et al. 2004). The data is for potential health impacts, which might occur due to the treatment of 50,000 tonnes of MSW by each technique, using the best currently available information. Very crudely this is approximately equivalent to the amount of MSW that might be treated by one of these techniques in a year in Milton Keynes. The results in Table 7.2 give an estimate of the order of magnitude of health impacts, which might be expected from using these techniques for MSW treatment in Milton Keynes.

These health impacts are very small when considered in the context of health impacts from other sources. Take the 'worst statistic' in Table 7.2, an incinerator in Milton Keynes might cause one extra hospital admission due to respiratory problems in Milton Keynes in about every 13 years. Of course we cannot rely on this statistic it is merely an indicator of the possible size of the impact. However, compare this to the thousands of hospital admissions in Milton Keynes from other causes every year.

What would be the situation if instead of an average incinerator we had based our calculations on an incinerator equipped with the best emissions abatement technology available? The health impacts would no doubt be substantially lower, possibly lower than most other MSW management techniques (Figure 7.2 above; Hogg and Mansell 2002).

Does this lead us to the conclusion that Milton Keynes should be equipped with a state-of-the-art incinerator with the very best abatement technology? No most certainly not. There are many other considerations that need to be taken into account in such a decision, not least whether such a facility would be cost effective when all things were considered.

However, by assessing all the data outlined in this report it is suggested we may be able to draw a few pragmatic and sensible conclusions about potential health and environmental impacts and how high a priority such considerations should be in the choice of what techniques we should use in Milton Keynes for managing our waste.

It is clear, notwithstanding the fact that data is lacking in some areas, that with few exceptions (landfilling of biodegradable waste and possibly open windrow composting), the health and environmental impacts of handling MSW as a whole are minor compared to those arising from other sources of emissions such as traffic, industry our domestic cookers and heaters etc. (Tables 6.2 to 6.4). It is also a reasonable conclusion that attempting to apportion up these minor impacts between different management options is fraught with difficulties. After all one assessment of the relative impacts says this technique is potentially the most harmful, whilst another assessment using different data concludes another technique has the most potential for harm (Section 7.1.4 above).

Taking into account that MSW emissions are, for the most part, tiny fractions of overall emissions from all sources and that the relative impacts of different techniques are so dependant on the exact design, location, pollution control technology etc. of a particular facility, leads inevitably to the conclusion that our choice of MSW management techniques should not be based principally on potential health and environmental impacts.

Is it then a sensible conclusion that we need not be concerned about potentially harmful emissions from our chosen MSW management technique or techniques? No most definitely not. However, a sensible conclusion is that in the choice of MSW techniques used in Milton Keynes many other factors are more important than potential health and environmental impact. However, whatever technique or techniques are chosen must be designed and operated in such a way that potentially harmful emissions are reduced to the lowest possible level.

The most important conclusion from this review is that (with the possible exception of landfill and open windrow composting) in respect of impact on health and the environment what matters is not which technique we use but how it is designed, constructed and operated. Any modern waste management technique is capable of operation in such a manner that it does not merely meet the regulatory requirements for emissions but surpasses them.

Table 7.2 Calculated health impacts per 50 thousand tonnes of waste per facility due to emissions to air very approximately equivalent to the number of health impacts in Milton Keynes per year if the technique was the main one used to treat our MSW						
	Composting	MBT	Anaerobic digestion	Pyrolysis Gasification	Incineration	Landfill
Deaths brought forward per 50,000 tonne waste	No data	0.00091 1 in 1000 years	0.000074 1 in 13,500 years	0.00154 1 in 650 years	0.0032 1 in 300 years	0.0006 1 in 1,600 yrs
Respiratory admissions to hospital per 50,000 tonne of waste	No data	0.002475 1 in 400 years	0.0036 1 in 270 years	0.01465 1 in 70 years	0.075 1 in 13 years	0.0055 1 in 180 years
Cardio-vascular admissions per 50,000 tonne of waste	No data	No data	No data	0.0002725 1 in 3,700 years	0.0000205 1 in 50,000 years	0.00005 1 in 20,000 years
Additional cancer cases per 50,000 tonne of waste	No data	No data	0.000000054 1 in 20 million years	0.00000095 1 in a million years	0.000001 1 in a million years	0.0000025 1 in 400,000 years
Data quality	n/a	Poor	Moderate	Moderate	Moderate	Poor

8. Conclusions from this review of potential health and environment impacts

8.1 The scientific position

There is disagreement amongst some scientists over the precise nature of technical points such as threshold and non-threshold chemicals and the low-dose effects of some toxic chemicals.

Further research urgently needs to be carried out in areas where there is a lack of good quality data. This is particularly true for the effects of bioaerosol emissions in general, and most emissions from composting, MBT and Anaerobic Digestion.

