UNITED BY OUR DIFFERENCE

WSP

AN INVESTIGATION INTO THE PERFORMANCE (ENVIRONMENTAL AND HEALTH) OF WASTE TO ENERGY TECHNOLOGIES INTERNATIONALLY

Stage Three - A Review of recent research on the health and environmental impacts of Waste to Energy Plants

WSP Environmental Ltd, on behalf of the Government of Western Australia's Department of Environment and Conservation

January 2013

Quality Management

Issue/revision	Issue 1	Revision 1	Revision 2	Revision 3
Remarks				
Date	10th January 2013			
Prepared by	Mick Fanning and Global WSP Team			
Signature				
Checked by	Kevin Whiting			
Signature	K.J. Whiting			
Authorised by	Kevin Whiting			
Signature	K.J. Whiting			
Project number	00031427 Stage 3			
Report number				

An investigation into the performance (environmental and health) of waste to energy technologies internationally

Stage Three - A Review of recent research on the health and environmental impacts of Waste to Energy Plants

WSP Environmental Ltd, on behalf of the Government of Western Australia's Department of Environment and Conservation

January 2013

Client

Waste Management Branch
Department of Environment and Conservation
Level 7, The Atrium, 168 St Georges Tce PERTH WA 6000
Locked Bag 104 Bentley DC WA 6983

Consultant

Mick Fanning
Associate Consultant
WSP Environmental Ltd.
Tel: +44 207 7314 5883
Fax: +44 207 7314 5005

Registered Address

WSP Environmental Ltd
WSP House, 70 Chancery Lane, London WC2A 1AF, United Kingdom
www.wspenvironmental.com

Table of Contents

Summary and Conclusions

This **Stage Three** report reviews the key environmental and health impact studies and publications relating to Waste-to-Energy (WtE) plants globally. It finds a complex and varied set of analyses and evaluations reviewing any association between the broad range of emissions arising from these facilities, predominantly gaseous or solid process residues, and effects on the environment and human health.

The decision making process on which technology to choose for the treatment of Municipal Solid Waste (MSW) in any setting is a complex process and one which relies on evidence based evaluation of the main issues. Key considerations when evaluating the environmental or health effects of thermal treatment technologies include direct comparison of potential impact with other waste treatment options, consideration of relative impact when compared to non-waste related anthropogenic activities and specifically for emission to air, the potential relative impact on air quality conditions. Whilst it is accepted all emissions from whatever process should be minimised as far as possible, understanding and recognising the context in which facilities may operate has been an element in the assessment process or regulatory considerations in other jurisdictions.

Key conclusions arising from this review are as follows:

- There appears to be little convincing and unequivocal evidence that excess risk of contracting specific illnesses is associated with waste facilities such as Waste-to-Energy plants, especially newer, well operated facilities i.e. those operated in compliance with the relevant regulations and emission standards, which seem to be more effective in mitigating potential risks from exposure to emissions;
- There is however still some uncertainty in relation to interpretation of the results of some literature and academic studies e.g. lack of data or potential limitations in methodologies used (acknowledged by some of the authors of papers reviewed in this report);
- The UK Health Protection Agency 2009 report states …*while it is not possible to rule out adverse health effects from modern, well regulated municipal waste incinerators with complete certainty, any potential damage to the health of those living close-by is likely to be very small, if detectable.*
- In relation to Particulate Matter (PM), there is on-going debate about whether it is their mass concentration that should be assessed in relation to health impacts, especially for fine and ultrafine particles, or whether it is the particle numbers that could potentially have a greater impact;
- Dioxin and furan emissions from the thermal treatment of MSW have decreased significantly over recent decades e.g. pre and post Maximum Achievable Control Technology (MACT) regulations in the United States demonstrates a 99.9% reduction, the Germans have also reported a reduction of three orders of magnitude;
- Considerable attention has been given to the difference in emission profiles for dioxins and furans when comparing steady state combustion and operational transients; one study found operational transients were found to considerably increase levels compared to steady state operation. A report by the UK Department for Environment, Food and Rural Affairs suggests that whilst emission above prescribed limits is of concern and should be investigated, it is unlikely to have a significant effect on emissions averaged over a long period such as a year;
- Incinerator Bottom Ash (IBA) has the potential to leach certain pollutants such as heavy metals. The recycling of IBA in bound applications shows a greatly reduced leaching potential and in Japan, slagging gasification processes and the use of plasma melting systems with conventional incineration systems produce a vitrified slag which locks the leachable heavy metals within the slag;
- The environmental impact of installations dedicated to the treatment of residual MSW may not be strictly proportional to treatment capacity. A significant role is played by the qualitative aspects of the waste feedstock; and

- Incineration with energy recovery is considered to generate greenhouse gas savings based on the studies reviewed for this report and is considered one of the most efficient processes for treating MSW when heat recovery is achieved.

The Government of Western Australia may be in a unique position to continue some of the studies and assessments detailed in this report. Should approval be granted for a local MSW thermal treatment plant in the future, the relevant authority could apply some of this analysis to what could be considered the ‘baseline case’ i.e. prior to operations, undertaking ongoing analysis thereafter for years/decades to monitor and evaluate findings for any statistically significant impact.

It is therefore clear that the shaping of policy, legislation and guidance to ensure the most appropriate future waste treatment infrastructure needs to remain mindful of these and related key issues and the impact on all stakeholders and the environment.

List of Abbreviations

AIE	Italian Association of Epidemiology
APC	Air Pollution Control
ATT	Advanced Thermal Treatment
BAT	Best Available Technique
BSEM	British Society for Ecological Medicine *(UK)*
CAA	Clean Air Act *(US)*
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide equivalent
CO	Carbon Monoxide
DEFRA	Department for Environment, Food and Rural Affairs *(UK)*
EASEWASTE	Environmental Assessment of Solid Waste Systems and Technologies
EIA	Environmental Impact Assessment
EIS	Environmental Impact Statement
EU	European Union
HPA	Health Protection Agency *(UK)*
IED	Industrial Emissions Directive *(EU)*
IEH	Institute for Environment and Health *(UK)*
GHG	Greenhouse Gas
GIS	Geographical Information System
IBA	Incinerator Bottom Ash
LEAP	Energy and Environment Laboratory Piacenza *(Italy)*
LCA	Life Cycle Analysis
LHV	Lower Heat Value
MACT	Maximum Achievable Control Technology *(US)*
MBI	Mass Burn Incineration
MBT	Mechanical Biological Treatment
MHT	Mechanical Heat Treatment
MMTCE	Million Metric Tonnes Carbon Equivalent
MSW	Municipal Solid Waste
MSWI	MSW Incineration
NO_2	Nitrogen Dioxide
NSPS	New Source Performance Standards *(US)*
PAH	Polycyclic Aromatic Hydrocarbon
PBDD	Polybrominated Dibenzo-para-dioxin
PBDF	Polybrominated Dibenzofuran

PCB	Polychlorinated Biphenyl
PCDD	Polychlorinated Dibenzo-para-dioxin
PCDF	Polychlorinated Dibenzofuran
PCDM	Polychlorinated Diphenylmethane
PFR	Persistent Free Radical
PM	Particulate Matter
RA	Risk Assessment
RDF	Refuse Derived Fuel
rMSW	Residual MSW
SIWMS	Stochastic Integrated Waste Simulator
SO_2	Sulphur Dioxide
SRF	Solid Recovered Fuel
TDI	Tolerable Daily Intake
TEQ	Toxic Equivalent
USEPA	United States Environmental Protection Agency
VOC	Volatile Organic Compound
WID	Waste Incineration Directive *(EU)*
WRATE	Waste and Resources Assessment Tool for the Environment
WtE	Waste-to-Energy
YOLL	Years of Life Lost

1 Introduction

In March 2012 the Waste Authority published the Western Australia Waste Strategy *Creating the Right Environment*. Central to the success of the strategy is the utilisation of high quality information to support effective decision making.

This Stage Three report presents the findings of the international literature review from the last 15 years encompassing potential environmental and health risks associated with emissions from Waste to-Energy (WtE) plants processing mixed non-hazardous and low-level hazardous solid waste. The report focuses necessarily on the incineration of mixed Municipal Solid Waste (MSW) as there is limited available information on the environmental or health impacts on alternative Advanced Thermal Treatment (ATT) technologies.

The report refers predominantly to peer-reviewed academic literature but does, however, also use published literature written by public and private organisations, where the content contributes to the broader debate on key issues. Governmental reviews and guidance are also used in the review.

The report presents a review of scientific assessment and, where relevant, aims to highlight concerns or shortcomings raised by authors in the assessment process; readers are however encouraged to use the reference section and read specific papers for further detail where required.

Section Two considers environmental impact in terms of comparison with other waste treatment options and anthropogenic activities, ecotoxicological impact, emissions of greenhouse gases/dioxins/furans and the management of process residues i.e. Incinerator Bottom Ash (IBA) and air pollution control residues.

Section Three considers health impacts in terms of comparison with other waste treatment options and anthropogenic activities, epidemiological studies, Particulate Matter (PM), odour, and carcinogens, mutagens and teratogens.

Section Four reviews the key issues arising from this review.

2 Environmental Impact

2.1 Introduction

This section presents a review of various literatures concerning the environmental and ecotoxicological impact associated with MSW Incineration (MSWI) and alternative options for the management of MSW. For thermal treatment of MSW, the review necessarily focuses on incineration due to the balance of literature and research available when compared to other ATT technologies.

2.2 Thermal Treatment of MSW

This section reviews literature comparing the environmental impact of MSWI with other waste management options, for residual MSW (rMSW) and other waste streams. It also reviews some Life Cycle Assessment (LCA) studies aimed at evaluating the environmental impact of MSWI.

Comparison with other waste processing options

Burnley et al (2011)[1] studied the energy implications of the thermal recovery of biodegradable MSW materials in the UK and found very little prior research on the subject of the overall energy balance for the collection, preparation and energy recovery processes for different types of wastes. The authors believe this may reflect the fact that such analysis requires extensive operational, waste collection and processing data, some of which is potentially commercially sensitive.

The study carried out energy balances for the thermal processing of food waste, garden waste, wood, waste paper and the non-recyclable fraction of MSW. The gross energy usage and production expressed per tonne of feedstock is summarised showing the chemical and electrical energy consumed by the collection and processing of each waste stream and by each process, with gross electrical energy generated by the process. It also presents the overall energy balance for each process in terms of tonnes of oil equivalent, enabling comparison of the processes and stages for each process on an equivalent basis.

The authors note there was a lack of reliable information on the energy consumed in collecting individual wastes or in preparing the wastes for thermal processing. There was also little reliable information on the performance and efficiency of anaerobic digestion and gasification facilities for waste. It is also acknowledged that the findings in this study are highly dependent on the composition of the waste streams. For all of the wastes included in the study, combustion in dedicated facilities or incineration with the MSW stream was the most energy-advantageous option.

Rada et al (2005)[2] presented some research perspectives on emissions from bio-mechanical treatments of MSW in Europe (a pre-treatment option prior to landfill disposal or combustion). This deals with the problem of assessment of significant data related to emissions to air from bio-mechanical treatments, necessary for LCA, verification of compliance with existing regulations, and environmental impact studies assessment. For bio-mechanical treatments, the latter is still not as developed as options such as incineration. The authors believe the reason for this is that the impact of a bio-mechanical treatment plant is considered low. On the contrary it can be demonstrated that a greater attention must be paid in the case of non optimised technologies and large plants. It concludes the following:

- The high variability in emissions from bio-mechanical treatments should be taken into account for LCA in conjunction with a sensitivity analysis;

[1] Burnley, S J et al (2011) Energy implications of the thermal recovery of biodegradable municipal waste materials in the United Kingdom. Waste Management 31 (9-10),1949-1959

[2] Rada, EC et al (2005) Some research perspectives of emissions from MBT of MSW in Europe Environmental Technology 26 1,297-1,302

- Regulation for bio-mechanical treatment processes varies from country to country; in some cases the list of monitored pollutants appears incomplete and sometimes inadequate when compared to other regulated processes and lack of monitoring methodology detail could lead to collection of non-representative samples;
- Detailed LCA should be used to set emission limit concentrations for bio-mechanical treatments; and
- More work is needed on secondary particulates arising from bio-mechanical treatments, with consideration for example to significant ammonia releases.

