Treatment of the Residual MSW of Leeds City Council – Overview of Potential Health and Environmental Impacts of Energy from Waste Incineration

Final Report (Part 2) to Leeds City Council

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1. Introduction

The term incineration simply means combustion with excess air – i.e. as a chemical process it is no different to coal or gas combustion. Combustion destroys organic carbon based materials, converting them to carbon dioxide and water, releasing the inherent chemical energy as heat. Thermal treatment can also be designed to operate under sub-stochiometric conditions – usually termed pyrolysis (no air) and/or gasification (reduced air/steam). Such processes generate gaseous, liquid, and char products which are normally fully combusted in a separate operation (e.g. as a transport fuel or boiler fuel) or in a separate unit within the same facility. From an environmental perspective, gasification/pyrolysis conditions can reduce the initial pollution loading in the gas phase but will not negate the need for gas phase treatment and abatement.

Emissions to the environment may cause damage to environmental media and/or physical ill health to human beings. The latter may be brought about directly (i.e., direct exposure of human beings to pollutants) or indirectly as a result of environmental damage (e.g., ozone depletion).

Health and environmental impacts have been influential factors in deploying incineration, including energy from waste incineration (EfW-I), mainly owing to emissions incidents from the past and the negative opinion of the public, including pressure groups, about incineration. It is frequently claimed that that negative opinion stems to an extent from the inherent nature of incineration which, contrary to non-combustion, less-intrusive processes such as composting and anaerobic digestion, treats waste “en masse” in large facilities that emit off-gases through a stack visible from a long distance. Also, often the public concentrates on primary impacts, i.e., those resulting from the operation of a waste management facility, ignoring potential secondary impacts such as those from the disposal or use of the outputs of a facility (e.g., introduction of heavy metals in the food chain through compost use). For example, the secondary impacts from the landfilling of the end residue from EfW-I are expected to be lower than those from the end residue of MBT.

A health and/or environmental impact prediction for an MSW treatment/management option should take into account secondary as well as primary impacts, since one of the ultimate goals of a waste management system should be to minimise the overall environmental and health impacts of that system as opposed to just those of one of its elements; e.g., those from an EfW-I or an MBT facility. Secondary impacts have often been found to significantly influence the total impact of waste management systems.

Whilst this study is confined to treatment of municipal waste it should be recognised that incineration is also widely used for treating hazardous wastes, clinical waste, animal waste, human bodies (crematoria) and sewage sludge. Furthermore, the study is primarily interested in plants operating to modern standards. Much of the popular general information available (e.g. from TV, radio, newspapers, pressure groups etc.) will fail to differentiate between the differing types of incineration or the period when they were operational. When discussing concerns on pollution or health issues, the type of waste processed, the age of the data and circumstances related to the operation must be stated to permit rational evaluation

EfW-I is widely used throughout Europe and the developed world for residual municipal waste due to its proven track record and the certainty offered in relation to reducing dependency on landfill. While such widespread acceptance may infer that health and safety impacts of such plant are within acceptable limits, adoption elsewhere and the practical advantages it may offer larger urban cities such as Leeds in meeting diversion targets for biodegradable municipal solid waste are not sufficient to confirm suitability. Health and environmental impacts are case specific, and a reliable indication of the impacts from the building and operation of an EfW-I plant to treat the residual municipal solid waste (RMSW) of Leeds City Council (Leeds CC) can only be provided if a specific study is carried out. Such a study will take in account the plant location, its design and other local conditions that are known to influence pollution dispersion and hence the environmental and health effects. This will usually be undertaken at the planning stage as part of the required Environmental Impact Assessment (EIA).

This report provides a general overview of key issues and the current status regarding environmental and health impacts from energy from EfW-I either at a plant level *per se* or by also considering secondary impacts, depending on the data available. This general overview aims at providing Leeds CC with information that will help them decide whether EfW-I may in general be a feasible option from an environmental and human health impacts point of view.

2. Methodology

A desk study was carried out reviewing relevant literature which was selected on the basis of its value for this project. Instead of an extensive literature search, this project focused on state-of-the-art, representative works.

Recent representative data/information that is particularly related to the UK situation were targeted. The work produced by Enviros et al (2004) was selected as a source of data on emissions and health effects from incineration by virtue of the extensive and representative studies that it reviewed and its systematic and informed methodology. Enviros et al (2004) reviewed 23 epidemiological studies and 4 review papers from around the world with respect to health and environmental impacts from waste incineration, with the particular aim to evaluate the impacts of MSW incineration.

In addition, the work of Koller and Soyez (2001) was used to comment on environmental and health impacts of incineration in comparison to those of mechanical and biological treatment (MBT). MBT and incineration are the most commonly used methods for RMSW treatment. The study of Koller and Soyez (2001) was conducted in the context of a national German research and development programme for the evaluation of potential, relative environmental impacts of MBT and incineration of RMSW. The evaluation was based on a life cycle analysis using state-of-the-art data for both MBT and incineration from literature and field/R&D measurements that were performed during that project.

3. Emissions from EfW-I

EfW-I gives rise to emissions in solid, liquid, and gaseous (including particulate matter) forms.