In spite of the above there is now sufficient good quality research available to be able to say that, with the exception of landfilling, municipal solid waste treatment is responsible for only a very small fraction of national emissions of hazardous chemicals. Furthermore, it does not lead to significant adverse health or environmental effects (with the exception of workers at some sites and open 'windrow' composting, see below).

8.2 Emissions from MSW treatment

All forms of MSW treatment give off potentially harmful emissions. There are strict controls on such emissions, which must be maintained and fully enforced.

'Dioxin' emissions from MSW incinerators make up between 0.3 and 0.8% of national 'dioxin' emissions. Domestic cooking and heating produce 18% of UK 'dioxin' emissions. Bonfire night and fireworks amount for about 14% of national emissions (Source National Society for Clean Air, www.nsca.org.uk). Therefore, with respect to 'dioxins', it makes more sense to introduce strict controls on bonfires and fireworks than to ban MSW incinerators, which are already tightly controlled.

MSW treatment is responsible for less than 2% of national emissions of volatile organic compounds (VOCs excluding methane). The VOC benzene, a known carcinogen, is of particular concern but less than 0.02% of UK emissions are due to MSW treatment. The level of VOCs in domestic indoor air is ten times greater than outside (from furnishings, cleaners, etc.).

Nitrogen oxides (NO_x) are a significant harmful air pollutant but less than 1% of national emissions arise from MSW management. Road traffic is responsible for 42% and electricity generation for 24% of these emissions.

Metal emissions from MSW treatment (incineration and landfill sites) amount to about 0.1% for As, 10% for Cd, 1.65% for Hg and 0.2% for Ni as percentages of national annual emissions. Almost all the Cd comes from landfill sites. Crematoria give rise to 16% of national emissions of Hg.

Data in respect of PAH emissions to air is poor but MSW treatment probably accounts for less than 3% of total national emissions to air.

Bioaerosol emissions may be a concern with non-combustion waste treatment technologies, particularly at composting, MBT and anaerobic digestion sites and possibly at some materials recycling facilities.

Emissions of methane from landfill sites amount to about 27% of the national total emissions of methane. Agriculture accounts for about 40 % of the national emissions of this ‘greenhouse gas’.

MSW management emits about 2.4% of the national total emissions of carbon dioxide.

8.3 Health impacts in the UK

There are adverse health impacts, especially from bioaerosols, for some workers at some MSW treatment facilities. But such impacts have not been shown to definitely affect residents near those sites. However, further research is needed with regard to the effects of bioaerosols in particular.

An exhaustive review has shown there is no definite evidence of a causal connection between living near a MSW landfill site and adverse health impacts.

MSW treatment is calculated to cause 4.9 hospital admissions per year compared to 14,000 for air pollution as a whole, (that is about 0.035%).

‘Deaths brought forward’ due to MSW treatment are calculated to be 0.55 per year as opposed to 11,600 due to air pollution as a whole (that is less than 0.005%).

Cancers caused by MSW treatment are calculated to be 0.0014 per year (one in seven hundred years) as opposed to some 6,000 skin cancers per year caused by sunlight and sunbeds and ‘hundreds’ of lung cancers per year caused by passive smoking from other people’s cigarettes.

8.4 The implications for waste management in Milton Keynes

Biodegradable waste should not be landfilled because it leads to considerable emissions of methane, which contribute significantly to global warming.

Landfilling should be the option of last resort for any waste containing cadmium as Cd emissions from landfills represent the vast majority of Cd emissions from MSW treatment which amounts to about 10% of national Cd emissions to air.

With the exception of landfilling and possibly composting, there are no compelling reasons, based on health or environmental impacts, to prefer one properly designed and managed MSW treatment technique over another.

With the exception of landfill sites and their emissions of methane and cadmium, provided MSW management sites are properly designed, managed and regulated, particularly with regard to emissions of bioaerosols, their overall impact on health and the environment is minimal, when compared to other causes of such impacts.

Open ‘windrow’ composting should be avoided close to where people live or work, especially if the boundary of the facility is within 250 metres of a workplace or the boundary of a dwelling, unless and until further research is able to show that potential health impacts near to composting sites are negligible.

There are no compelling reasons based on possible health and environmental impacts to rule out any form of modern thermal treatment of MSW, including incineration.

When deciding which MSW management techniques should be used comparing potential health and environmental impacts of one technique against another has no real meaning, as the impacts are so minimal compared to other sources and the differences between the techniques are small (with the exception of landfilling and ‘windrow’ composting as noted above). Rather the choice of techniques should be based on the most efficient techniques representing the most economically attractive option, always providing that they must meet or exceed all the requirements of the planning and pollution control regimes.