A **2009** report produced by the **University of California**[3] for the Bioenergy Producers Association evaluates emissions from thermal conversion technologies processing MSW and biomass and provides emissions data from operational waste conversion plants in five countries, comparing this data with regulatory standards in California, the United States, the European Union and Japan. In its introduction the report states that the environmental implications of these technologies are critically important to their feasibility and that current information suggests they can be operated in a manner that presents no greater threat to human health or the environment than other common industrial processes.

In a study of two operations in northern Illinois, **Eschenroeder and Stackelberg (1999)**[4] found that the potential risks to human health associated with a MSW landfill site and a MSW combustion plant fell within acceptable limits with respect to emissions. However, there was a significant risk to human health from potential exposure to groundwater associated with the MSW landfill that did not exist for the combustor facility - a difference in potential risks that differentiates WtE and landfill operations.

Life Cycle Assessment

El Hanandeh et al (2010)[5] propose a new LCA model for determining the environmental impact and associated costs of MSW management alternatives under conditions of uncertainty, the Stochastic Integrated Waste Management Simulator (SIWMS) model (a non-deterministic model). The model is validated using four other publicly available models and used to estimate emissions from 'best practice' MSW management in metropolitan Sydney. It addresses the typical aspects of downstream MSW management starting from the moment the waste item enters the waste stream to the point of its ultimate disposal, relying on process sub-models to calculate emissions and energy consumption from each waste management operation.

The system boundaries are further expanded by introducing upstream and downstream compensation systems to account for displaced emissions that result from recycling or energy generation. For example, the landfill model considers two types i.e. a traditional and a bio-reactor landfill. The former is further divided into 'engineered lined with gas collection' and 'landfill without gas collection'. The bio-reactor landfill is a highly engineered sanitary landfill designed to enhance biodegradation of biomass, typically achieved by leachate recirculation. The reason for the different categories lies in assessing the biogas production and that recovered for electricity generation.

The purpose of the model is to provide a decision-making tool to assess potential environmental and economic impacts of MSW alternatives under conditions of uncertainty, but does not claim to be as comprehensive as other models, such as WRATE (Waste and Resources Assessment Tool for the Environment) or EASEWASTE (Environmental Assessment of Solid Waste Systems and Technologies). The analysis highlights the importance of considering this uncertainty in relation to global warming potential and greenhouse gas (GHG) emissions.

---

[3] Bioenergy Producers Association (2009) Evaluation of Emissions from Thermal Conversion Technologies processing MSW and Biomass.

[4] Eschenroeder, A. and von Stackelberg, K. (1999) Health Risks of Landfilling versus Combustion of Municipal Solid Waste: An Illinois Comparison. Air & Waste Management Association's 92nd Annual Meeting, St. Louis, Missouri.

[5] El Hanandeh, A et al (2010) Life-cycle assessment of MSW alternatives with consideration of uncertainty: SIWMS development and application. Waste Management (30) 902-911

Another LCA model was used by **Fruergaard et al (2011)**[6] for studying a complicated scenario of two types of MSW, mixed high calorific value suitable for Solid Recovered Fuel (SRF) production and source separated organic waste. For Solid Recovered Fuel (SRF), co-combustion was compared with mass burn incineration and for organic waste AD was compared with mass burn incineration. In both cases of mass burn incineration, with and without energy recovery were considered. All relevant consequences for energy and resource consumptions, emissions to air, water and soil, upstream and downstream processes were included in the LCA model. In summary, the authors suggest *'…. mass burn incineration with efficient energy recovery is a very environmentally competitive solution overall based on Danish conditions.'*

Morselli et al (2005)[7] used a combination of LCA and an integrated environmental monitoring system tool to evaluate the impact associated with MSWI. Whilst LCA was a proven methodology at time of publication, its application to waste management was considered a relatively new field of application. The integrated environmental monitoring system was considered an innovative approach based on the understanding of impact to a contamination source.

The study concludes that the LCA provides a useful approach to gain awareness of the important indicators of impact from the incineration process and information on the sustainability of a process compared to alternative processes. In this study, the authors conclude from the LCA that the environmental impact of many indicators were negative (avoided) due to the energy produced without using non-renewable sources. The integrated environmental monitoring system is used to understand direct impacts, where the analysis is performed on the territory most affected by pollutant fall-out. Heavy metals were the chosen environmental tracers for this study and a dependence upon distance was found, in particular in depositions and for those metals which are not associated with other important contamination processes e.g. lead due to vehicular traffic.

Scale and environmental impact

Rada et al (2009)[8] observed trends in the management of residual MSW (rMSW) and as part of this review considered health and environmental impact. The environmental impact of installations dedicated to the treatment of rMSW is not considered to be proportional to their treatment capacity. A more significant role is played by the qualitative aspects of the rMSW. A combustion plant treating 50,000 tonnes per annum can have an environmental impact similar to that of a combustion plant treating 100,000 tonnes per annum, where the available potential energy within the material in each case significantly differs. The available potential energy within a material is often termed the Lower Heating Value (LHV) when used in reference to thermal processing and combustion systems. In the hypothetical example above, if the LHV of rMSW treated in the 50,000 tonnes per annum facility is twice as much as the LHV material entering 100,000 tonnes per annum facility, this has implications for environmental performance, as thermal power rather than capacity becomes an increasingly significant aspect when comparing the environmental performance of the two facilities.

In summary, whilst the debate regarding authorisation of Waste-to-Energy plants is often concerned with the amount of waste that will be treated, this can cause misunderstanding as it may not take into account different specific flow rates that characterise rMSW when its LHV varies.

---

[6] Fruergaard, T et al (2011) Optimal utilization of waste-to-energy in an LCA perspective. Waste Management 31 572-582

[7] Morselli, L et al (2005) Tools for the evaluation of impact associated with MSW incineration, LCA and integrated environmental monitoring systems Waste Management 25 191-196

[8] Rada, EC et al (2009) Trends in the management of residual municipal solid waste. Environmental Technology 30 (7) 651-661

2.3 Ecotoxicological Impact

Based on the results of a literature search for US studies, it is obvious that there has been very little work done to evaluate both the short and long-term ecological effects specifically associated with operation of a WtE facility. As part of a project that is being conducted to evaluate the need for cleanup of a site where a WtE facility was operated from 1985 through 2000, in Sitka, Alaska, **Exponent (2004)**[9] conducted a human health and ecological risk assessment for the site and surrounding area.

The Exponent risk analysis is significant primarily for the evaluation of the potential effects resulting from historical operation of the facility on ecological receptors, including a neighboring wetland. The report noted that potential risks could not be ruled out with respect to aquatic organisms, benthic invertebrates, terrestrial plants, soil fauna, and terrestrial wildlife. This would suggest that further evaluation of the potential ecological risks needs to be conducted. In general, this is perceived to be a substantial data gap with respect to the existing WtE knowledge base.

2.4 Greenhouse Gases

A key area of concern in the US with respect to WtE facility emissions is their contribution to the accumulation of greenhouse gases. In a study that evaluated potential GHG emissions associated with various MSW management practices, **Weitz et al. (2002)**[10] used a LCA approach to track GHG emissions over time. They reported a substantial reduction in GHG emissions that resulted from improvements in management of MSW, including WtE operations, from 36 million metric tons of carbon equivalents (MMTCE) in 1974 to 8 MMTCE in 1997.

The article noted that there were two important ways that waste combustion and energy recovery contributed to a reduction in GHG emissions - waste is diverted from landfills where there is a continuous release of GHG emissions over time, and the resulting energy replaces electricity generated from fossil-fuel burning facilities that contribute substantially higher GHG emissions.

In **2011** the **European Environment Agency** published a document titled **'Wasted Opportunities: Past and future climate benefits from better municipal waste management in Europe'**[11]. The report claimed improved MSW management in the EU, Norway and Switzerland cut annual net GHG emissions by 48 million tonnes of carbon dioxide equivalent (CO_2e) between 1995 and 2008 due mainly to reduced methane emissions from landfill and increased avoided emission through recycling. If all countries fully met the European Landfill Directive waste diversion targets, potential life-cycle GHG emissions from MSW management in 2020 could be cut by a further 62 million tonnes, 1.23% of their total emissions in 2008. A complete ban on landfilling could cut this even further, reducing potential net emission from waste management in 2020 by 78 million tonnes compared to 2008.

The figures quoted are based on a life-cycle approach, different to that undertaken in the annual EU GHG inventory reports i.e. these reports also consider the effects of waste management on other parts of the economy and includes all processes and activities that are directly or indirectly influenced by waste management measures. Direct emissions are those that originate from waste management activities such as methane from landfills and CO_2 from transport, incineration and recycling plants, avoided emissions are the life-cycle benefits from resource recovery e.g. waste as a secondary material or energy source and replacing the use of virgin material or fuels. Further details of the methodology, assumption, data and scenario building are available from the **European Topic Centre on Sustainable Consumption and Production (ETC/SCP 2011)**.

---

[9] Exponent (2004) Former Municipal Solid Waste Incinerator, Human Health and Ecological Risk Assessment. Prepared for City of Sitka, Sitka, AK.

[10] Weitz, K.A., Thorneloe, S.A., Nishtala, S.R., Yarkosky, S.; Zannes, M. (2002) The Impact of Municipal Solid Waste Management on Greenhouse Gas Emissions in the United States. Journal of the Air & Waste Manage. Assoc. 52: 1000-1011.

[11] European Environment Agency (2011) Waste Opportunities. Past and future climate benefits from better municipal waste management in Europe

Muhle et al (2010)[12] compared carbon emissions associated with MSW management in Germany and the UK. The analysis indicates that the carbon emissions associated with MSW management in the UK are approximately five times higher than that for Germany, 175kg CO_{2e}/tonne and 34kg CO_{2e}/tonne respectively. This difference equates approximately to removing 1.2 million cars from the roads in England and Wales.

The authors acknowledge the data presented is partially based on assumptions and approximations and make specific recommendations on how future studies may be improved. It concludes that the tightened waste acceptance criteria for landfills, increased use of WtE and a recycling policy enabled by a proven source separation system in Germany, were all identified as major reasons for the difference.

Pavlas et al (2009)[13] evaluated the environmental impact of a WtE facility in a case study using a simple methodology focussed on calculating primary energy savings resulting from export of energy, defined as the difference between primary energy consumed in conventional utility systems corresponding to the same amount of energy which is supplied by the WtE facility and primary energy necessary for the operation of the incineration process itself.

The study concludes that thermal treatment of MSW with heat recovery represents one of the most efficient ways of treatment. The energy generated in WtE plants contributes to primary energy savings and consequently to the reduction in GHG emissions.

Finally, **Papageorgiou et al (2009)**[14] assessed the GHG effects of technologies used for energy recovery from MSW for England. Three technologies were assessed, mass burn incineration (MBI) with energy recovery, Mechanical Biological Treatment (MBT) via bio-drying and Mechanical Heat Treatment (MHT); the last two can convert MSW into a Solid Recovered Fuel (SRF) as an energy source for combustion in other industrial processes. The analysis shows that MBT and MHT performance depends strongly on the final use of the SRF and they could produce GHG savings only when there was a market for the fuel. MBI generates GHG savings when it produces electricity and heat, but is a net producer if not. The study includes detailed scenario and sensitivity analysis to test the GHG effects of different outcomes.

2.5 Dioxins and Furans

Dioxins and furans are common names used to describe two groups of complex organic compounds with similar properties:

- Polychlorinated Dibenzo-para-Dioxins (PCDDs); and
- Polychlorinated Dibenzofurans (PCDFs).

The terms dioxins and furans are often used in the generic sense to describe these compounds.

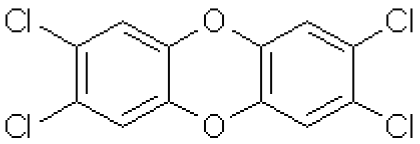
The group of dioxins is made up of a total of 75 PCDDs and 135 PCDFs. Dioxins occur as mixtures in related compounds (congeners) in varying composition. The most toxic form of dioxin is **2,3,7,8-Tetrachlorodibenzodioxin** (2,3,7,8 TCDD), which is sometimes referred to as Seveso poison after the chemical accident which polluted the environment in Seveso, Italy, in July 1976.