Air emissions are by far the most well studied and the quality of data for air emissions is substantially better than that for EfW-I emissions to land and water (Enviros et al., 2004).

Air pollutants associated with combustion processes fall into three main groups. All three types will be present to a greater or lesser degree when burning most solid fuels (e.g. coal, wood, waste).

Pollutants such as heavy metals (e.g. lead, cadmium, and mercury) and acid gas forming elements such as sulphur and chlorine which are present in the fuel/waste are not destroyed by the process, and must be controlled and removed from the stack gas by appropriate gas cleaning systems to prevent entry into the air. Fine ash particulate matter can also be considered alongside these pollutants as being part of the original waste/fuel.

Although full combustion destroys organic matter, destruction is rarely perfect. Pollutants associated with incomplete combustion of the carbon based materials range from carbon monoxide, particulates (smoke/soot) through to toxic organic micro-pollutants such as polycyclic aromatic hydrocarbons (PAH's) and dioxins, Primary control over such pollutants is based on ensuring the combustion conditions are correct – particularly in the gas phase above the grate, Secondary controls include minimising opportunities for re-formation or *de-novo* synthesis of pollutants in downstream boiler/abatement systems and finally by applying appropriate gas cleaning technology.

There are pollutants inherent in combustion processes or high temperature environments. Carbon dioxide is now commonly recognised to be a global "pollutant" but clearly is the natural end-product of any combustion system utilising a carbon based fuel. Another example are the oxides of nitrogen – while some of the NO_x will be from nitrogen sources in the fuel, oxidation of the nitrogen in the combustion air makes a major contribution in high temperature environments. Primary control is by design and operating conditions in the combustion zone. Secondary (gas cleaning) is needed to reduce levels of NO_x to modern standards. No commercially available solutions exist for removing carbon dioxide from flue gases, off-gases from biological treatment of waste or combustion of biogas or fuels in general.

Air emissions have been regulated by two European Directives transposed into the UK legislation. The first EU Directive setting limits to air emissions from MSW incinerators was the Council Directive 89/369/EEC (Anonymous 2004). In 2000 the waste incineration directive (WID) was put in force (Anonymous, 2000a). The environmental controls resulting from the enforcement of the directive 89/369/EEC in the UK through the Environmental Protection Act 1990 have led to a substantial decrease in emissions of key incineration pollutants (Table 1).

The emission limits under WID have applied since the end of 2002 to all new incineration plants and will apply to all plants existing at the time WID was put in force (i.e., 2000) by the end of 2005. In general, owing to WID's stricter emission limits (Table 2), incineration plants now have a reduced impact on health and environmental safety. In the UK, based on best estimates for operational data, existing incinerators already comply with WID emission limits except for NOx (Enviros et al, 2004). Thus, WID would be expected to have a beneficial impact on the further reduction of NOx emissions in the UK.

Table 1. Air emissions from UK MSW incinerators (adapted from Enviros et al., 2004)

Pollutant	Estimated emissions to air (g /tonne MSW incinerated)			
	1980	**Data pedigree [a]**	**2000**	**Data pedigree**
NOx	1,878	Moderate (5)	1,600	Good (9)
Total particulate matter	313	Poor (4)	38	Good (9)
SO_2	1,421	Moderate (5)	42	Good (9)
HCl	3,791	Moderate (5)	58	Good (9)
HF	No data	N/A	1	Good (9)
Volatile organics	25	Poor (4)	8	Moderate (8)
Cd	2.6	Poor (3)	0.005	Good (9)
Ni	2.8	Poor (3)	0.05	Moderate (8)
As	0.4	Poor (3)	0.005	Moderate (8)
Hg	1.8	Poor (3)	0.05	Good (9)
Dioxins and Furans	No data	N/A	$4x10^{-7}$ (g TEQ/t MSW)	Good (9)
Dioxin-like polychlorinated Biphenyls	No data	N/A	0.0001 (g TEQ/t MSW)	Moderate (7)

[a] Poor: 0 – 4; Moderate: 5 – 8; Good: 9 – 12; and Very good: 13 – 16.

For dioxins/furans no UK data exists that would allow definitive calculation of the mass of toxicity equivalent (gTEQ/t MSW) for UK incinerators operating in the 80's (the calculation requires individual isomer analysis which was not undertaken). However, data from Warren Spring Laboratory (Woodfield 1987) reported total levels of the T4CDD (dioxin) and T4CDF (furan) compounds for operational plants in the UK. The range was very large, between 0.8 and 204 ng/m^3 for T4CDD and 7.6 to 282 ng/m^3 for T4CDF's. Whilst the sum of these values will overestimate the TEQ value for dioxin /furans, they do indicate some plants were discharging levels up to 1000 times higher than the current limits permit, the best plants in the 80's were probably some 10 times higher than the current limits.