The population of Milton Keynes may or may not be convinced that these conclusions are valid. It is essential that every opportunity be taken to make freely available fair and balanced reviews of the available information on health and environmental impacts of MSW treatment, placing it in its proper context relative to other causes of impacts on health and the environment.

This will help to enable a properly informed debate to take place about any issue of health or environmental concern. This will help to avoid positions being taken based on inadequate information, fear of the unknown, information referring to old outdated processes, or allowing the debate to be dominated by narrow pressure groups whose main focus in not necessarily on what is best for the population of Milton Keynes as a whole.

Information and advice about environmental issues

Milton Keynes Council’s scientists in the Environmental Protection Team are always willing to provide information and advice about these issues or any aspect of the Milton Keynes environment. They may be contacted through the Environmental Services helpline (01908 252398) or by e-mail on ehept@milton-keynes.gov.uk

References

Abbott, J., Coleman, P., Howlett, L., Wheeler, P. 2003. *Environmental and Health Risks Associated with the Use of Processed Incinerator Bottom Ash in Road Construction.* AEA Technology Report ENV/R/0716 for BREWEB www.breweb.org.uk.

Agrawal, S.B. and Agrawal, M.A. (Eds.). 1999. *Environmental pollution and plant responses.* Lewis Publishers: Boca Raton, Florida.

Agzarian, J. & Foster, W.G. 2004. Towards Less Confusing Terminology in Endocrine Disrupter Research. *Reproductive Biology Division, Department of Obstetrics & Gynaecology, McMaster University. Internet* www.emcom.ca/EM/ENDOCRINE%20DISRUPTORS%20defini.pdf.

Allsopp, A., Costner, P. & Johnston, P. 2001. *Incineration and human health*. Greenpeace, London.

Berglund, B. & Lindvall, T. 1999. Guidelines for community noise. *World Health Organisation.*

Bertazzi, P.A., Consonni, D., Bachetti, S., Rubagotti, M., Baccarelli, A., Zocchetti, C. & Pesatori, A.C. 2001. Health Effects of Dioxin Exposure: A 20-Year Mortality Study. *American Journal of Epidemiology* Vol. 153, No. 11 : 1031-1044 2001

Bunger, J., Antlauf-Lammers, M., Schulz, T. G., Westphal, G. A., Muller, M.M., Ruhnau, P. and Hallier, E. (2000). Health complaints and immunological markers of exposure to bioaerosols among biowaste collectors and compost workers. *Occ. Environ. Med*. 57(7), 458-464.

Calabrese, E.J. 2000. Societal Implications of Hormesis. *Journal of Applied Toxicology*, 91.

Calabrese, E.J. 2003. The Hormetic Dose-Response Model Is More Common Than the Threshold Model In Toxicology. *Toxicological Sciences*, 246.

Calabrese, E.J. 2005. Challenging dose-response dogma. *The Scientist,* 19(3).

Calabrese, E.J. & Baldwin, L.A. 2003a. Toxicology Rethinks Its Central Belief. *Nature*, 691.

Calabrese, E.J. & Baldwin, L.A. 2003b. Inorganics and Hormesis. *Critical Reviews in Toxicology*. 2003.

CIWM (Chartered Institution of Wastes Management). 2003. *Biological Techniques in Solid Waste Management and Land Remediation*

Clewell, H.J. and Andersen, M.E. 1989. Biologically motivated models for chemical risk assessment. *Health Phys.* **57** Suppl. 1: 129-37.

Colborn, T., vom Saal, F.S. & Soto, A.M. 1993. Developmental Effects of Endocrine-Disrupting Chemicals in Wildlife and Humans. *Environmental Health Perspectives*,101.

COMEAP (Committee on the Medical Effects of Air Pollutants). 1998. *The quantification of the effects of air pollution on health in the United Kingdom*.
Department of Health, London: The Stationary Office

COMEAP (Committee on the Medical Effects of Air Pollutants). 2000. *Statement on the applicability of time-series coefficients to areas affected by emissions of air pollutants from industrial sources.* (www.doh.gov.uk/comeap)

COMEAP (Committee on the Medical Effects of Air Pollutants). 2001. *Statement on the short-term associations between ambient particles and admissions to hospital for cardiovascular disorders.* (www.doh.gov.uk/comeap)

Committee on Carcinogenicity. 1998. *Statement on Environmental Tobacco Smoke (ETS) and Lung Cancer*. (A www.doh.gov.uk/ets)

Committee on Carcinogenicity. 2000. *Cancer incidence near municipal solid waste incineration in Great Britain*. Statement COC/00/S1/001. Department of Health.