The other 2,3,7,8 chlorinated dioxins and furans which have additional chlorine atoms are also pertinent in a toxicological assessment of dioxins. These 17 compounds (7 dioxins, 10 furans) are used to assess toxicity, which is expressed as a toxic equivalent (TEQ) in relation to 2,3,7,8 TCDD.

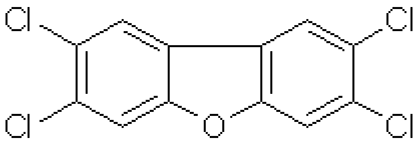
[12] Muhle, S et al (2011) Comparison of carbon emissions associated with municipal solid waste management in Germany and the UK. Resources, Conservation and Recycling 54 (11) 793–801

[13] Pavlas, M et al (2010) Waste to energy – An evaluation of the environmental impact. Applied Thermal Engineering 30 (16) 2326–2332

[14] Papageorgiou, A et al (2010) Assessment of the greenhouse effect impact of technologies used for energy recovery from municipal waste: A case for England. Journal of Environmental Management 90 (10) 2999-3012



2,3,7,8-Tetrachlorodibenzodioxin (2,3,7,8 TCDD)



2,3,7,8-Tetrachlorodibenzofuran (2,3,7,8 TCDF)

PCDDs and PCDFs may form after the furnace from precursor compounds e.g. polychlorinated biphenyls (PCB), polychlorinated diphenylmethanes (PCDM), chlorobenzenes and chlorohydroxybenzenes. The EU waste incineration BAT reference document suggests the following three mechanisms are believed to lead to the formation of dioxin/furan in waste incineration:

- Formation of PCDD/F from chlorinated hydrocarbons already in, or formed in the furnace, (such as chlorohydrobenzene or chlorobenzene);
- De-novo synthesis in the low-temperature range (typically seen in boilers, dry electrostatic precipitators); and
- Incomplete destruction of the PCDD/F supplied with the waste.

Emissions of dioxins and furans from incineration plants have been greatly reduced due to better cleaning of the flue gases and improved incineration performance i.e. correct combustion conditions being maintained.

Psomopoulos et al (2009)[15] reviewed the status and benefits of WtE as applied in US and presented data on dioxin emissions from WtE between 1987 and 2002 i.e. pre and post MACT regulations, demonstrating the 99.9% reduction in air emissions over this period.

Wyrzykowska-Ceradini et al (2011)[16] of the National Risk Management Research Laboratory, US Environmental Protection Agency, investigated concentrations of Polybrominated Dibenzo-para-dioxins and Polybrominated Dibenzofurans (PBDD/F) and PCDD/F in the raw and clean flue gas during steady state and transient operation of a MSW combustor, pre- and post-Air Pollution Control (APC) system flue gas.

Operational transients were found to considerably increase levels of PBDD/F and PCDD/F compared to steady state operation, for both raw and clean flue gas. The profile of PBDD/F and PCDD/F in the raw flue gas (both steady and transient state) was dominated by hexa- and octa-isomers, while the clean gas profile was enriched with tetra- and penta-isomers. The APC system efficiency of removal was estimated at 98.5% for PBDD/F and 98.7% for PCDD/F. Finally, the cumulative TEQ (PCDD/F+PBDD/F) from the stack was dominated by PCDD/F, the TEQ of PBDD/F contributed less than 0.1% to total cumulative toxic equivalency of the stack emissions.

In **2008 AEA technology** (on behalf of the Environment Agency in England and Wales) published a report entitled **'The Investigation of Waste Incinerator Dioxins during start-up and shutdown operating**

[15] Psomopoulos, CS. et al (2009) Waste to Energy: A review of status and benefits in USA. Waste Management, 29 1718-1724

[16] Wyrzykowska-Ceradini, B et al (2011) PBDDs/Fs and PCDDs/Fs in the raw and clean flue gas during steady state and transient operation of a municipal waste combustor. Environ Sci Technol Jul 1;45(13) 5853-60

phases'[17]**.** The study found elevated emissions during shutdown and start-up relating to the waste was not being fully established on the grate. Increases in emission concentration and rate were reported as less than one order of magnitude when compared to normal operations. The report also found that the mass of dioxins emitted during these stages as part of a four day planned outage was similar to the emissions which would have occurred during normal operation in the same period.

Department for Environment, Food and Rural Affairs (DEFRA) (UK, 2004) published its **'Review of Environmental and Health Effects of Waste Management: MSW and Similar Wastes'**[18]. The report represents an extensive piece of work peer reviewed by **the Royal Society** (included as an annexe to the report). It examined the waste management options for treating MSW and similar waste and focussed on the principal types of facilities used for dealing with such waste in the UK and in Europe and on available scientific evidence on environmental and health effects. On the subject of abnormal operating conditions and associated emission fluctuations, it states the following:

'Any emission above prescribed limits is of concern, and it is important that these incidents are investigated and their recurrence prevented. However, the low frequency of these incidents and the lack of any consistent evidence for health effects in people living near Waste-to-Energy facilities (see Chapter 3) suggest that emissions above consented limits are not a significant issue for waste incinerators. Also, an exceedance over a short period is not likely to have a significant effect on emissions averaged over a long period such as a year. Exceedances may be more likely to occur from facilities which are undergoing commissioning, and particular attention should be paid to regulation of facilities in these circumstances.'

2.6 Other Emissions to Air

Previous sections have focussed on some of the key emissions arising from waste-to-energy plants such as particulate matter and dioxins/furans. Other potential pollutants found in emissions to air are toxic elements such as mercury. Levels of mercury released to atmosphere in waste-to-energy plant emissions, like dioxins/furans, have decreased over recent years, due in part to greater control over segregating mercury containing items from MSW, greater regulatory control and improved abatement systems for plant emissions. In their 2009 paper **Waste-to-energy:A review of the status and benefits in USA**[15], Psomopoulos et al support this by suggesting the implementation of the MACT regulations decreased mercury emissions from waste-to-energy plants from 81 tonnes of mercury in 1989 to less than 1.2 tonnes per year by 2009, with the major sources of mercury in the atmosphere attributed to coal-fired power plants.

Whilst modern well managed waste-to-energy plants implement control systems to ensure the release of mercury is minimised and kept within the emission limit values specified in the relevant regulations and associated environmental permits, similar to the dioxin/furan exceedance discussion in the previous section, mercury levels in emissions may also fluctuate during periods of abnormal operating conditions e.g. bag house failure.

2.7 Process Residues

It is proven that modern compliant and well run MSWI now emit significantly less pollutants in stack gases compared to older plants previously operated under less stringent regulatory regimes. For non-gaseous emissions i.e. process solids such as IBA and APC residues, there is an increasing interest in studying the potential long term environmental impacts based predominantly on leaching of pollutants from either landfill sites used for final disposal or from products used in the construction sector e.g. road applications.

Incinerator Bottom Ash

In **2003 AEA Technology** carried out a study entitled '**Environmental and Health Risks Associated with the Use of Processed Incinerator Bottom Ash in Road Construction'**[19]**.** The commission was part funded by

[17] Investigation of Waste Incinerator Dioxins During start-up and shutdown operating phases, AEA Technology 2008

[18] UK DEFRA (2004) Review of Environmental and Health Effects of Waste Management: Municipal Solid Waste and Similar Wastes.DEFRA Publications.

[19] Environmental and health risks associated with the use of processed IBA in road construction, EA Technology 2003

the Sita Environmental Trust and London Waste under the terms of the Landfill Tax Credit Scheme, including input from the Environmental Services Association. The scope of the study was limited to consideration of the risk which might arise from the use of processed IBA in asphalt or cement-bound material in the road base (the study excluded the use of IBA in unbound applications or in the surface course of the road). In the case of the bound applications, the leaching potential is greatly reduced, seen as a key environmental advantage as the most significant ecosystem exposure route during the existence of the road was considered likely to be through leaching of metals into local surface waters.

The report also makes the following key findings in relation to dioxin content:

'*A major area of public concern appears to be the dioxin content of IBA and the likely effects of exposure resulting from this. The concentration of dioxins present, in the IBA samples for which information is available, fall within the range of rural and urban soils. As such the risks arising from the dioxins present in the IBA will be no different to those risks arising from natural materials and are likely to be very low.*'

The executive summary concludes:

'*The future use of unmixed municipal waste incinerator bottom ash to dilute or replace primary aggregates will offer benefits in improving the sustainable use of waste materials and reducing primary aggregate demand. If used in an appropriate manner the risks to human health and the environment from municipal waste incinerator bottom ash use in road construction in hard water areas are likely to be minimal and certainly undetectable in a typical UK situation.*'

It is interesting to compare this to the difficulties in meeting leaching limit values applied in Denmark. **Astrup (2007)**[20] noted that whilst researchers had investigated processes such as those related to carbonation, weathering, metal complexation, and leaching control, most had a strong emphasis on lab experiments with little focus on full-scale IBA upgrading methods. The introduction of regulatory limit values restricting leaching from utilised IBA created a need for a better understanding of how lab-scale experiences could be utilised in full-scale IBA upgrading facilities, and the possibilities for complying with the regulatory limit values.

A collection of **Danish research and development projects from 1997 to 2005** investigated important techniques for IBA upgrading. The primary focus was on curing/aging, washing with and without additives, organic matter, sampling techniques, utilisation options, and assessment tools. The **2007 paper** provides an overview of these projects and found that no single process ensured compliance with Danish limit values on leaching, however extended curing along with washing could, in most cases, decrease leaching significantly.

Astrup et al (2011)[21] studied the stability of performance of modern incinerators in relation to changes in waste input and furnace operation and subsequent impact on emissions. The study investigated how inorganic air emissions and residue composition at an incinerator were affected by known additions of specific waste materials to the normal MSW input. Six individual experiments were carried out (% ww of total waste input): sodium chloride (0.5%), shoes (1.6%), automobile shredder waste (14%), batteries (0.5%), poly vinyl chloride (5.5%) and chromate-copper-arsenate impregnated wood (11%). Materials were selected based on chemical composition and potential for being included or excluded from the waste mix. Critical elements in the waste materials were identified based on comparison with six experiments including 'as-large-as-possible' changes in furnace operation (oxygen levels, air supply and burnout level) only using normal MSW as input.

The experiments showed that effects from the added waste materials were significant in relation to: air emissions (in particular arsenic, cadmium, chromium, mercury and antimony), element transfer coefficients, and sulphur residue composition (arsenic, cadmium, chloride, chromium, copper, mercury, molybdenum, nickel,

[20] Astrup, T (2007) Pretreatment and utilisation of waste incineration bottom ashes: Danish Experiences Waste Management 27 1452-1457

[21] Astrup, T et al (2011) Incinerator performance: effects of changes in waste input and furnace operation on air emissions and residues. Waste Management and Research 29 57-68

lead, antimony and zinc). Changes in furnace operation could not be directly linked to changes in emissions and residues. The results outlined important elements in waste which should be addressed in relation to waste incinerator performance. Likely ranges of element transfer coefficients were provided as the basis for sensitivity analysis of LCA results involving waste incinerator technologies.

Triffault-Bouchet et al (2005)[22] undertook an ecological assessment of pollutant flux released from IBA reused in road construction to test the impact on lentic ecosystems. It applied a methodology to determine the ecocompatibility of this reuse option using a laboratory lysimteter (instrument for measuring water percolating through soil or other media) to simulate a road embankment and from this produced IBA leachate. The results from the associated bioassay test demonstrated all three species tested were impaired, with toxicity effects increasing with leachate concentration from 1.56% to 8%. The predicted environmental concentration is close to the concentration that caused first effects in microcosms. The leachate toxicity was due mainly to the presence of copper. The authors make the following recommendations:

- IBA could be weathered for several weeks before being used in road construction to stabilise most of the pollutants;
- The road embankment could be covered be protected by a plant cover;
- Leachate from the road embankment could be collected in a basin; and
- Leachate could be partly treated before discharged into aquatic ecosystems at a flow rate which would keep pollutant concentrations at non-hazardous levels.