Table 2. Air emission limits from MSW incinerators under the directives 89/369/EEC and 2000/76/EC

Pollutant	Limit values according to Directive 89/369/EEC	Limit value according Directive 2000/76/EC (newest directive) [c]
Total dust (particulate matter)	[a] 30 – 200 mg/m^3	10 mg/m^3
Gaseous and vaporous organic substances, expressed as total organic carbon (TOC)	N/A	10 mg/m^3
HCl	[a] 50 – 250 mg/m^3	10 mg/m^3
HF	2 - 4 mg/m^3	1 mg/m^3
SO_2	300 mg/m^3	50 mg/m^3
NO and NO_2	N/A	200 mg/m^3
Total of Pb, Cr, Cu, and Mn	5 mg/m^3	N/A
Total of Ni and As	1 mg/m^3	N/A
Total of Cd and Hg	0.2	N/A
Total of Cd and Tl and their compounds	N/A	[d] 0.05 mg/m^3
Total Hg and its compounds	N/A	[d] 0.05 mg/m^3
Total of Hg, Sb, As, Pb, Cr, Co, Cu, Mn, Ni, V and their compounds	N/A	[d] 0.5 mg/m^3
Dioxins and furans	N/A (1 ng/m^3) [b]	[e] 0.1 ng/m^3

[a] Lower values for higher plant throughputs; [b] the 1 ng/m3 was UK guidance by HMIP; [c] Daily average values; [d] Average values over a period of a minimum 30 minutes and maximum of 8 hours; [e] Averaged values over a period of a minimum of 6 hours and a maximum of 8 hours

Solid residues from incineration plants are the result of the inherent ash content of the waste. Most reports as bottom ash, smaller amounts report in the boiler sections and in combination with gas cleaning chemicals (e.g. lime, activated carbon) and in the pollution control systems. Solid residues from EfW-I comprise air pollution control (APC) residues, which are also known as fly ash, and boiler or grate ash (bottom ash). APC residues are designated as hazardous waste (previously special) and thus are landfilled (after treatment under the new landfill regulations) in designated hazardous waste landfills. Bottom ash is a relatively benign, stable, non hazardous waste and, if not re-used following recovery of ferrous and non ferrous metals (e.g., as aggregate, bulk fill, or in other building materials) can be landfilled in non hazardous waste landfills (Enviros et al, 2004). Indicative, best estimate values for APC and bottom ash have been given as 0.18 tonnes APC and 0.03 tonnes bottom ash per tonne MSW incinerated. Detailed pollutant loads in APC and bottom ash can be found in Enviros et al (2004).

Liquid residues may be produced as a result of the flue-gas cleaning system, but nowadays incinerator installations are using anhydrous systems for flue-gas cleaning which do not produce any liquid effluents. Instead, liquid effluents may mostly be produced from quenching water used in ash pits. Quenching water is generally disposed of into the sewer.

4. Health Impacts

4.1 General comments

4.1.1 Introductory comments

Health impacts related to emissions to air from incineration plants are focused upon in this report since data limitations do not allow the investigation of health effects that potentially arise from exposure to pollutants released by incineration to groundwater, surface water, sewer, and to land from solid or liquid incineration residues. As a general comment, it seems that liquid effluent and solid residues from incinerators do not represent a high risk to human health or the environment since they are managed through controlled waste management activities (e.g., landfill and the sewerage system). In addition WID has set quality standards for liquid effluents from the cleaning of incinerator flue gases.. Indeed, EA (2003) concluded that there would be limited scope for human exposure to pollutants from liquid or solid residues from incinerators if normal controls are observed.

Epidemiological studies on health impacts due to exposure to air in the vicinity of incinerators often suffer from methodological drawbacks that influence the quality of their findings and make comparisons between studies difficult. Three of the most important factors responsible for limiting the quality of epidemiological studies are the retrospective character of those studies, the use of distance from an incinerator as an indicator for exposure, and the sample size of the cases examined. The latter often inhibits statistical validity in identifying links between exposure and health impacts.

Often, epidemiological studies are triggered by complaints from or suspicion about populations that may suffer ill health and are located close to an incinerator. Inevitably, such studies may be unintentionally biased. Further, all retrospective studies are based on routinely collected health data like cancer cases and birth and death rates. Such data may indicate connections between the presence of pollutants and health effects, but they cannot establish cause-and-effect relationships (Enviros et al, 2004).

Using distance as a surrogate for exposure measurement may ignore other influential factors such as landscape, climatic conditions, stack height and other confounding factors (e.g., socio-economic factors) that may affect exposure. (Distances up to 7.5 km from an incinerator are commonly used in epidemiological studies).

Indeed, the need for considering important factors in studies about health impacts from incineration was recognised by the UK “Committee on Carcinogenicity of Chemicals in Food, Consumer Products and the Environment” which in 2000 suggested that the following should be taken into account (Enviros et al, 2004): accuracy of health statistics, accuracy of cancer diagnosis, potential confounding factors for individual cancers, and variables specific to incineration (e.g., technology, waste feedstock, geographical and meteorological conditions and pollution control systems).

Air emissions from incinerators have been said to have potential health impacts in relation to cancer occurrence, respiratory function, and reproduction. Incineration health impacts can be brought about by exposure to air pollutants through a number of pathways. However, inhalation and the food chain have been identified as the most important pathways. Through the food chain human beings may be exposed to trace metals and potential carcinogenic compounds while inhalation is important regarding emissions of SO_2, NO_2, and particulate matter (PM_{10}). This is particularly so for the more vulnerable members of society, e.g. children, the elderly and, through acute exposure, existing patients with respiratory or cardiovascular diseases (Enviros et al, 2004).