Committee on Toxicity. 2001. *Study by the Small Area Health Statistics Unit (SAHSU) on health outcomes in populations living around landfill sites.* (COT/2001/04) (www.doh.gov.uk/cotnonfood) (see also Elliott *et al*., 2001).

Committee on Toxicity of Chemicals in Food and Consumer Products (COT). 2001. *Statement on the TDI for dioxins and dioxin-like polychlorinated biphenyls*. COT/2001/07 October 2001.

Crook, B., Higgins, S., & Lacey, J. 1987. *Airborne Micro-organisms associated with domestic waste disposal*. Final Report to the HSE Contract Number 1/MS/126/643/82. Health and Safety Executive, London.

Crowley, D., Staines, D., Collins, C., Bracken, J., Bruen, M., Fry, J. Hrymak, V., Malone, D., Magette, B., Ryan, M., Thunhurst, C. 2003. *Health and Environmental Effects of Landfilling and Incineration of Waste - A Literature Review. (pdf)* Dublin: Health Research Board.

Department for Environment Food and Rural Affairs (DEFRA). 2003. *Municipal Waste Survey*. Report available from www.defra.gov.uk.

De Marchi, B., Funtowicz, S. & Ravetz, J. 1996. Seveso: A paradoxical classic disaster. *In,* Mitchell, J.K. (ed.) *The long road to recovery: Community responses to industrial disaster*. United Nations University Press.

DETR (Department for Environment, Transport and Regions) 2000. *A Way with Waste*. Waste Strategy, 2000. The Stationery Office (available from www.defra.gov.uk).

Dolk, H., Vrijheid, M., Armstrong, B., Abramsky, L., Bianchi, F., Garne, E., Nelen, V., Robert, E., Scott, J.E.S., Stone, D. and Tenconi, R. 1998. Risk of congenital anomalies near hazardous-waste landfill sites in Europe: the EUROHAZCON study. *Lancet* **352** (9126):423-427.

Dore , C.J., Watterson, J.D, Goodwin, J.W.L., Murrells, T.P., Passant, N.R., Hobson , M.M,. Baggott, S.L., Thistlethwaite, G., Coleman, P.J., King, K.R., Adams, M., & Cumine, P.R. 2004. *UK Emissions of Air Pollutants 1970 to 2002.* UK National Atmospheric Emissions Inventory (NAEI). National Environmental Technology Centre.

Douwes, J., Wouters, I., Dubbeld, H., van Zwieten, L., Steerenberg, P., Doekes, G. and Heederik, D. 2000. Upper Airway Inflammation Assessed by Nasal Lavage in Compost Workers: A Relation With Bio-Aerosol Exposure. *Am. J. of Ind. Med*. 37, 459-468.

Douwes, J. Thorne, P. Pearce, N. & Heederik D. 2003. Bioaerosol Health Effects and Exposure Assessment: Progress and Prospects. *Ann. occup. Hyg*., Vol. 47, No. 3, pp. 187–200.

Eduljee G. 1992. *Assessing the risks of landfill activities*. Harwell Waste Management Symposium. New developments in landfill proceedings1992; Harwell, Didcot, Oxfordshire, UK. Oxfordshire, UK: AEA Environment and Energy.

Elliot, P., Cuzick, J., English, D. and Stern, R. (Eds.) 1996. *Geographic and Environmental Epidemiology, Methods for Small-Area Studies.* Oxford University Press: Oxford.

Elliott, P., Briggs, D., Morris, S., de Hoogh, C., Hurt, C., Jensen, T. K., Maitland, I., Richardson, S., Wakefield, J. and Jarup, L. 2001. Risk of adverse birth outcomes in populations living near landfill sites. *BMJ.* 323(7309), 363-368.

Elliott, P., Morris, S., Briggs, D., de Hoogh, C., Hurt, C., Jensen, T., Maitland, I., Lewin, A., Richardson, S., Wakefeld, J. and Jarup, L. 2001. Birth outcomes and selected cancers in populations living near landfill sites - Report to the Department of Health, The Small Area Health Statistics Unit (SAHSU).

Entec UK Ltd. 2005. *Best Practicable Environmental Option*. Report for Milton Keynes Council.

Environment Agency. 2001. *Health Effects of Composting, A Study of Three Compost Sites and Review of Past Data*. R&D Technical Report P1-315/TR

Environment Agency (2001b) *Review of BAT for New Waste Incineration Issues, Part 3: New IPPC Considerations.* Environment Agency Report.

Environment Agency. 2002. *Solid Residues from Municipal Waste Incinerators in England and Wales*, Report May 2002.

Environment Agency, 2002b. *Waste Pre-Treatment: A Review.* Report P1-344.