In **July 2012 WRc (Water Research Centre, UK)**[23] produced an assessment of hazard classification of UK IBA based on the January to June 2011 dataset. This project was conducted under the remit of a collaborative agreement in the UK between the Environmental Services Association and DEFRA's Waste and Resources Evidence Programme to deliver a programme of research and development, seeking to present the scientific evidence required to inform the regulatory framework governing the reuse and management of processed IBA. It found that IBA produced by the facilities in the sample population did not exceed thresholds for any of the 15 hazard properties during the first six months of implementation of the sampling protocol.

Air Pollution Control Residues

The **British Society for Ecological Medicine (BSEM)** issued the **4th report (2008)** titled **'The Health Effects of Waste Incinerators'**[24]. The authors have concerns relating to leaching of ash pollutants from landfill sites, the reuse of IBA in construction products and moreover, question the inert waste status classification given to IBA. The authors state modern abatement equipment delivering improvements to gaseous emissions merely transfer the toxic load from gaseous emissions to process residues.

It is correct that the residues of abatement processes contain toxic pollutants, for this reason Air Pollution Control (APC) residues for example are treated as hazardous waste, in accordance with the regulatory framework applicable to the jurisdiction of origin. The treatment and subsequent disposal or reuse of these residues should be regulated to prevent release of any polluting species to the environment. For example, in the EU, most APC residues will not meet the waste acceptance criteria for landfill disposal in hazardous waste cells without pre-treatment to reduce the leaching potential of certain polluting species.

---

[22] Triffault-Bouchet, G et al (2005) Ecotoxicological assessment of pollutant flux released from bottom ash reused in road construction. Aquatic Ecosystem Health & Management 8 (4) 405-414

[23] Water Research Centre (2012) Assessment of Hazardous Classification of IBA

[24] British Society of Ecological Medicine (2008) 2nd Edition The Health Effects of Waste Incinerators

Fruergaard et al (2010)[25] evaluated seven different management options for APC residues by LCA using the EASEWASTE model. The assessment addressed treatment and final placement of one tonne of APC residue in seven scenarios as follows:

- Direct landfilling without treatment (baseline);
- Backfilling in salt mines;
- Neutralization of waste acid;
- Filler material in asphalt;
- Ferrox stabilisation;
- Vitrification; and
- Melting with automobile shredder residues.

Scenarios were evaluated with respect to both non-toxicity impact categories e.g. global warming, and toxicity impact categories e.g. ecotoxicity and human toxicity. Results from the LCA were discussed with respect to importance of energy consumption/substitution, material substitution, leaching, air emissions, time horizon aspects for the assessment, and transportation distances. The LCA modelling showed that thermal processes were associated with the highest loads in the non-toxicity categories (energy consumption), while differences between the remaining alternatives were small and generally considered insignificant. In the toxicity categories, all treatment/utilisation options were significantly better than direct landfilling without treatment (lower leaching), although the thermal processes had somewhat higher impacts than the others options (air emissions).

[25] Fruergaard, T et al (2010) Life-cycle assessment of selected management options for APC residues from waste incineration Science of the Total Environment 408 4672-4680

3 Health Impact

3.1 Introduction

This section presents a summary of literature concerned with the health impacts of MSW management in relation to MSWI and alternative treatment options. For thermal treatment of MSW, the review necessarily focuses on incineration due to the balance of literature and research available when compared to other ATT technologies.

This review includes studies aimed at predicting future impacts based on complex modelling scenarios using a variety of methodologies to investigate whether statistically significant associations exist between health impacts and outputs from MSWI or alternative MSW treatment options e.g. landfill operations.

3.2 Health Risk Assessment Process

The **DEFRA (2004)** report focussed on the understanding of emissions from operations involving MSW and of the health impacts of managing this waste. The report refers to the source-pathway-receptor model for risk assessment to assess the health and environmental risks of waste management activities or facilities and indicates whether there is empirical evidence for theoretical health and environmental risks being realised in practice.

The document reviewed scientific literature and other published information on emissions from MSW management and its health and environmental effects. This included papers published in peer-reviewed literature, research carried out by governmental and non-governmental organisations and information from the operators of waste management processes.

On the subject of critical appraisal and risk assessment, the DEFRA report states the following:

'*There are a limited number of epidemiological studies on populations around incinerators and the results of these are typically inconsistent and inconclusive. Based on current epidemiological evidence it is difficult to establish causality, particularly once confounding factors such as socio-economic variables, exposure to other emissions, population variables and spatial/temporal issues are taken into account. In reality, most data on the possible health effects of incinerator emissions are derived from risk assessments, which are routinely used to evaluate the potential for both direct and indirect carcinogenic and non-carcinogenic risks from proposed installations.*'

The **BSEM 4th report (2008)** concludes the following in relation to assessing the health impact of MSWI:

'*Typically this decision is based on an inexact method called risk assessment. They tend to rely almost exclusively on this type of assessment and often have little understanding of its limitations. Risk assessment is a method developed for engineering but is very poor for assessing the complexities of human health. Typically it involves estimating the risk to health of just 20 out of the hundreds of different pollutants emitted by incinerators.*'

The limitations of some risk assessment models are widely acknowledged and usually openly specified within academic studies.

Demidova et al (2005)[26] propose a model for embedding Risk Assessment (RA) into Environmental Impact Assessments (EIAs) as there was, at the time of writing, virtually no universally agreed methodological and procedural framework for this process. The paper evaluates Environmental Impact Statements (EISs) for seven UK waste incinerators and concludes systematic use of RA in accordance with best practice was not

[26] Demidova, O et al (2005) Risk assessment for improved treatment of health considerations in EIA Environmental Impact Assessment Review 25 411-429

observed. They also observed particular omissions including identifying receptors of health impacts (affected population), interpreting health impacts and health risks, dealing with uncertainties and risk communications. Only two of seven dealt with human health impact separately from environmental impact. In only three cases public health hazards associated with stack emissions were attempted to be interpreted as health risks. Others used impact prediction by comparing estimated ground level concentrations of indicator chemicals against the recommended air quality standards, air quality guidelines or baseline air quality parameters.

Roberts et al (2006)[27] presented a quantitative method to allow comparison of waste incineration with other health risks. This was based on a health impact assessment element of a planning application for an incinerator designed to annually treat 52,500 tonnes of RDF to generate electricity and focussed on those health aspects of greatest public concern i.e. particularly emissions of carcinogens and fine particles. The authors used a prospective health assessment utilising U.S. Environmental Protection Agency (USEPA) methods for hazardous waste combustion facilities and UK coefficients for the impacts of sulphur dioxide (SO_2) and particulates.

The authors acknowledge incineration is associated with considerable public concern which may have a significant harmful effect on the mental, physical and emotional health of local residents, regardless of whether emissions have any direct effect on health, therefore anxiety was considered as a potential effect. Employment, noise, road traffic accidents, occupational risks and reduced use of landfill were also considered as potential effects.

The report finds stack emissions over 25 years in a population of 25,389 within 5.5km distance of the stack would result in an additional 0.018 cancers, 0.46 deaths brought forward due to SO_2 and 0.02 deaths due to fine particles, with the overall risk of dying due to emissions in any one year being 1 in 4 million. The authors suggest the only way to develop a better understanding about the significance of these risks is through comparing them with other exposures to risks with which we are more familiar. The authors acknowledge limitations within the study to include the understanding of the health impact of environmental pollution and methods and assumptions used, as these were utilised for the purpose of illustration and not to provide epidemiological projections.

3.3 Thermal Treatment of MSW

This section reviews literature comparing the potential health impacts of MSWI with other waste management options for MSW.

The **DEFRA 2004** report estimated emissions from waste management operations, as a quantity of each substance emitted per tonne of waste processed. Using this information, it estimated the quantities emitted by an individual facility and derived a national total for these emissions, enabling consideration of the relative performance of different kinds of waste processing and disposal operations, and the potential environmental and health effects of MSW management compared to other activities. It highlighted areas where MSW management operations may give rise to health effects and areas where no health effects have been found, quantifying the significance of some of these effects. It also highlighted where further research could usefully be carried out to improve understanding of the relationship between waste processing and adverse environmental and health effects. In its conclusions, it summarises the findings on health impact as follows:

'*We looked at evidence for ill-health in people who might possibly be affected by emissions from MSW processes. For most of the MSW facilities studied, we found that health effects in people living near waste management facilities were either generally not apparent, or the evidence was not consistent or convincing. However, a few aspects of waste management have been linked to health effects in local people. We would need more research to know whether or not these are real effects. We also investigated the health effects of*

[27] Roberts, RJ et al (2006) Waste incineration - how big is the health risk? A quantitative method to allow comparison with other health risks. Journal Public Health, 28 (3) 261-266

emissions of some important airborne pollutants from waste management facilities. Although the data was of moderate or poor quality, we found that these emissions are not likely to give rise to significant increases in adverse health effects.'

For a comparison of incineration and landfill in relation to dioxin emissions, **Bridges et al (2000)**[28] evaluated airborne risks to human health from both on a generic basis. The study assessed relative risk based on airborne emission concentrations and maximum ground level concentrations at an 800m distance from the waste facility. Worst case emission profile values were used as no average performance value data were available. The authors acknowledge the generic nature of this assessment, however they conclude that specifically for dioxins the landfill without gas collection scenario poses potentially a higher generic risk than MSWI performing to UK standards (supported by some US site specific assessments). Whilst the consideration of potential health impacts relating to dioxins is given priority by the authors, it should also be noted that the consideration of environmental impact is of equal relevance with respect to this study i.e. in comparing emissions from landfill with those from incineration.

Moy et al (2008)[29] used published data and exposure modelling to perform health risk assessments for landfill disposal versus WtE treatment options for the management of New York City's MSW. The assessment includes the use of a Waste Transfer Station in Brooklyn. The overall results indicate the cancer risks for both options were generally acceptable however the risk from the landfill scenario was five times greater than that of WtE. The individual non-cancer health risks from both would be considered generally acceptable and once again, the risk from the landfill scenario was five times greater than the WtE scenario.

The authors suggest these results should be considered preliminary due to several acknowledged limitations of the study e.g. only inhalation exposure considered, assumes only volume and not composition of the waste stream is altered by WtE treatment, reliance on data from literature rather than actual measurements of the sites considered and assuming comparability of the sites. Nevertheless, despite the uncertainties and assumptions, the results are considered to be reasonable based on comparison to other literature studies.

Saffron et al (2003)[30] reviewed literature and evaluated evidence on the human impact of waste management practices, to include landfill, incineration, composting, land spreading, sewage sludge and sewer discharges. A protocol was applied to evaluate the strength and reliability of evidence using an algorithm with defined criteria. Key questions applied in this evaluation process were as follows:

- Have studies been done on human populations?
- Have hazards been identified? Does the appearance of the hazard precede the health outcome? Is the association biologically plausible?
- Are there any hypothesis-testing studies?
- Have any of the hypothesis-testing studies controlled for possible confounding factors?
- Are there more than 20 hypothesis-testing studies consistently showing strong or moderate relative risks?

The review found that the evidence linking any adverse health outcomes with incineration, landfill or land spreading sewage sludge was insufficient to claim causal association. The evidence is insufficient to link residence near a centralised composting facility with adverse health outcomes but it is possible that working at such a facility causes adverse health outcomes.

[28] Bridges, O et al (2000) A generic comparison of the airborne risks to human health from landfill and incineration of MSW Environmentalist 20 (4) 325-334

[29] Moy, P et al (2008) Options for management of municipal solid waste in New York City: A preliminary comparison of health risks and policy implications. Journal of Environmental Management 87 73-79

[30] Saffron, L et al (2003) Human health impact of WM practices: A review of literature and an evaluation of the evidence, Management of Environmental Quality 14 (2) 191-231

Cocarta et al (2009)[31] reviewed the health risk associated with three different MSW treatment strategies i.e. incineration with BAT, anaerobic/aerobic treatment and an aerobic treatment prior to landfill. The study presented a dioxin health risk assessment for each process; the authors note that related works focussed on MSW WtE plants but missed the importance of considering the human health risks from other MSW processes such as bio-drying, particularly in relation to dioxins. The authors refer to the paper by **Rada et al (2005)** where emission values from a pilot scale bio-dryer were comparable to that of a modern incinerator.