4.1.2 Pollutant from EfW-I and their possible health impacts

This section provides background information on the health effects that might be caused by key pollutants emitted from MSW incinerators; namely, metals (Cd, Hg, As, Cr, Ni, and Pb), particulate matter (i.e., micro-particles carried out by off-gases), nitrogen dioxide (NO_2), sulphur dioxide (SO_2), polycyclic aromatic hydrocarbons, and dioxins and dioxin-like compounds. This information has been obtained from Farmer and Hjerp (2001).

Cd (cadmium) compounds are found in fly ash and in off-gases. Long term exposure to Cd is known to cause renal and pulmonary toxicity and carcinogenicity to humans.

Hg (mercury) organic methylated forms are highly toxic and cause neurotoxicological disorders to humans mainly through exposure via the food chain, mainly fish.

Arsenic (As) is mainly present in flue gases. Its major health risk is carcinogenicity although it may also negatively affect the respiratory, skin, vascular and haematopoetic systems.

Hexavalent chromium (Cr(VI)) is the form of Cr of health concern. Cr(VI) can cause lung cancer at environmental exposure levels while at occupational exposure levels Cr can also cause damage of nasal septum and dermatitis.

Ni (nickel) is contained in fly ash and flue gases (as particulate matter) and its most significant route of exposure is inhalation. It can cause respiratory tract irritation and is classified as carcinogenic for humans.

Pb (lead) alkyls are predominantly produced by combustion carried by particulate matter. The main exposure route for human is the food chain. Long term exposure to Pb is linked to negative impacts on haem biosynthesis, nervous system, kidney function, blood pressure, and cardiovascular system.

Particulate matter (PM) is carried to the ambient air by flue gases. PM_{10} means particulate matter having a particle size less then 10 µm. Inhalation is the principal pathway for exposure of humans to PM. Short term exposure to PM_{10} has been associated with increased morbidity and mortality, particularly with regard to cardiopulmonary diseases, with the elderly and infirm being at much higher risk. Also, long term exposure to PM might cause increased mortality and morbidity and respiratory symptoms.

NO_2 is emitted through flue gases to the air and the consistent general conclusion is that it affects respiratory function in older children (5 to 15 years old).

SO_2 is emitted through flue gases and is a potent respiratory irritant. It can also be a contributory factor in cardiovascular disease.

Polycyclic aromatic hydrocarbons are organic compounds that are created by incomplete combustion of organic substances. They are mainly carried out by flue gases in a gaseous form or adsorbed on particulate matter. They are classed as substances potentially carcinogenic to humans and general epidemiological studies have linked them to an elevated risk for lung, skin, and perhaps bladder and gastrointestinal cancers.

Dioxins and dioxin-like compounds comprise polychlorinated dibenzo-p-dioxins (PCDDs – commonly referred to as dioxins), polychlorinated dibenzofurans (PCDFs – commonly referred to as furans) and polychlorinated biphenyls (PCBs). The toxicity of these compounds and their mixtures they form with each other is usually expressed as a toxic equivalent (TEQ) factor in relation to the most toxic dioxin which is the 2,3,7,8-tetrachlorodibenzo-p-dioxin. The most important route for exposure of humans to dioxins is through food consumption (95% to 98%). PCDDs/Fs and PCBs may be linked to carcinogenicity, reproductive effects, neurotoxicity, immunotoxicity, and diabetes.

4.2 Cancer occurrence

Generally, the few epidemiological studies that have been carried out regarding cancer in communities located in the vicinity of incinerators have considered data from older generation incinerators which have been phased out owing to new regulations (e.g., WID, integrated pollution control regulations, and prevention and pollution control regulations). The reason for the absence of studies about the current situation is that cancer occurrence is associated with a latency time (exposure time). The expected, improved impacts of the new generation incinerators will thus be able to be evaluated in a few years from now. This is a point that has to be constantly kept in mind in reading this report, as studies in the UK have so far focused on emissions of dioxins and furans (Enviros et al, 2004) for which strict emission limits are imposed by WID, and it is logical to expect that any carcinogenic effects of those pollutants owing to incineration will be reduced accordingly. For example, Enviros et al (2004) reported that a study conducted by Gonzales et al (2000) indicated that a “modern incinerator” did not cause any differences in exposure levels, based on blood sample analysis, between residents close to the incinerator and residents living further away from it.

Table 3 presents a compact overview of the data about cancer occurrence that were considered in the work of Enviros et al (2004). Owing to the compact character of Table 3 the reader is advised to consult Enviros et al (2004) for details on the examination of the reviewed studies, including accounting for biases, data validity and confounding factors.

Table 3. Overview of major outcomes from the review of epidemiological data on cancers occurrence based on information presented in Enviros et al (2004).