Environment Agency. 2003 draft. *Review of Incineration and other combustion techniques*. prepared by: The University of Birmingham, Sheffield University, Leeds University, Leicester University (Draft report), qv Enviros et al. 2004.

Enviros Aspinwall 2002. *Comparison of Emissions from Waste Management Options*. Report for the National Society for Clean Air and Environmental Protection.

Enviros. 2003. *Norfolk County Council - waste technology review* Enviros Consulting Ltd. Shrewsbury (unpublished).

Enviros Consulting Ltd., University of Birmingham with Risk and Policy Analysts Ltd., Open University and Maggie Thurgood. 2004. *Review of Environmental and Health Effects of Waste Management: Municipal Solid Waste and Similar Wastes*. Department for Environment, Food and Rural Affairs, London.

EPA (US Environmental Protection Agency).1995. *Environmental, Economic and Energy Impacts of Materials Recovery Facilities*. National Risk Management Research Laboratory.

Farmer, A., & Hjerp, P. 2001. *Municipal solid waste incineration: health effects, regulation and public communication*. The National Society for Clean Air and Environmental Protection, Brighton.

FoE (Friends of the Earth) 2003. *Up In Smoke Why Friends of the Earth opposes incineration.* Friend of the Earth, London. http://www.foe.co.uk/resource/briefings/up_in_smoke.html

Gargas M.L., Kirman C.R., Hays S.M. and Voytek P. 1999. Using physiologically based pharmacokinetic modeling to minimize animal testing and associated costs under USEPA's Hazardous Air Pollutants Test Rule. *Toxicol. Sci.* 48 *(Supplement: The Toxicologist)*: 141.

Gonzalez, C. A., Kogevinas, M., Gadea, E., Huici, A., Bosch, A., Bleda, M. J. and Papke, O. 2000. Biomonitoring study of people living near or working at a municipal waste incinerator. *Archives of Environmental Health*. 55(4), 259-267.

Guinée, J. and R. Heijungs. 1993. A Proposal for the Classification of Toxic Substances within the Framework of Life Cycle Assessment of Products. *Chemosphere* 26(10): 1925-1944

Hansen, E., Skarup, S. and Jensen, A. (2000) *Substance Flow Analysis for Dioxins in Denmark.* Environmental Protection Agency No. 570, Danish EPA: Copenhagen.

Hens L., Howard C.V., Lafere J., Staats De Yanes G. 2000. *Towards a precautionary approach for waste management supported by education and information technology.* In: Nicolopoulou-Stamati P *et al*. Health impacts of waste management policy, Kluwer Academic Publisher, The Netherlands.

Herbst, A.L., and H.A. Bern, eds. (1981). *Developmental Effects of Diethylstilbestrol (Des) in Pregnancy.* New York: Thieme-Stratton.

Hertwich, E.G. 2001. *Life cycle impact assessment*. Course notes for Industrial Ecology Programme, Norges teknisk-naturvitelskapelige universitet.

Hertwich, E. G., S. F. Mateles, W. S. Pease and T. E. McKone. 2001. Human Toxicity Potentials for Life Cycle Assessment and Toxics Release Inventory Risk Screening. *Environmental Toxicology and Chemistry* 20(4)

Hill, B.A. 1965. The environment and disease, association or causation. *Proceedings of the Royal Society of Medicine.* **58**

Hogg, D. & Mansell, D. 2002. *Maximising recycling rates: tackling residuals*. Report for the Community Recycling Network, Resource Publishing Limited.

Huijbregts, M. A. J., U. Thissen, J. B. Guinee, T. Jager, D. Kalf, D. van de Meent, A. M. J. Ragas, A. Wegener Sleeswijk and L. Reijnders. 2000. Priority Assessment of Toxic Substances in LCA I: Calculation of toxicity potentials for 181 substances. *Chemosphere* 41(4): 575-588

Johnson, M.D., Kenney, N., Stoica, A., Hilakivi-Clarke, L., Singh, B., Chepko, G., Clarke, R., Sholler, P.F., Lirio, A.A., Foss, C., Reiter, R., Trock, B., Paik, S., Martin, M. **Title** Cadmium mimics the in vivo effects of oestrogen in the uterus and mammary gland. *Nature Medicine*. 2003.

Juniper Consultancy Services Ltd. 2005. *MBT: A Guide for Decision Makers - Processes, Policies and Markets*. Published 23 March, 2005. www.juniper.co.uk

Kaiser, J. 2003a. Sipping From a Poisoned Chalice. *Science*, 376.

Kaiser, J. (2003b). A Healthful Dab of Radiation? *Science*, 378.

Kokki, E., Ranta, J., Penttinen, A., Pukkala, E. and Pekkanen, J. 2001. Small area estimation of incidence of cancer around a known source of exposure with fine resolution data. *Occupational and Environmental Medicine* **58**:315-320.