The three processes selected were as follows:

- Incineration;
- MBT; and
- Aerobic digestion with biostabilisation, followed by biofilters or regenerative thermal oxidation.

The authors conclude that the results from the modelling presented in the paper demonstrate that process type should not be the key factor in determining the acceptability of a plant; it in fact should be consideration of real local human health risk taking into account local context. Height of gas release, gas velocity and temperature are key factors where a population is close to the plant or agricultural activity. It suggests a modern incinerator with BAT could have a lower impact than MBT without BAT for pollutants such as dioxins.

On the theme of improved emissions control with new or updated incinerators and in compliance with EU legislation, **Glorennec et al (2005)**[32] studied the risks associated with emissions from the Angers MSW incinerator in France based its performance before and after it was upgraded in 2000. The incinerator is located in the suburbs of a metropolitan area, close to a market garden zone therefore its emission could in theory have led to significant exposure ingestion. The study encompassed an array of pollutants, measured both before and after plant upgrade and both inhalation (for normal and unfavourable dispersion conditions) and ingestion routes were considered.

It highlights two areas of potential concern i.e. SO_2 inhalation during episodes of little atmospheric dispersion and the ingestion of local products, whilst acknowledging and discussing uncertainties and variability within the results. It concludes that compliance with current emission standards substantially reduced both emission and exposures and has vastly reduced the probability of health effects.

3.4 Epidemiological Studies

In the US, there have been very few epidemiological studies conducted that focus specifically on potential health risks associated with WtE facilities. Much of the relevant work that has been done was completed in the late 1980s to early 1990s, which represents the period that saw the most significant development of WtE facilities across the country. A **2000** publication titled, **Waste Incineration & Public Health**[33], a US-government sponsored public-private study of health effects associated with waste incineration in the US and internationally, included the following key findings:

'*Few epidemiologic studies have attempted to assess whether adverse health effects have actually occurred near individual incinerators, and most of them have been unable to detect any effects. The studies of which the committee is aware that did report finding health effects had shortcomings and failed to provide convincing evidence. That result is not surprising given the small populations typically available for study and the fact that such effects, if any, might occur only infrequently or take many years to appear. Also, factors such as emissions from other pollution sources and variations in human activity patterns often decrease the likelihood of*

---

[31] Cocarta, DM et al (2009) A contribution for a correct vision of health impact from municipal solid waste treatments. Environmental Technology 30 (9) 963-968

[32] Glorennec, P et al (2005) Public health benefits of compliance with current EU emissions standards for municipal waste incinerators: A health risk assessment with the CalTox multimedia exposure model. Environment International 31 693-701

[33] Committee on Health Effects of Waste Incineration; Board on Environmental Studies and Toxicology; Commission on Life Sciences; National Research Council (2000) Waste Incineration & Public Health, National Academies Press, Washington DC, 312 pp.

determining a relationship between small contributions of pollutants from incinerators and observed health effects. Lack of evidence of such relationships might mean that adverse health effects did not occur, but it could also mean that such relationships might not be detectable using available methods and data sources.'

And,

'*Studies of workers at municipal solid-waste incinerators show that workers are at much higher risk for adverse health effects than individual residents in the surrounding area. In the past, incinerator workers have been exposed to high concentrations of dioxins and toxic metals, particularly lead, cadmium, and mercury.*'

The authors also concluded that, based on the available studies, waste incineration facilities are not likely to be major contributors to local ambient concentrations of PM, carbon monoxide (CO), nitrogen and sulfur oxides, metals, dioxins, furans, and polycyclic aromatic hydrocarbons (PAHs), which are all attributed to emissions from WtE operations, but are also present in ambient air from many other sources including industrial operations, power plants and vehicular traffic, among others.

Giusti (2009)[34] suggests epidemiological studies dealing with the impact of waste management activities on human health are usually observational rather than experimental, due to ethical reasons. For observational studies, the most common types are listed as follows:

- Prospective cohort studies: Two cohorts of people, exposed and non-exposed, are assessed over a long period of time during which the degree of exposure of the population and the rate of development of disease is recorded, in addition to other information collected via questionnaires. These studies normally involve the collection of human fluid or tissue and to control possible confounding factors and ensure statistical significance, a large population is enrolled;
- Retrospective case controlled studies: A case group of people with a developed disease and a control group of healthy people are interviewed and past exposure investigated. Involves smaller groups but this type is more prone to bias; and
- Cross sectional studies: Conducted on a specific exposed sub-group of the population over a relatively short period of time. This can be useful to generate hypotheses that can be tested later in more comprehensive studies. It can be difficult to distinguish whether a particular illness developed before or after exposure the group was exposed.

'*In most cases, environmental epidemiologists need to investigate the occurrence of clinical effects in a population that may have been affected by emissions slightly above natural background levels…becomes particularly difficult where [waste facilities] are state of the art, built with best available technology and are operated according to guidelines and in full compliance with legislation.*'

The study concludes that existing epidemiological evidence linking waste management and human health is quite controversial; most studies are based on old types of waste facilities, especially in the case of incinerators. There is very little data on direct human exposure and most studies resort to surrogates such as residence information; most recent studies include data on potential exposure pathways. It also concludes that the overwhelming majority of epidemiological studies have not managed to prove convincingly and unequivocally that excess risk of contracting specific illnesses is associated with waste facilities.

'*The level of significance of risk to develop cancers or other illnesses from emissions from waste facilities should be seen in the overall context of other risks to the local population…*

It is extremely important to have direct human exposure biomarkers, possibly collected before (not only during and after) a waste facility becomes operational.'

[34] Giusti, L et al (2009) A review of waste management practices and their impact on human health, Waste Management 29 2227-2239

The **Institute for Environment and Health** (IEH, established by the Medical Research Council in the UK), published a report in **1997 'Health effects of waste combustion products'**[35], partly funded by the UK Department of the Environment, the Department of Health and other government departments. It aimed to provide information and guidance on the environmental costs and benefits of the technology to developers, local authorities and others involved in WtE projects. It also reviewed and assessed the evidence for adverse health effects in epidemiological studies of incinerator workers and individuals living near incinerators. It acknowledged the uncertainties surrounding some of these issues and made recommendations for further studies on exposure and health effects.

The ten selected pollutants comprise five metals: cadmium, mercury, chromium, arsenic and nickel; three groups of organic compounds: dioxins (PCDD/Fs), PCBs and PAHs; SO_2; and fine PM (PM10). Literature searches provided the most up-to-date information about the health effects of these pollutants, especially at low levels of exposure (where available) and these datasets were then reviewed.

The report stated that most of the health data in the published literature related to occupational or accidental exposure, and generally therefore to higher levels of exposure than those expected from waste incineration. At the time of writing there were few published studies on low level exposure, and very few on the effects of exposure to mixtures of chemicals. Most studies concern exposure to a single chemical or a single group of chemicals (e.g. PCDD/Fs, PCBs and PAHs). Also, the health effects reported were not specific to incinerator emissions; they were the health effects of the individual chemicals, regardless of exposure source, as reported in the literature. The executive summary contains the following conclusion:

'*Generally, however, data on the effects of low-level exposure to these pollutants, either singly or in combination, is lacking. Moreover, all the pollutants considered are already present in the environment and it is difficult to assess what effect, if any, a small additional exposure resulting from incinerator emissions may have.*'

The report further concludes:

'*No consistent pattern of ill-health has emerged from studies of incinerator workers or populations living near incinerators. Any future epidemiological studies investigating the health effects associated with living near incinerators should be designed so that small increases in risk can be detected, and should also adequately account for the various confounding or modifying factors.*'

The findings of this report were used as a base of information for a leaflet produced by **IEH in 2000** that concluded no studies to date have found significantly more disease, compared with the general population, in either incinerator workers or people living near incinerators. It concludes two possible interpretations for this may be there really are no effects on these populations, or the studies have not been sensitive enough to identify any effects which are present.

Hu et al (2001)[36] studied the health effects of waste incineration based upon a literature review of previously published work on health effects for incinerator workers and residents of communities near incinerators. The key areas of potential impact and summary findings were as follows:

Community Residents

- Reproductive health (conflicting results);
- Cancer risk (inconsistent findings);
- Respiratory health (not significantly related to living near an incinerator); and

[35] Health Effects of Waste Combustion Products (1997) Page Bros, Norwich ISBN 1 899110 09 7

[36] Hu, S W et al (2001) Health Effects of Waste Incineration: A Review of Epidemiologic Studies Journal of the Air & Waste Management Association 51 1100-1109

- Body levels of heavy metals (one study found significant but small increase in body mercury levels with decreased distance from the incinerator over a ten year period).

Incinerator Workers

- Mortality (excessive deaths from ischemic heart disease, lung cancer mortality showed conflicting results, significantly excessive deaths from gastric cancer in one study and a non-significant increase in oesophageal cancer in another;
- Urinary mutagens and promutagens (higher frequency of urinary mutagens and promutagens);
- Lung and renal function (no evidence of adverse effect on lung function); and
- Body level of chemicals (increased blood levels of certain organic compounds and some heavy metals).

In conclusion, these epidemiologic studies consistently observed higher body levels of some organic chemicals and heavy metals, and no effects on respiratory symptoms or pulmonary function. The findings for cancer and reproductive outcomes were inconsistent. More hypothesis-testing epidemiologic studies are needed to investigate the potential health effects of waste incineration on incinerator workers and community residents.

Porta et al (2009)[37] undertook a systematic review of epidemiological studies on health effects associated with management of solid waste, mainly landfill and incineration. They examined published, peer-reviewed literature on the subject from 1983 to 2008 and for each paper examined the study design and assessed potential biases in effect estimates, resulting in an evaluation of evidence and grading of associated uncertainties.

In most cases the overall evidence was inadequate to establish a relationship between a specific waste process and health effects; the evidence for occupational studies was not sufficient to make an overall assessment. For community studies, for some processes there was limited evidence of a causal relationship and some were selected for quantitative evaluation. For populations living within 3 km of old incinerators there was limited evidence of an increased risk of cancer (estimated at 3.5%). The confidence in the evaluation and in the estimated excess risk tended to be higher for specific cancers e.g. non-Hodgkins lymphoma and soft tissue sarcoma, than others.

The study concludes that poor exposure assessment, ecological level of analysis and lack of information on relevant confounders contribute many limitations in the papers reviewed. With a moderate level of confidence however, they derive some effect estimates that could be used for health impact assessment of old landfill and incinerators, whilst reaffirming the importance careful consideration when using these numbers for estimating health effects.

Franchini et al (2004)[38] evaluated the epidemiological literature on health effects in relation to incineration facilities and found several adverse health effects were reported. The majority of these studies concern old plants often in association with other sources of pollution. Significant exposure-disease associations were reported by two thirds of the papers focusing on cancer (lung and larynx cancer, non-Hodgkin's lymphoma). Positive associations were found for congenital malformations and residence near incinerators. Exposure to PCBs and heavy metals were associated with several health outcomes and in particular with reduction of thyroid hormones. Findings on non-carcinogen pathologies were considered inconclusive. It is acknowledged that effects of biases and confounding factors must be considered in the explanation of findings. Methodological problems and insufficient exposure information generated difficulties on study results.

[37] Porta, D et al (2009) Systematic review of epidemiological studies on health effects associated with management of solid waste. Environmental Health 8:60

[38] Franchini, M et al (2004) Health effects of exposure to waste incinerator emissions: a review of epidemiological studies. Ann Ist Super Sanità 40(1) 101-115

In **2008** the **Italian Association of Epidemiology (AIE)**[39] produced a position document assessing the potential impact of waste processing and health. The stated objectives of AIE in preparing this document are to support the decision makers on the safety of the existing waste treatment/disposal plants and of the planned new plants, to recommend protective actions in favour of populations exposed to toxic agents linked to illegal waste treatment/disposal and to signal circumstances that require the adoption of surveillance plan or ad hoc studies in order to unveil possible health effects associated to the environmental exposure to toxic agents derived from waste treatment/disposal. The evaluations presented are based on the available scientific literature. The document concludes the following:

'……the few available epidemiological surveys have assessed that waste management by incineration in new generation plants built with BAT do not increase the risk to human health. This conclusion is supported mostly by the extremely low concentrations of toxic substances in the emissions of the new incinerators. However, a realistic measurement of the volumes of toxic substances released by the chimneys in the environment is a critical factor in judging safety of new plants, which needs the conduction of accurately planned observations. In large installations, the low concentrations of toxic substances in the emissions may be overcome, at least in theory, by the high quantities in volume of emissions in unit of time. Indeed, this type of plant may interfere with policies of waste recycling in the surrounding areas, because large moving-grate plants need large volumes of waste and low caloric index fuel for a perfect control of combustion temperatures. Other technologies (fluid bed, gasification), activated in smaller installations, are more suitable for a waste cycle that considers also recycle and re-use.'