Cancer Type	Comments
Stomach, colorectal and liver	- Four UK studies were considered that were conducted up to 1987. Thus, they do not correspond to emissions from new generations incinerations. - The report found no link between incineration and any of those cancers, but it was not possible to absolutely preclude the existence of a link with liver cancers.
Larynx and lung	- One UK and two Italian studies were considered. The studies were published in 1992, 1996, and 1998. - The reported concluded that a significant relationship between Larynx and lung cancers and pollution from incineration of MSW could not be established.
Childhood cancers	- Five UK studies were examined. One of them was published in 1995, two in 1996, one in 1998, and one in 2000. - A link between emissions from incineration and childhood cancers could not be established.
Soft tissue sarcomas and non-Hodgkin's lymphomas	- One UK and three French studies were reviewed. One was published in 1996, two in 2000, and one in 2003. - Based on the analysis performed by Enviros et al (2004), it seems that a link could not reliably be established between those cancers and emissions from incinerators.

Enviros et al (2004) concluded that a consistent and convincing evidence of a link between incineration and carcinogenicity has not been published.

Enviros et al (2004) also reported that specifically for the UK, large epidemiological studies on a total of 14 million people living in a radius up to 7.5 km from 72 incinerators (i.e., all the incinerators existing in the UK up to 1987 irrespective of age) were conducted (Elliot et al, 1992; 1996; 2000). Those studies were not able to demonstrate convincingly increased carcinogenicity due to incineration emissions if one considers socio-economic confounding effects.

Further the UK Department of Health's Committee on Carcinogenicity of Chemicals in Food, Consumer Products and the Environment concluded in a recent statement about cancers from MSW incinerators: "The Committee was reassured that any potential risk of cancer due to residency (for periods in excess of 10 years) near to municipal solid waste incinerators was exceedingly low and probably not measurable by the most modern epidemiological techniques. The Committee agreed that, at the present time, there was no need for any further epidemiological investigations of cancer incidence near municipal solid waste incinerators" (Anonymous, 2000b).

Work undertaken on behalf of the UK environment Agency calculated potential health impacts by modelling the concentration of pollutants in emissions from incineration and considering exposure-response coefficients. Although that work is now completed it has not been possible to obtain a copy of the final report in the time frames available for the completion of this report, and we have therefore reviewed the comments provided by Enviros et al (2004) with respect to a final draft report for the Environment Agency work (EA, 2003). According to Enviros et al (2004) the work commissioned by the EA focused on key, specific substances known for their potential impact on human health such as SO_2, PM_{10}, NO_2, As, Cr(IV), Ni, dioxins and furans, polychlorinated biphenyls etc. The work considered a number of waste management treatment methods, including composting, mechanical and biological treatment, gasification, pyrolysis, and incineration of MSW. Broad estimations of the potential number of deaths, respiratory hospital admissions and cancers that may be caused by incineration per tonne waste incinerated considering the whole of the UK are presented in Table 4.

The data presented in Table 4 are provided merely to give a rough idea about potential differences between waste treatment options in causing ill health. These data differ in uncertainty and are influenced by factors such as dispersion modelling and exposure-response coefficients. According to Table 4, the cancers due to incineration were found to be almost equal to that of gasification/pyrolysis. Figures for composting and MBT were not calculated owing to limited data.

Table 4. Approximate values for potential effects of composting, MBT, gasification/pyrolysis, and incineration on selected health outcomes in the context of the whole of the UK –based on EA (2003) as reported by Enviros et al (2004)

Health outcome	Composting	MBT	Gasification or pyrolysis	Incineration
Deaths brought forward	No data	10^{-9} - $10^{-6.5}$	10^{-9} – 10^{-6}	$10^{-8.5}$ to 10^{-6}
Respiratory hospital admissions	No data	$10^{-8.5}$ – 10^{-6}	$10^{-7.5}$ – $10^{-5.5}$	10^{-7} – $10^{-4.5}$
Cancers	No data	No data	10^{-12} – $10^{-9.5}$	10^{-12} – $10^{-9.5}$

Specifically with regard to cancers due to dioxins and furans, Enviros et al (2004) commented based on information reported by EA (2003) that the incremental exposure to dioxins and furans from incineration through inhalation found to be an insignificant proportion of typical human intakes in the UK. Moreover, regarding exposure to dioxins and furans through the food chain the estimation of EA (2003) was that even for people living and consuming foodstuffs grown at the point of maximum ground-level concentration, the contribution of incineration to the intake of dioxins and furans was between 0.66% and 0.8%.

4.3 Respiratory function

Enviros et al (2004) reviewed six studies on respiratory effects from incineration; four from the USA, one from Australia and one from Taiwan (Gray et al, 1994; Hsuie et al, 1991; Hu et al, 2001; Lee and Shy 1999; Mohan et al, 2000; Shy et al, 1995) . All of those studies concerned incinerators of the older generation and most of them are based on self-reporting of effects which may affect their objectivity.

Of these studies the ones that were not disputed by Enviros et al (2004) on methodological or data quality grounds indicated that no excess acute or chronic respiratory symptoms were shown, and that emissions from incinerators did not make a significant contribution to background particulate matter air pollution.