Konheim C.S. 1991. Useful communication of risks to decision makers. Chapter 20. *In*: Hattemer-Frey H.A. & Travis C., editors, *Health effects of municipal waste incineration*, CRC Press, Boston.

Krimsky, S. 2000. *Hormonal Chaos: The Scientific and Social Origins of the Environmental Endocrine Hypothesis*. John Hopkins University Press.

Maynard R.L., & Howard C.V. 2000. *Particulate Matter: Properties and Effects upon Health*. BIOS Scientific Publisher, Oxford.

McCarthy, M., Gallivan, S. & Utley, U. 2005. Quantitative health impact estimates for a proposed new waste incinerator. Unpubl. University College London, Gower Street, London WC1E 6BT.

Michelozzi, P., Fusco, D., Forastiere, F., Ancona, C., Dell'Orco, V. and Perucci, C.A. 1998. Small area study of mortality among people living near multiple sources of air pollution. *Occupational & Environmental Medicine* **55** (9):611-615.

Office of National Statistics. 2003. *Total domestic and industrial waste arising in the UK*. Report available from http://www.statistics.gov.uk.

Pheby, D., Grey, M., Giusti, L. & Saffron, L. 2002. *Waste management and public health: the state of the evidence*. Centre for Research in Environmental Systems, Pollution and Remediation, University of the West of England, UWE. South West Public Health Observatory, Bristol.

Pukkala, E. and Ponka, A. 2001. Increased incidence of cancer and asthma in houses built on a former dump area. *Environmental Health Perspectives* **109**:1121-1125.

Rahkonen, P. (1992). Airborne Contaminants at Waste Treatment Plants, *Waste Manage. Res*. 10, 411-421.

Renwick A.G. and Lazarus N.R. 1998. Human variability and noncancer risk assessment — An analysis of the default uncertainty factor. Regul Toxicol Pharmacol 27(1 Pt 2): 3–20.

Salem, H. 2000. Toxicology of Low-Level Exposure: Evidence for Hormesis? *Journal of Applied Toxicology,* 89.

Shaddick, G. & Elliott, P. 1996. Use of Stone's method in the study of disease risk around point sources of environmental pollution. *Statistics in Medicine* **15**:1927-1934.

Smith, A., Brown, K., Ogilvie, S., Rushton, K., & Bates, J. 2001. Waste Management Options and Climate Change: Final Report. AEA Technology for the European Commission, DG Environment

Spadaro, R. 2002. *European Union citizens and sources of information about health.* Eurobarometer 58.0. European opinion research group. http://europa.eu.int/comm/health/ph_information/documents/eb_58_en.pdf

Steinheider, B., Both, R., & Winneke, G. (1998). Field studies on environmental odours inducing annoyance and gastric symptoms. *Journal of Psychophysiology*, 12.

Strange, K. 2002. Overview of Waste Management Options: Their Efficacy and Acceptability. *In*: Hester, R. E. & Harrison, R.M. editors, *Environmental and Health Impact of Solid Waste Management Activities*. Issues in Environmental Science and Technology 18. Royal Society of Chemistry, Cambridge.

Sukata, T. et al., 2002. Detailed low-dose study of 1,1-BIS (p-chlorophenyl)-2,2,2-trichloroethane carcinogenesis suggests the possibility of a hormetic effect. *International Journal of Cancer,* 99.

Swan, J. R. M., Crook, B. & Gilbert, E. J. 2002. *Microbial Emissions from Composting Sites*. In. *Environmental and Health Impact of Solid Waste Management Activities*. Issues in Environmental Science and Technology 18, *Eds*: R. E. Hester and R. M. Harrison. Cambridge, Royal Society of Chemistry 73-101.

Thayer, KA, R Melnick, K Burns, D Davis, and J Huff. 2005. Fundamental Flaws of Hormesis for Public Health Decisions. *Environmental Health Perspectives, in press*.

UNCED 1992. United Nations Conference on Environment and Development (UNCED), Rio de Janeiro, 3-14 June 1992.

Van Tongeren, M., Van Amelsvoort, L. and Heederik, D. 1997. Exposure to Organic Dusts, Endotoxins, and Microorganisms in the Municipal Waste Industry. *Int. J. Occup. Environ. Health* **3**:30-36.

Viel, J.F., Arveux, P., Baverel, J. and Cahn, J.Y. 2000. Soft-tissue sarcoma and non-Hodgkin's lymphoma clusters around a municipal solid waste incinerator with high dioxin emission levels. *American Journal of Epidemiology* 152 (1):13-19.