3.5 Particulate Matter

PM arises from a variety of sources including traffic emissions, agricultural, domestic and industrial processes including MSWI. It is commonly categorised by size, summarised as follows:

- PM10 - airborne particulate matter passing a sampling inlet with a 50 per cent efficiency cut-off at 10 µm aerodynamic diameter and which transmits particles below this size.
- PM2.5 - airborne particulate matter passing a sampling inlet with a 50 per cent efficiency cut-off at 2.5 µm aerodynamic diameter and which transmits particles below this size; and
- PM0.1 - particles smaller than 100 nm in diameter (often referred to as ultrafine particles).

In the UK, **AEA Technology** prepared a report for the Environmental Services Association (**2012**) titled **'Review of research into health effects of Waste-to-Energy facilities'**[40]. In a section on process emissions, the authors provide a quantitative context for assessing the impact of PM by referring to the **DEFRA National Atmospheric Emissions Inventory 2009** data where it provides the following source contribution for UK emissions of fine particles (PM2.5):

- MSWI 0.042%;
- Road traffic 29%;
- Residential combustion 14%; and
- Electricity generation 5.5%.

The authors discuss the relevance of nano- or ultrafine particles (PM0.1) in relation to concerns with regard to their effects on health and suggest it is plausible that risks to health associated with PM are more closely linked with numbers of particles rather than mass of particles.

---

[39] Waste processing and health. A position document of the Italian Association of Epidemiology (AIE) Ann Ist Super Sanità (2008) 44 No.3 301-306

[40] Environmental Services Association (2012) Review of health effects of EfW facilities

The 10th International Congress on Combustion Byproducts and their Health Effects was held in Ischia, Italy **2007**. The summary of the congress by **Dellinger et al**[41] focussed on the following:

- Origin, characterisation and health impacts of combustion generated fine and ultrafine particles;
- Emissions of mercury and dioxins; and
- Development/application of novel analytical/diagnostic tools.

It should be noted this document considers combustion per se i.e. not just MSWI.

Consensus of the discussion concluded that particle associated organics, metals and Persistent Free Radicals (PFRs) produced by combustion sources are the likely source of observed health impacts of airborne PM rather simple physical irritation caused by the particles. Some of the key conclusions are as follows:

- Exposure to airborne fine particles is associated increased risk of cardiopulmonary disease and cancer;
- In urban settings, 70% of airborne fine particles result from combustion emissions and 50% due to primary emissions from combustion sources;
- In addition to soot, combustion produces one, maybe two classes of nanoparticles with mean diameters of approximately 10 nm and 1 nm;
- Most common metrics used to describe particle toxicity (surface area, sulphate concentration, total and organic carbon) cannot fully explain the observed health impacts;
- Metals contained in combustion generated ultrafine and fine particles mediate formation of toxic air pollutants such as PCDD/F and PFRs; and
- The combination of metal-containing nanoparticles, organic carbon compounds and PFRs can lead to a cycle of generating oxidative stress in exposed organisms.

Buonanno et al (2009)[42] studied the size distribution and number concentration of particles in the stack of a MSW incinerator, noting that fine and ultrafine particle stack emissions were not fully characterised at that time. They found the mass concentrations obtained were well below the imposed daily threshold value for both incineration lines tested (0.2mg/Nm^3 dry) and the mass size distribution was on average very stable. The total number of concentrations was between 1 x 10^5 and 2 x 10^5 particles/cm^3 and on average relatively stable from one test to another. The authors observed that particle size PM2.5 is made up of 99% sub-micron particles and 65% (on average) of ultrafine particles and that these are insignificant in terms of mass since they represent less than 5% of the total mass of PM2.5.

The measured values and the comparison with other point sources showed a very low total number concentration of particles at the stack gas, revealing the importance of the flue gas treatment also for ultrafine particles. Also in respect to linear sources (high and light duty vehicles), the comparison showed a negligible emission in terms of the total number of particles. The comparison tended to roughly estimate only equivalence for the total number of particles without consideration of the different chemistry of emissions and distance from source, important in assessing human health impacts. Finally, particle number concentration as with concentration of gaseous pollutants and other surrogates for very small particles decrease significantly with distance from the source.

In a subsequent study, **Buonanno et al (2010)**[43] investigated the dimensional and chemical characterisation of particles at a downwind receptor site of a WtE plant, specifically evaluating seasonal concentrations and size

---

[41] Dellinger, B et al (2008) Combustion byproducts and their health effects. Env Eng Science, 25 (8) 1108-1114

[42] Buonanno, G et al (2009) Size distribution and number concentration of particles at the stack of a MW incinerator. Waste Management 29 749755

[43] Buonanno, G et al (2010) Dimensional & chemical characterisation of particles at a downwind receptor site of a WtE plant. Waste Management 30 1325-1333

distributions of particles in the proximity of a modern RDF MSWI in terms of number, surface area, mass and chemical composition. They found annual mean values of 8.6×10^3 +/-3.7×10^2 particles/cm^3 and 31.1+/-9.0 µg m^{-3} for number and mass concentration, typical of a rural site. Most of the elements can be attributed to long-range transport from other natural and/or anthropogenic sources.

Buonanno et al (2011)[44] further investigated chemical, dimensional and morphological ultrafine particle characterisation from a WtE plant where particle size distributions and total concentrations were measured both at the stack and before the fabric filter inlet in order to evaluate the removal efficiency of the filter for ultrafine particles. The authors performed a chemical characterisation of ultrafine particles for heavy metal concentration and a mineralogical investigation in order to evaluate shape, crystalline state and mineral compound of sampled particles.

The authors found maximum values of 2.7×10^7 particles/cm^3 and 2.0×10^3 particles/cm^3 for number concentration before and after the fabric filter respectively, showing a very high efficiency in particulate removal by the fabric filter (99.99%). The most frequent particle size before the filter was approximately 150 nm and after the filter, 90 nm. With regard to heavy metal concentrations, the elements with higher boiling temperature present higher concentrations at lower diameters showing incomplete evaporation in the combustion section and the consequent condensation of semi-volatile compounds on solid nuclei. In terms of mineralogical and morphological analysis, the most abundant compounds found in samples collected before the fabric filter were sodium, potassium and lead oxides followed by phyllosilicates (sheet silicates). Different oxides of comparable abundance were detected in the samples collected at the stack. These measurements were performed during stable combustion conditions.

Analysis of airborne particles to identify key elements/elemental ratios is used for identification of important sources of air pollution. **Aboh et al (2007)**[45] used the technique for the assignment of major sources of aerosol particles (PM2.5) in a Swedish city in which a new incinerator of household and industrial waste had recently been installed. Irrespective of a small data set they identified five major local sources for collected PM2.5, waste incineration, oil incineration, biomass burning, long distance transport and traffic emissions. The authors noticed the relative strength of the identified sources was seen to change when the variables included in the analysis were varied in number and character, although the same sources remained. It was also noted that the quantitative contribution from the different sources should only be treated as informative in the study, as the number of observations were small compared to the number of variables.

In relation to the **Aboh et al (2007)** findings, the **AEA Technology report (2012)** suggests *'…the identification of incineration as a source was no more than a tentative indication based on an assumed and potentially inaccurate emission profile'*, referring to clarification in a subsequent related study by **Laursen et al (2009)**[46] where it concludes *'…even with the relative small data set the source 'wind radar plots together with selected variables indicate the identification of some of the (point) sources might be possible'.*

In its position statement of **2009**, the **UK Health Protection Agency (HPA)**[47] acknowledge that both long-term and short-term increases in exposure to particles can damage health and that no thresholds of effect can be identified for either the effects of long-term exposure or for the effects of short-term increases in concentrations. From this they suggest that any increase in particle concentrations should be assumed to be associated with

[44] Buonanno G, et a (2011) Chemical, dimensional and morphological ultrafine particle characterization from a waste-to-energy plant Waste Management 31 2253-2262

[45] Aboh IJK, et al "EDXRF characterisation of elemental contents in PM2.5 in a medium-sized Swedish city dominated by a modern waste incineration plant," X-Ray Spectrometry Volume 36, Issue 2, pages 104–110

[46] Laursen J, et al "Urban PM2.5 aerosol source identification by factor analysis of elemental composition related to meteorological data," IOP Conf. Series: Earth and Environmental Science 6 (2009)

[47] UK Health Protection Agency (2009) The Impact on Health of Emissions to Air from Municipal Waste Incinerators

some effect on health. However, they suggest the critical step in the assessment of health effects lies in estimating the size of the effect.

In terms of how particles can effect health, they refer to several plausible hypotheses being pursued based on the generation of free radicals in the respiratory system and more widely in the body, the induction of an inflammatory response in the lung, effects on blood clotting factors, effects on the rate of development of atherosclerotic plaques in coronary arteries and effects on the regulation of the heartbeat. It is acknowledged that these and other possibilities are not yet proven

The position statement responds to the claim that PM10 measurements ignore particles most likely to be deposited in the lung (specifically the gas exchange zone), claiming this is incorrect and based on a misunderstanding of the term PM10.

'*PM10 measurement is designed to collect effectively all those particles small enough to pass the upper airways (nose, mouth, pharynx, larynx) and thus of a size that allows a chance of deposition in the lung. PM2.5 is intended to represent that fraction of the aerosol with a high probability of deposition in the gas exchange zone of the lung in vulnerable individuals. It will be obvious that PM10 includes PM2.5 and that PM2.5 cannot exceed PM10 in any given sample of air.*'

It also responds to the claim that PM10 or PM2.5 does not include nanoparticles present in the air, once again claiming this is incorrect.

'*Nanoparticles are efficiently collected by PM10 and PM2.5 samplers but make only a small contribution to the results expressed as PM10 or PM2.5. If particles of less than 100 nm diameter alone were collected from a known volume of air and weighed, the resulting concentration could be expressed as PM0.1 (100 nm = 0.1 microns). In a sample of air collected in a UK urban area on a typical day we might expect results similar to those given below:*

PM10 20 μg/m^3

PM2.5 13 μg/m^3

PM0.1 1-2 μg/m^3'

The **HPA** confirms that nanoparticles make a large contribution to the number of particles per unit volume of air, with those of less than 500 nm in diameter dominating the number concentration of ambient particles. From this, it might be correctly suggested that if an incinerator or other specified source produced many nanoparticles, changes in local mass concentrations (PM10 and PM2.5 to a lesser extent) would not reflect the increase in numbers of particles in the air. It suggests that although the evidence is as yet weak in comparison with that relating to mass concentrations, particle numbers will link with some effects on health better than mass concentrations. It goes on to state that no generally accepted coefficients that allow the use of number concentrations in impact calculations have yet been defined.

The **BSEM report** refers to strengthening evidence that fine particulate pollution plays an important role in both cardiovascular and cerebrovascular mortality. In the section on particulates it states that incinerators produce huge quantities of fine and ultrafine particulates and that measurement of the particle size distribution by weight gives a false impression of safety due to the higher weight of larger particles (PM10). The authors suggest modern baghouse filters only remove 5-30% of PM2.5 (particles with a diameter less than 2.5 microns) and virtually none of the PM0.1 (particles with a diameter less than 0.1 microns).