Thus overall lit was concluded that review of the aforementioned literature provided little evidence about incineration increasing the prevalence of respiratory symptoms.

Table 4 indicates that respiratory hospital admissions owing to pollution from incineration in the UK may be comparable to that of MBT and pyrolysis/gasification, albeit slightly higher.

4.4 Reproductive system

Incineration has been suspected for potentially affecting the reproductive system due to dioxin and furan emissions causing phenomena such as an increase of twining rates, changes in sex birth ratios, and congenital malformations (Enviros et al, 2004).

Enviros et al (2004) reviewed nine studies on this topic originating from a number of countries including the UK, the Netherlands, and Italy (Dummer et al, 2003; Jansson and Voog, 1989; Jones, 1989; Lloyed et al, 1988; Mocarelli et al, 1996; Rydhstroem, 1998; Straessen et al, 2001; ten Tusscher et al, 2000). Notwithstanding studies with doubtful quality Enviros et al (2004) reported that none of those studies delivered adequate evidence that incineration is linked to reproductive problems. Studies that claimed there was any potential for such links examined older generation incineration which did not feature the controls for dioxins and furans that newer generations of incinerators do, particularly those complying with WID standards.

4.5 Overall human toxicity

Koller and Soyez (2001) collated data from the studies of Koller et al (2000) and IGW (1999) to estimate human toxicity from MBT and incineration of RMSW as part of a life cycle analysis. Human toxicity estimations were carried out by using a method developed in the Netherlands (Guinée et al, 1996). However, unlike the results presented above from Enviros et al (2004), their assessment was not based merely on potential pollutant emissions from MBT and incineration plants, but they rather considered secondary effects by including effects from recycling of or energy recovery from materials separated from MBT or incineration outputs, or the recovery of energy from EfW-I to substitute conventional fossil energy.

The MBT systems considered by Koller et al (2000) and IGW (1999) included the following alternatives:

a) a modern intensive aerobic MBT featuring 8 weeks retention time for biological treatment and separation and recycling of Fe metals;

b) a modern intensive combined aerobic (8 weeks retention time) and anaerobic MBT with production of solid recovered fuel used at a cement kiln;

c) a modern 30 ktpa intensive aerobic MBT (16 weeks biological treatment retention time) which separates 13% of the incoming RMSW (light high calorific value fraction) as solid recovered fuel;

d) a modern 60 ktpa intensive aerobic MBT (12 weeks biological treatment retention time) separating 20% of the high calorific value fraction of RMSW to produce a solid recovered fuel;

e) a relatively basic MBT option having the same degree of mechanical separation as that of options “a” to “d” above, but having an aerobic passively-aerated biological treatment of a retention time of 52 weeks; and

f) a basic MBT option featuring no separation of materials and passively-aerated biological processing (52 weeks retention time) without off-gas cleaning.

Except for alternative “f” all other MBT alternatives were assumed to have off-gas cleaning by means of water scrubbers and biofilters.

The incineration systems considered included four systems representative of German conditions, including satisfaction of the German air emission standards for waste incinerators (abbreviated as 17 BImSchV, version 1999/2). Those standards were the same as those of WID.

The four incineration scenarios included the following: a) grate firing system representing the German average performance of incinerators regarding emission control; b) exact satisfaction of 17 BImSchV emission limits and electricity recovery (13% efficiency); c) being 25% below the 17 BImSchV air emission limits without recovering energy; and d) being 5% below the 17 BImSchV air emission limits while recovering electricity and heat (efficiency: 10% for electricity and 50% for heat recovery).

Based on the data presented in Koller and Soyez (2001) only the incineration scenario “d” (EfW-I with combined heat and power) could have a relative human toxicity impact comparable or even better than that of the MBT options considered. Caution should be advised as these comments are valid for the conditions applicable to the studies conducted by Koller et al (2000) and IGW (1999). Only a life cycle analysis specific to the conditions of the Leeds CC, such as RMSW composition, products to be claimed from MBT options, EfW-I energy and heat recovery and associated efficiencies, energy form substituted etc. may be able to provide specific answers.

4.6 Indication of health impacts from EfW-I treating Leeds CC’s RMSW

Based on emission coefficients of the UK Committee on the Medical Effects of Air Pollutants and unit risk factors of the World Health Organisation, Enviros et al (2004) calculated unit health impacts (i.e., impact per tonne MSW incinerated) for a number of key incineration pollutants. The unit health impacts have been calculated for two specific incineration installations examined in the study of EA (2003) and which were selected because of their stack heights; one being close to the UK median stack height, and the other having one of the lowest UK stack heights.

Based on those unit health impacts and the amount of RMSW to be produced at Leeds CC in 2013 (i.e., 285 ktpa), potential health impacts have been estimated (Table 5). Attention should be paid to the fact that the figures provided in Table 5 do not claim to provide anything other than a general feeling about potential impacts. A reliable prediction of health impacts for Leeds CC should be based on unit health impacts specific to Leeds CC by considering local conditions that are known to potentially influence incineration health effects such as population density, exposure to other emissions, temporal/spatial variables etc.