Vrijheid, M., Dolk , H., Armstrong, B., Abramshy, L., Bianchi, F., Fazarinc, I., Garne, E., Ide, R., Nelen, V., Robert, E., Scott, J. E. S., Stone, D. and Tenconi, R. (2002). Chromosomal congenital anomalies and residence near hazardous waste landfill sites. Lancet. 359,

Wilson, R. 1979. Analyzing the Risks of Daily Life. *Technology Review*, 81.

US National Research Council 1983.*Risk assessment in the Federal Government: Managing the process.* NRC, Washington.

Vrijheid, M., Dolk , H., Armstrong, B., Abramshy, L., Bianchi, F., Fazarinc, I., Garne, E., Ide, R., Nelen, V., Robert, E., Scott, J. E. S., Stone, D. and Tenconi, R. 2002. Chromosomal congenital anomalies and residence near hazardous waste landfill sites, Lancet. 359, 320-322.

World Health Organisation. 2000. *Air quality guidelines for Europe* (Second edition), WHO regional Publications, European Series No. 91. Copenhagen: WHO European Regional Office.

Wouters, I.M., Hilhorst, S.K.M., Kleppe, P., Doekes, D., Douwes, J., Peretz, D., Heederik, D. 2002. Upper airway inflammation and respiratory symptoms in domestic waste collectors. *Occupational and Environmental Medicine*. **59**:106-112.

Glossary

Acid rain: Defined as rain with a pH below 5.6. Normal rain has a pH of slightly under 6, which is slightly acidic. This natural acidity is caused by dissolved carbon dioxide dissociating to form weak carbonic acid. 'Acid rain' is caused by sulphur from impurities in fossil fuels, and nitrogen from the air combining with oxygen to form sulphur dioxide and nitrogen dioxide. These diffuse into the atmosphere and react with water to form sulphuric and nitric acids which are soluble and fall with the rain. Some hydrochloric acid is also formed. The resulting increased acidity in soil and waterways has proven to be harmful to fish and vegetation.
http://en.wikipedia.org/wiki/Acid_rain

Aquifer: An underground layer of rock, sand, or gravel that contains water in sufficient quantities to supply a well.

Bioaerosol: An airborne dispersion of particles comprising large molecules or volatile compounds that are living or contain living organisms or were released from living organisms. They can include fungi, pathogenic or non-pathogenic live or dead bacteria, viruses, high molecular weight allergens, endotoxins, mycotoxins (and other parts of bacterial and fungal cells) and other particles.

Dioxins: 'Dioxin' and 'dioxins' are shorthand terms used here to refer to polychlorinated dibenzo-para-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs, 'furans'). There are 200+ types of 'dioxins' but they are all based on similar chemical structures with chlorine atoms linked to the molecule in a variety of positions giving 75 possible PCDDs and 135 possible PCDFs. Seventeen of these compounds may have significance to health. Of these 17 compounds the most toxic is 2,3,7,8-TCDD i.e. 2,3,7,8-tetrachlorodibenzo-para-dioxin (the numbers refer to the position of the chlorine atoms in the molecule). Sometimes the term "dioxin" also includes the co-planar polychlorinated biphenyls (PCBs) which have 'dioxin-like' properties. Dioxin compounds are environmentally persistent i.e. after release they break down very slowly. They are fat-soluble and the vast majority of the human intake is through food. Intake can be minimised by adopting a vegan diet (i.e. avoiding meat and diary products).

Dioxins are released into the environment as contaminants in other products, notably some herbicides and wood preservatives. Dioxins are also formed in trace amounts in combustion processes, such as power plant, cement kilns, diesel vehicles, buses, open fires in the home, bonfires, barbecues, cigarettes, jet engines, forest fires and waste incinerators.

It is generally accepted that high combustion temperatures in the presence of an adequate supply of oxygen provides a good basis for destroying dioxins that come into an incinerator as contaminants in the waste and for minimising their re-formation in the hot gases. This was the rationale for specifying detailed combustion conditions under current UK and EU Regulations. Dioxins can also be formed in the cooling gas stream as it leaves the incinerator furnace. This process can be minimised by reducing the time the combustion gases spend at the critical temperature range (about 200-450°C) at which dioxin formation is most rapid, and by reducing contact with fly ash, which may help to accelerate formation.

Since dioxins contain chlorine, a great deal of debate has revolved around the issue of how effective the removal of chlorine-containing materials (such as PVC) from the waste stream would be in reducing their formation. The problem is that chlorine is present in one form or another in virtually all materials and so there will always be a large excess available compared with the tiny amounts that may become incorporated into dioxin. Trials on laboratory, pilot and full-scale plant have all confirmed the lack of beneficial effects on dioxin emissions, and therefore this cannot be used as a strategy for controlling dioxin emissions.