In its evaluation of the BSEM report, **Enviros (2006)**[48] make the following comments in relation to particulates:

[48] Enviros Consulting (2006) Evaluation of the 4th Report of the British Society for Ecological Medicine

'*This means that, while the report may make valid comments about the risks to health associated with exposure to these substances, the conclusion should be to consider what needs to be done to deal with the main sources of these emissions. For example, emissions of PM10 from MSW incineration are approximately 100 tonnes per year, compared to 22,000 tonnes per year from electricity generation. Emissions of finer particles (e.g. PM2.5 and PM1) and secondary particles would be expected to be in a similar proportion. If it is right to be concerned about fine particulate matter, then attention needs to be paid to controlling emissions from electricity generation, road transport, agriculture and domestic sources. No discernible benefit would be gained by any policy change relating to waste incineration, because the source is simply too small to be significant.*'

These discussions relate to quantitative considerations of particulate emissions i.e. the authors suggest 'huge' quantities arise from MSWI in the view of BSEM and in their response, Enviros compare quantities to other sources such as electricity generation and consider MSWI too small to be significant. The consideration of relative impact can introduce an alternative methodology in assessing the suitability of a proposed Waste-to Energy development.

The **Florida Department of Environmental Protection Department** regulates major air pollution sources in accordance with Florida's Prevention of Significant Deterioration (PSD) programme. A PSD review is only required in areas currently in attainment with the National Ambient Air Quality Standard (AAQS) for a given pollutant or areas designated as "unclassifiable" for the pollutant. A new facility is considered "major" with respect to PSD if the facility emits or has the potential to emit:

- 250 tons per year or more of any regulated air pollutant, or
- 100 tons per year or more of any regulated air pollutant and the facility belongs to one of the facility categories listed in document 62-210.200 (definitions, Major Stationary Source), or
- 5 tons per year of lead.

In their technical evaluation and preliminary determination for the **Hillsborough Municipal Waste Incinerator**[49], the Department undertook a significant impact analysis for each specified pollutant to determine if the project could cause an increase in ground level concentration greater than the Significant Impact Level (SIL) for each pollutant. In order to conduct this analysis, the applicant used the proposed project's emissions at worst load conditions as inputs to the impact model; if the modelling at worst-load conditions shows ground-level increases less than the SILs, the applicant is exempted from conducting any further modelling. If the modelled concentration's from the project exceed the SILs, then additional modelling including emissions from all major facilities or projects in the region (multi-source modelling) is required to determine the proposed project's impacts compared to the AAQS or PSD increments.

In the case of the Hillsborough assessment, the Department found the applicant's initial PM/PM10, CO, NOX, and SO2 air quality impact analyses for this project indicated that maximum predicted impacts from all pollutants were less than the applicable SILs for the area.

Table 1 provides the findings of this part of the assessment.

[49] Florida Department of Environmental Protection Department, technical evaluation and preliminary determination for the Hillsborough County Resource Recovery Facility (2006) http://www.dep.state.fl.us/air/emission/construction/hillsborough/369tebact.pdf

Table 1: Maximum Projected Air Quality Impacts from Hillsborough County RRF Unit 4 Project for Comparison to the PSD Class II Significant Impact Levels

Pollutant	Averaging Time	Max Predicted Impact (ug/m3)	Significant Impact Level (ug/m3)	Baseline Concentrations (ug/m3)	Ambient Air Standards (ug/m3)	Significant Impact?
SO2	Annual	0.1	1	~5	60	NO
	24-Hour	2	5	~55	260	NO
	3-Hour	6	25	~218	1300	NO
PM10	Annual	0.2	1	~26	50	NO
	24-Hour	0.7	5	~76	150	NO
CO	8-Hour	6	500	~4600	10,000	NO
	1-Hour	12	2000	~4600	40,000	NO
NO2	Annual	0.4	1	~15	100	NO

Macleod et al (2006)[50] modelled human exposure to APC residues released from landfills in England and Wales. Following a qualitative risk characterisation, direct and indirect exposures were quantified. Site specific air modelling was conducted for PM10, PCDD/F, lead, cadmium, arsenic and chromium (VI) concentrations at the closest residential points of exposure for four landfill sites accepting in total 75% of the APC residues landfilled in 2000-2001.

Inhalation risks assessed by reference to air quality standards at residential exposure points were assessed as insignificant, however preliminary modelling suggested that indirect exposure from PCDD/F at the 95th percentile level for the site where APC residue deposition rates were highest, exceed the daily soil intake (authors acknowledge this warrants further study given limitations within the model). In concluding, the authors suggest the results provide an indication of the relative magnitude of risks posed but they are generic and do not reflect all exposure circumstances at all locations. The following summarises the key conclusions:

- Seven important pollutant linkages were identified with medium and high risk to human health. These considered the atmospheric transport and subsequent direct and indirect exposure to nearby workers and residents. The key pollutant linkages were potentially present at four of the six landfill sites studied;
- Direct exposure through ingestion and inhalation are the critical exposure pathways;
- Dust does not appear to be of major concern give the deposition rates modelled;
- The main APC landfill site (> 40% of the total APC residues disposed in 2000-1) was found not to cause significant release of APC residues that reached the nearby receptors. The predicted annual mean of PM10 at the nearest sensitive human receptor was 1.8 µg/m^3, significantly lower than the air quality strategy objective of 40 µg/m^3;
- The long term accumulation of dioxins from deposited dust is tentative and warrant further study. Indications in this work are that indirect exposures require more detailed investigations; and
- On the basis of this preliminary analysis, the disposal of APC residues at landfill sites does not appear to pose significant harm to nearby human receptors. However, this assessment was made using a restricted data set and more information is required to fully understand the nature of the hazard.

[50] Macleod, C et al (2006) Modelling human exposure to APC residues released from landfill in England and Wales Environmental International 32 (4) 500-509

A **2010 study** carried out by **LEAP (Energy and Environment Laboratory Piacenza)**[51], a consortium supported by Milan Polytechnic, reviewed issues relating to the emissions of fine and ultrafine particles from stationary combustion plants. The section on health effects reviews the epidemiological and toxicological approach to assessment. It concludes that there is emerging evidence that exposure to PM, no matter what size fraction, is associated not only with the aggravation of pre-existing disease, but represents a real risk factor for the development of chronic degenerative diseases. However, it acknowledges that whilst it would be desirable to isolate the effect of particles from that of other pollutants, this is generally impossible and moreover, in the majority of studies the effect of ultrafine particles is inseparable from that of other co-pollutants generated by traffic such as oxides of nitrogen, CO and that of fine particles. Furthermore, the following statement closes this section of the report:

'*To summarise, while attention should be paid to the environmental role of ultrafine particulate and its components, no indication emerges from analysis of the toxicological implications of studies in this area, of special risk which can be attributed to UFP [ultrafine particles] from the incineration of waste with energy recovery, if this is carried out in line with best available technology.*'

Vilavert et al (2011)[52] monitored air levels of Volatile Organic Compounds (VOCs) and bio-aerosols in the vicinity of a MSWI in Catalonia, Spain during four 6-month campaigns, to investigate the temporal trends associated with these chemical and microbiological pollutants. The authors suggest that although emissions of VOCs and bio aerosols are of concern to non-combustion waste treatment technologies e.g. composting and MBT plants, incinerators can accumulate considerable amounts of residues at entrance halls, and therefore may be of similar concern.

They note that whilst there is much information available regarding emission of PCDD/F levels by incinerators, data on the potential environmental impact and associated human health risks of VOCs and bio-aerosols are particularly sparse. Concentrations of microbiological agents were very similar to those found in urban zones worldwide and concentrations of VOCs were typical of suburban zones. The levels of VOCs also showed notable decrease to those recorded in a previous survey. They conclude that the current exposure to these compounds should not mean additional health risks for the population living nearby.

Miyake et al (2005)[53] studied the relationship between distance of schools from the nearest MSWI plant and child health in Japan, based on a questionnaire completed by the parents of 450,807 children aged 6-12 attending 996 public elementary schools in Osaka. Distance from each school from the 37 MSWI plants in Osaka was measured using a geographical information system and adjustments were made for grade, socio-economic status and access to healthcare per municipality. They found decreases in the distance of schools from the nearest waste incinerator were independently associated with an increased prevalence of wheeze, headache, stomach ache and fatigue. A positive association was fatigue was pronounced within 4 km of the second nearest MSWI plant. They suggest the proximity of schools to MSWI plants may be associated with increased prevalence of wheeze, headache, stomach ache and fatigue in Japanese children.

3.6 Odour

Aatamila et al (2011)[54] studied odour annoyance and physical symptoms among residents living near waste treatment centres. The aim of the study was to assess odour-associated self-reported physical symptoms

---

[51] Cernuschi, S et al Emission of fine and ultrafine particles from stationary combustion plants. Final Summary 2010

[52] Vilavert, L et al (2011) Levels of chemical and microbiological pollutants in the vicinity of a waste incineration plant and human health risks: Temporal trends. Chemosphere 84 (10) 1476–1483

[53] Miyake, Y et al (2005) Relationship between distance of schools from the nearest municipal waste incineration plant and child health in Japan European Journal of Epidemiology 20 1023-1029

[54] Aatamila, M et al (2011) Odour annoyance and physical symptoms among residents living near waste treatment centres. Environmental Research 111 164-170

among residents living near waste treatment centres, conducted in the surroundings of five large-scale Finnish waste treatment centres with composting plants.

A large group of residents were interviewed by telephone and a questionnaire asked about respondents' personal characteristics, odour exposure and symptoms during the preceding twelve months. Physical symptoms were analysed by distance to the waste treatment centre and by the respondents' perception and annoyance of waste treatment odour. The residents who were classified as 'annoyed by the odour' reported the following physical symptoms more than those who did not: unusual shortness of breath, eye irritation, hoarseness/dry throat, toothache, unusual tiredness, fever/shivering, joint pain and muscular pain. Reported odour annoyance near the waste treatment centres showed an association with many physical symptoms among residents living in the neighbouring areas.

Whilst compost related, rather than MSWI, this provides an interesting perspective on odour and perceived links to health issues. It concludes that reported odour annoyance near waste treatment centres was associated with physical symptoms among residents living in neighbouring areas and that the associations were consistent although not strong.

3.7 Carcinogens, Mutagens and Teratogens

Some of the key MSWI emission pollutants of concern are PCDD/F, PAHs and heavy metals. Certain metals, such as cadmium and lead, are classified as carcinogens and halogenated dioxins and furans are classified as mutagenic and teratogenic.

Body Burden

Fatima Reis et al (2007)[55 56 57 58 59] used human bio-monitoring to evaluate selected pollutant levels in the general population living in the vicinity of two solid waste incinerators near Lisbon and Madeira Island, Portugal. These environmental health surveillance programmes were launched in response to public and scientific concerns regarding these facilities. The former had been operating since 1999 in Metropolitan North Lisbon and the latter was an old incinerator retrofitted with modern technology in 2002. The selected pollutants and study matrices comprised PCDD/F in human milk, PCDD/F, lead, mercury and cadmium in human blood (including children under six years old) and lead in maternal and umbilical cord blood.

Dioxin/furan body burden by PCDD/F levels in blood: The study was carried out on 138 adults from the general population living in the vicinity of the incinerators. The same questionnaire was administered to both populations and in the different examinations to gather data on individual characteristics i.e. for specific features such as smoking, drinking and dietary habits, professional activity, past history of diseases and treatment etc.

'*The overall conclusion points to a non-significant regional difference on dioxin levels when exposed and control populations relative to each incinerator are considered. This may indicate that dioxin exposure of global populations, as estimated by blood PCDD/F levels in the general population, cannot be related to the emissions from the studied facilities, meaning that dioxin sources control seems to be effective in relation to both incinerators.*'

---

[55] Fatima Reis, M et al (2007) Determination of dioxins and furans in blood of non-occupationally exposed populations living near Portuguese solid waste incinerators. Chemosphere 67 S224-S230

[56] Fatima Reis, M et al (2007) Biomonitoring of PCDD/Fs in populations living near Portuguese solid waste incinerators: Level in Human Milk. Chemosphere 67 S231-S237

[57] Fatima Reis, M (2007) Human exposure to heavy metals in the vicinity of Portuguese solid waste incinerators - Part 1: Biomonitoring of Pb, Cd and Hg in the blood of general population. International Journal of Hygiene and Environmental Health 210 439-446

[58] Fatima Reis, M (2007) Human exposure to heavy metals in the vicinity of Portuguese solid waste incinerators - Part 2: Biomonitoring of lead in material and umbilical cord blood. International Journal of Hygiene and Environmental Health 210 447-454

[59] Fatima Reis, M (2007) Human exposure to heavy metals in the vicinity of Portuguese solid waste incinerators - Part 3: Biomonitoring of Pb in blood of children under the age of 6 years. International Journal of Hygiene and Environmental Health 210 455-459

Dioxin/furan body burden by PCDD/F levels in human milk: The paper investigates differences between exposed and non-exposed subjects under study and possible covariates of the dioxin levels in human milk. The authors acknowledge that the study of mothers' milk in probability based surveys to extract results for the general population is questionable, as only a specific demographic segment i.e. breast feeding women at reproductive age.