Table 5. Estimates of health impacts from the incineration of Leeds CC RMSW

Type of health impact	Impact per annum	
	Median UK stack height	*Lower UK stack height*
Deaths brought forward – SO_2	0.0182	0.0285
Death brought forward – PM_{10}	< 0.00011	0.00285
Respiratory hospital admissions – NO_2	0.4275	1.168
Respiratory hospital admissions – SO_2	0.013	0.021
Respiratory hospital admissions – SO_2	< 0.00011	0.00285
Cardiovascular hospital admissions – PM_{10}	< 0.00011	0.00216
[a] Cancers – As	0.000004	
[a] Cancers – Cr (IV)	0.000004	
[a] Cancers – Ni	0.000004	
[a] Cancers – Polycyclic aromatic hydrocarbons	0.000004	

[a] No differentiation based on stack height

The figures presented in Table 5 indicate rather negligible impacts and this is particularly evident when one compares them with the impacts of other causes of ill health or common activities (Table 6).

Table 6. Health impacts induced by various causes of ill health or human activities

Health impact type	Impact per annum and town (UK) [a, b]						
	Skin cancer	***Lung cancer***	***Air pollution***	***Road traffic accidents***	***Natural environmental factors (e.g., excessive cold)***	***Choking on food***	***Injury from fire works***
Deaths brought forward			Approx. 1 (for small towns)	Approx.1 (for small towns)	1 (for large towns)	1 (for large towns)	
Hospital admissions			Approx. 1 (for small towns)	1 per street			1 (for small towns)
Cancers	Approx.1 (for small towns)	Approx.1 (for large towns)					
Data quality	Moderate	Poor	Poor quality	Good	Good	Good	Good

[a] Blank cells indicate lack of data; [b] Statistics presented were published between 1998 and

2004 (see Enviros et al (2004) for more details)

5. Environmental Impacts

5.1 General Comments

Environmental impacts may generally be evaluated in relation to the environmental media of soil, water and air, and impact categories, like noise odour, dust, flora and fauna, and climate, which however are not expressed as quantitatively estimated environmental phenomena. That approach is commonly met in environmental impact assessment studies for planning applications.

On the other hand, life cycle analyses quantitatively estimate environmental impact categories that relate to key environmental phenomena. With regard to waste management life cycle analysis studies, impact categories commonly include global warming potential (GWP), acidification, euthrophication, ozone depletion potential (ODP) photo-oxidant building potential (POBP), and ecotoxicity.

GWP is associate with emissions that may cause temperature increase such as CO_2, CH_4 (methane), and N_2O (nitrous oxide).

Acidification of the soil or surface water is brought about by substances that release protons or are transformed into acids in the atmosphere following their oxidation and reaction with water. Acidification has ecological effects such as deforestation and fish toxicity.

Euthrophication is the phenomenon of aquatic ecosystem damage through excessive plant growth caused by an excessive supply of nutrients, mainly nitrogen and phosphorus. In the case of incineration these could be emitted to the atmosphere and end up in the water body.

ODP is caused by the emissions to the air of chorofluorocarbons and some persistent halogenated hydrocarbons. Ozone depletion can have negative impacts on the biosphere and human health.

POBP (summer smog) is caused by reactions taking place between nitrogen oxides and organic compounds under the influence of ultraviolet radiation. Photo-oxidants (e.g., ozone) are built in the troposphere. POBP can affect human health (e.g., function of lungs) and ecosystems such as forests (Koller and Soyez, 2001).

Ecotoxicity is taken in this report to mean any toxic effect to an environmental medium/element (i.e., water, ambient air, or soil) based on a method that was developed by Guinée et al (1996) (Koller and Soyez, 2001).

5.2 Potential environmental impacts considering only environmental media and qualitative evaluation of impact categories

Enviros et al (2004) reviewed international literature in this area and identified major data gaps and quality limitations. The areas they considered were noise, odour, dust, flora/fauna, soils, water quality/flow, air quality, climate, and building damage (due to acid gases). Based on the findings of that report incineration of unsegregated MSW may have potentially significant effects in relation to flora/fauna, soil, and water quality. Their comments are quoted verbatim in the following paragraphs.

Flora/fauna: *"Potentially significant risk of accumulation of metals and dioxins and furans, though other sources are more significant. No adverse animal health effects were observed"*.

Soils: *"Potentially significant risk of accumulation of metals and dioxins and furans, though other sources are more significant and found not to be a significant health issue. Dioxins: contribution 0.1 – 1 ng/kg compared to background of 0.1 – 100 ng/kg"*.

Water quality/flow: *"Potentially significant risk of contaminants leaching from ash. Contributes less than 20% of contaminants in precipitation"*.

Attention should be drawn to the fact that these statements are general statements about potential effects. Information about effects based on epidemiological evidence and prediction of the impact on human health was discussed earlier. In addition, it was noted earlier that the historical data indicate a decrease of relevant incineration emissions in the UK and it was pointed out that strict environmental controls are enforced in the UK.