Ecosystem: In ecology, an ecosystem is a community of organisms (plant, animal and other living organisms - also referred as biocenose) living together with their environment (or biotope), functioning as a unit. **en.wikipedia.org/wiki/Ecosystems**

Global warming: The climate system varies both through natural, "internal" processes as well as in response to variations in external "forcing" from both human and non-human causes, including changes in the Earth's orbit around the Sun (Milankovitch cycles), solar activity, and volcanic emissions as well as greenhouse gases. [See Climate change for further discussion of these forcing processes].

Climatologists accept that the earth has warmed recently. Somewhat more controversial is what may have caused this change. [See attribution of recent climate change for further discussion].

Atmospheric scientists know that adding carbon dioxide (CO_2) to an atmosphere, with no other changes, will tend to make a planet's surface warmer (this is know as "climate forcing"). Indeed, greenhouse gases create a natural greenhouse effect without which temperatures on Earth would be 30°C lower, and the Earth uninhabitable. It is therefore not correct to say that there is a debate between those who "believe in" and "oppose" the theory that adding CO_2 to the Earth's atmosphere will result in warmer surface temperatures on Earth, on average. Rather, the debate is about what the *net* effect of the addition of CO_2 will be, and whether changes in water vapor, clouds, the biosphere and various other climate factors will *cancel out* its warming effect. The observed warming of the Earth over the past 50 years appears to be at odds with the skeptics' theory that climate feedbacks will cancel out the warming. **http://en.wikipedia.org/wiki/Global_warming - Warming_of_the_Earth**

Greenfield land: a term used to describe a piece of undeveloped land, either currently used for agriculture or just left to nature.

Greenhouse gas: A gas in the atmosphere that freely allows radiation from the sun through to the Earth's surface, but traps the heat re-radiated back from the Earth's surface and radiates it back to the Earth. This heating effect is said to be analogous to the manner in which the glass of a greenhouse traps the sun's radiation (but this is not strictly correct the main 'warming' effect of a glasshouse is in keeping the wind out). The so-called 'greenhouse effect' is a natural process. Most greenhouse gasses occur naturally (mainly from volcanic emissions), but their concentrations can be increased by human action, causing an enhanced 'greenhouse effect' and potentially accelerating climate change. Greenhouse gases include water vapour, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), halogenated fluorocarbons (HCFCs) , ozone (O_3), perfluorinated carbons (PFCs), and hydrofluorocarbons (HFCs).

Groundwater: Water beneath the surface of the earth which saturates the pores and fractures of sand, gravel, and rock formations.
www.gem.msu.edu/gw/vocabulary/glossary.html

Milligrammes per litre mg/L: a measure of concentration of a dissolved substance. A concentration of one mg/L means that one milligram of a substance is dissolved in each litre of water. For practical purposes, this unit is equal to parts per million (ppm) since one litre of water is equal in weight to one million milligrams. Thus a litre of water containing 10 milligrams of calcium has 10 parts of calcium per one million parts of water, or 10 parts per million (10 ppm).
lib1.store.vip.sc5.yahoo.com/lib/allergybegone/glossary.html

Non-monotonic dose-response curve: A 'non-monotonic dose response curve' is a line on a plot or graph where as the dose of a chemical increases or decreases the response does not increase or decrease in line with the dose. Some of these curves are shaped like U's, with high responses at low and at high doses, together with low responses at intermediate doses. Others are shaped like inverted U's with the greatest response in intermediate ranges.

Thus with some U-shaped curves low doses may cause a greater impact than high doses for a specific response. To explain this effect a plausible hypothesis is that at low doses the chemical interferes with the organism's developmental signalling, thus causing a significant impact, but does not activate the biochemical defences against such impacts. At intermediate doses, these defences are activated and the chemical is successfully prevented from producing a significant impact, thus the response is lower. At even higher levels, the biochemical defence mechanisms are overwhelmed by the chemical and a more straightforward toxicological effect is induced where response increases with increase in dose.

Volatile organic compounds (VOCs): Organic chemicals all contain the element carbon (C); organic chemicals are the basic chemicals found in living things and in products derived from living things, such as coal, petroleum and refined petroleum products. Many of the organic chemicals we use do not occur in Nature, but were synthesized by chemists in laboratories. Volatile chemicals produce vapors readily; at room temperature and normal atmospheric pressure, vapors escape easily from volatile liquid chemicals. Volatile organic chemicals include gasoline, industrial chemicals such as benzene, solvents such as toluene and xylene, and tetrachloroethylene (perchloroethylene, the principal dry cleaning solvent).
www.epa.gov/oar/oaqps/peg_caa/pegcaa10.html