5.3 Potential environmental impacts in relation to specific adverse environmental phenomena

Koller and Soyez reviewed information published by Koller et al (2000) and IGW (1999) to compare potential environmental impacts of incineration and MBT. The MBT and incineration alternatives that were compared are given in Section 4.5 of this report. The environmental impact categories they considered included GWP, acidification, euthrophication, ODP, POBP, and ecotoxicity and a brief overview of their findings about those categories are presented in this section.

Once again attention should be drawn to that the comments provided in this section are general. If one wishes to evaluate the potential impacts of EfW-I and MBT options for Leeds CC RMSW a dedicated study should be carried out. Also, it should be borne in mind that the studies from which the following comments have been adopted or on which they have been based did not examine only the primary effects of EfW-I or MBT facilities alone, but they also took into account secondary impacts as also explained in Section 4.5. Therefore, the comments on impacts are for RMSW management systems built around either incineration or MBT, including landfilling of residues, recycling of separated materials, or energy recovery from manufactured solid recovered fuel.

5.3.1 Global warming potential (GWP)

EfW-I was said to score better than the MBT options if one assumes that landfill will not act as a carbon sink for MBT processed outputs being landfilled. If it is assumed that landfill does act as a carbon sink for MBT outputs (which is a debatable issue) and thus leads to methane emission reduction, then MBT could score as well or even better than EfW-I. Factors of importance in shaping the outcomes were found to be the substitution of fossil energy and the recycling of materials separated during MBT.

5.3.2 Acidification

Whether MBT scores better than EfW-I depends primarily on the amount and type of fossil energy substituted by each one of them. This is because acidification potential is driven by SO_2, NO_x, and NH_3 emissions, which are chiefly associated with the production of energy from fossil fuels (Koller and Soyez, 2001). According to their findings, although acidification impacts owing to MBT are in general relatively smaller than those of EfW-I, EfW-I has the potential to improve the baseline situation, i.e., to reduce the baseline acidification if it substitutes appropriate amounts and types of fossil fuel energy.

5.3.3 Euthrophication

They reported that the main causes of euthrophication for MBT and incineration were emissions of ammonia/ammonium, and nitrogen oxides. However, both MBT and incineration options examined were found to have very small to negligible euthrophication potential. The best performance was achieved by modern intensive MBT featuring recovery of value from separated materials, and EfW-I.

5.3.4 Ozone depletion potential (ODP)

EFW-I was found to be performing much better than MBT with regard to ODP. This was owing to the emissions of chlorofluorocarbons from MBT that cannot be removed from off-gases by means of scrubbers and/or biofilters whilst they are destroyed during incineration. This has been one of the reasons why in Germany off-gases from MBT have come under strict controls. However, the current UK regulations do not require such high levels of control for MBT facilities, and therefore commonly-used scrubbers/biofilters would be the type of off-gas cleaning expected at MBT facilities which in turn would mean that EfW-I in the UK would be expected to be a better option than MBT regarding ODP.

5.3.5 Photo-oxidant building potential (POBP)

EfW-I was found to have at worst very small negative impacts with regard to POBP. It can even result in huge improvement (i.e., reduction of baseline POBP) given appropriate substitution of fossil energy. On the other hand MBT appeared to always have a negative impact which could be balanced by benefits brought about if MBT features extensive recovery of value from waste fractions (e.g., recycling and/or energy recovery). This situation is due to methane and non-methane volatile organic compound air emissions (particularly linear chlorinated hydrocarbons) that cannot be removed by conventional off-gas treatment technology such as scrubbers and biofilters. As explained above, scrubber sand biofilters are the technology that is likely to be used at UK MBT facilities.

5.3.6 Ecotoxicity

EfW-I was found to cause as much toxicity as MBT or even outperform MBT if it recovers both heat and power to replace fossil energy. When energy is not recovered incineration was found to have greater ecotoxicity potential than MBT. Gaseous emissions of polychlorinated biphenyls were the principal cause of ecotoxicity in the case of MBT while Cd, and Hg were the main causes for ecotoxicity for incineration.

6. Conclusions

Based on the information that was reviewed in this report the following conclusions may be drawn:

i. Potential health/environmental effects from EfW-I are most likely to be associated with its emissions to air while emissions through its solid or liquid outputs should not be of any concern provided that expected control measures are adequately enforced..

ii. The findings reported in this work did not provide sufficient evidence on the existence of a link between EfW-I and cancer occurrence. There appears to be little evidence linking EfW-I with respiratory disorders and reproductive disturbances.

iii. Using unit health impact figures from the literature, that are however not specific to the Leeds CC conditions, it was estimated that the EfW-I of the amount of RMSW produced in Leeds CC would result in health impacts that are likely to be so small as to be negligible.

iv. Although local conditions are of decisive importance, in general it might be said that MSW management schemes employing EfW-I might give rise to lower global warming potential, ozone depletion potential, summer smog and human toxicity than those employing MBT. A general opinion cannot be expressed with regard to acidification and ecotoxicity.

v. In order to predict reliable environmental and health impacts for the EfW-I option and compare it to those of other treatment options, a specific study should be carried out taking into consideration the conditions that apply to Leeds CC. The impacts of any EfW-I plant proposed for treating RMSW for Leeds CC would be subject to a full environmental impact assessment that is required at the planning stage.

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