'*The results indicate that dioxin milk levels of the group living in the area of potential influence of each incinerator are not significantly increased by their PCDD/F stack emissions. This is both an important finding and accurate statement, supporting the dioxin sources control effectiveness.*'

Lead, cadmium and mercury levels in human blood: The paper addresses exposure to these metals determined by blood levels in adult population across each area of residence. In general, the authors found a lack of statistically significant differences between exposed and non-exposed individuals for any of the studied metals. They also note that when differences do have a statistical difference, they are so small that they consider them irrelevant form a health perspective.

'*These findings are suggestive of effectiveness in metal source control in relation to both incinerators under study, confirming, for the three studied heavy metals, previous conclusions relative to dioxin exposure.*'

The paper also concludes that levels of these metals in the global population show a general significant trend for reduction when compared to the baseline period. Comparing metal levels between Lisbon and Madeira, the authors noted a significantly higher exposure in Lisbon; assuming a lack of association with metal exposure from the incinerators and heavy metal burden in the body for each case, the authors suggest higher exposure in Lisbon may be attributed to alternative sources not present or less intensive in Madeira e.g. higher traffic density or industrial density.

Lead in maternal and umbilical blood: The authors observe some statistically significant differences between both study groups, however this is not considered, by them, to be large enough to have any impact on health, and that no additional health risk for residents in the vicinity of the two incinerators may be derived. In absolute terms the blood lead values are significantly lower than the established action level (Centre for Disease Control and Infection 1991) and in relation to baseline levels for Lisbon, results for both maternal and cord blood levels show a marked tendency for reduction.

Madeira exhibits a better situation when compared to Lisbon, as noted in previous studies in relation to pollutants potentially emitted by incinerators. The authors also note however, comparison with similar groups and conditions also show the results, mainly for the most recent observations are close to the lower limit of the range for published blood levels. In particular for Lisbon, where it stated this is probably attributed to the use of unleaded gasoline.

Lead in blood of children under six years old: 250 children from Lisbon and 247 from Madeira were involved in the study and evaluates spatial and temporal trends of lead exposure, based on comparisons of children's blood lead levels, either stratified by living area (exposed and control groups) or by time of exposure (baseline and approximately two years after regular operation of the incinerator. The results obtained correspond to a reduced number of individuals and therefore this may be the reason they are not fully conclusive in relation to whether living in the vicinity of an incinerator represents an additional risk of higher exposure to lead. Time trends also show no clear pattern.

'*These conclusions and the fact that altogether around 3% of children from the whole group have blood levels of greater than or equal to 10ug/dl warrant further investigation in order to clarify the contribution of incinerator emissions to the levels of lead in children and to identify alternative sources for preventative purposes, taking into consideration the relevance of even low lead exposure from a public health perspective, mainly in relation to children.'*

Kumagai et al (2003)[60] evaluated exposure of MSWI workers to dioxins in Japan, describing the dioxin exposure concentration, daily dioxin intake and blood dioxin levels. The difficulty in directly measure dioxin exposure concentrations during work activities was noted, because the flow rate of personal sampler was too low to collect enough airborne dust to quantitatively determine dioxins. Thus, total dust concentrations in the breathing zone of incinerator workers were measured and the dioxin exposure concentrations were estimated by multiplying the total dust exposure concentrations by the dioxin concentrations in deposited dust, fly ash and slag. Daily dioxin intake was estimated based on a set of stated assumptions and using the specified methodology, it was found that daily dioxin intake can exceed the Tolerable Daily Intake (TDI) in incineration plants with fly ash of high dioxin concentration. The estimated dioxin exposure concentrations were 0.5 to 7.2 pg TEQ/m^3 during daily operation and 0.2 - 92,000 pg TEQ/m^3 in the periodic maintenance. The mean of blood dioxin concentration was 346 pg TEQ/g lipid in the highest exposed worker group and 11 to 40 pg TEQ/g lipid in the other incineration plants.

The **2009 HPA publication** states that the majority of non-occupational human exposure to dioxins occurs via the diet e.g. animal based foodstuffs such as meat, fish, eggs and dairy products (particularly fatty foods). It also states that inhalation of dioxins is a minor exposure route and then using the **DEFRA 2004** data, estimating less than 1% of UK dioxin emissions arise from MSWI, suggests the contribution of incinerator emissions to direct respiratory exposure of dioxins is a negligible component of the average human intake. It concludes:

'*However, dioxins may make a larger contribution to human exposure via the food chain, particularly fatty foods. Dioxins from emissions could also be deposited on soil and crops and accumulate in the food chain via animals that graze on the pastures, though dioxins are not generally taken up by plants. Thus the impact of emissions on locally produced foods such as milk and eggs is considered in deciding whether to grant a permit. These calculations show that, even for people consuming a significant proportion of locally produced foodstuffs, the contribution of incinerator emissions to their intake of dioxins is small and well below the tolerable daily intake (TDI) for dioxins recommended by the relevant expert advisory committee, Committee on Toxicity of Chemicals in Food, Consumer Products and the Environment.*'

Exposure and Risk

Cangialosi et al (2008)[61] delivered a case study based on a risk assessment of air pollution from a MSWI plant in Italy. They note that the major steps contributing to a risk assessment paradigm include determination of stack emission for selected persistent pollutants, evaluation of pollution transport in environmental media, exposure and dose assessment and health risk assessment.

Ground level air concentrations and soil deposition of PCDD/F, cadmium, lead and mercury pollutants were estimated using an atmospheric dispersion model. Health risk values for air inhalation, dermal contact, soil and food ingestion were calculated based on a combination of these concentrations and a matrix of environmental exposure factors. Exposure of the surrounding population was addressed for different release scenarios based on four pollutants, four exposure pathways and two receptor groups (children and adults). Spatial risk distribution and cancer excess cases projected from plant emissions were compared with background mortality records. It concludes MSWI emissions based on this study show individual risk well below maximum accepted levels and very small incremental cancer risk compared with background levels. It also concludes:

- Pollutants concentration at ground level decreases very quickly with distance;
- Risk values due to carcinogenic and non-carcinogenic pollutants for both receptors (children and adults) are well below maximum acceptable levels issued by USEPA (1990) in the clean air act;

[60] Kumagai, S et al (2003) Exposure evaluation of dioxins in municipal waste incinerator workers. Industrial Health 41 167-174

[61] Cangialosi, F et al (2008) Health risk assessment of air emissions from a MSW incineration plant - a case study Waste Management 28 885-895

- Food ingestion represents the most significant exposure pathway for both receptors; and
- Standardised rate for additional cancer mortality due to the considered carcinogenic pollutants over a lifetime is lower than background level for cancer diseases.

Forastiere et al (2011)[62] conducted a health impact assessment of landfilling and incineration in Italy, Slovakia and England. The study considered incinerators and landfills operating in 2001 and the population living within 3 km of an incinerator and 2 km of a landfill. Excess risk estimates from epidemiological studies were used combined with air pollution dispersion modelling for PM10 and Nitrogen Dioxide (NO_2). For the impact of incinerators, it estimated attributable cancer incidence and Years of Life Lost (YOLL) and for landfill it estimated congenital anomalies and low birth weight infants.

The study concludes that past exposures from incinerators were likely to cause a sizeable health impact, especially for cancer, in Italy and England. However, the current impacts from landfill and incineration is characterised as moderate when compared to the impact of other sources of environmental pollution e.g. traffic or industrial emissions. The authors acknowledge uncertainties and critical assumptions used in the assessment model typical of complex problems, however they believe it provides insight into the relative health impact attributable to waste incineration and landfill and could be used as part of more articulate assessments for evaluating waste policy options, identifying knowledge gaps and providing a framework for future comparative risk assessment. The summary detail is presented in Table 1.

[62] Forastiere, F et al (2011) Health impact assessment of waste management facilities in three European countries. Environmental Health 10:53

Table 2: Summary findings from Forastiere et al (2011)

	Landfill 2001	Incinerators 2001	Estimate population for incineration	Additional NO2 contribution ug/m^3	Annual cancer cases 2020[1]	Annual cancer cases 2050[1]	YoLL 2050[2]	Estimate population for landfill	Additional cases of congenital abnormalities[3]	Additional cases of low birth weight newborns[3]
Italy	619	49	1,000,000	0.23	11	0	3,621	1,350,000	2	42
Slovakia	121	2	16,000	0.15	0	0	37	329,000	2	13
England	232	11	1,200,000	0.14	7	0	3,966	1,425,000	3	59

1. Authors are moderately confident due to exposure between 2001-2020.

2. Authors are moderately confident that this represents attributable impact on the 2001 cohort of residents.

3. Authors are moderately confident that this represents an estimate to 2030.

Federico et al (2010)[63] conducted a retrospective study to assess cancer incidence during the period 1991-2005 in the proximity of a MSWI in Modena, Italy. During the 15 year period, 16,443 new cases of cancer were diagnosed amongst residents of Modena. The authors make the following observations:

- The space-time clustering test identified three significant clusters but their shapes were not associable with the MSWI exposition;
- The purely spatial analysis showed no statistical significant clusters; and
- The standardised incidence ratio computed for all cancers and selected sites did not show any excess risk in the area closest to the [MSWI] plant.

The authors acknowledge the intrinsic limits of the study, as follows:

- Emission characteristics of the Modena incinerator were not available for the time period of the study, the authors therefore used distance from source as a measure of exposure; and
- The first exploratory analysis of cancer risk had an ecological study design. Ecological studies investigate relationships at the level of a group rather than the level of an individual. Although such studies are common in epidemiology, it is well known that the obtained estimates may be may be subject to ecological bias.

They also suggest further research is required for measuring environmental contamination from this facility to allow a better assessment of the population exposure.

Whilst acknowledging the above, the authors conclude that the results suggest there is no detectable increase of cancer risk for people living in proximity to the Modena incinerator.

Knox et al (2000)[64] studied childhood cancers, birthplaces, incinerators and landfill sites. This study examined 70 municipal incinerators, 307 hospital incinerators and 460 toxic waste landfill sites in Great Britain for evidence of effluents causing childhood cancers. The technique of analysis compared distances from suspect sources to the birth addresses and death addresses of cancer children who had moved house. A localised hazard, effective at only one of these times, must be preferentially associated with the corresponding address, creating an asymmetry of migrations towards or away from age-restricted effective sources.

The child/cancer/leukaemia data highly significant excesses of migration away from birthplace close to municipal incinerators. It concluded that because of their locations, the specific effects of the municipal incinerators could not be separated clearly from those of adjacent industrial sources of combustion effluents. Both were probably carcinogenic. Landfill sites showed no such effect.

Lonati et al (2007)[65] evaluated incremental lifetime health risks due to PCDD/F emitted from MSWI, for the resident population in the area of a specified plant. The chosen risk assessment methodology was a multi-pathway combined probabilistic/deterministic approach for analysing the effects of uncertainty and intrinsic variability of the main PCDD/F emission related parameters on final predicted values. Exposure considered direct inhalation of contaminated air, soil ingestion, soil dermal contact and diet. This was applied to a case study based on two different technological scenarios i.e. modern facilities equipped with BAT and older plants in northern Italy.

---

[63] Federico, M et al (2010) Cancer incidence in people with residential exposure to a municipal waste incinerator: an ecological study in Modena (Italy), 1991-2005, Waste Management 30 1362-70

[64] Knox, A et al (2000) An Overview of Incineration and EFW Technology as Applied to the Management of Municipal Solid Waste, International Journal of Epidemiology 29 391-397

[65] Lonati, G et al (2007) Health risk analysis of PCDD/F emissions from MSW incineration: comparison of probabilistic and deterministic approaches Chemosphere 67 S334-S343

The preliminary evaluation finds that potential for plants equipped with flue gas treatment units included in the BAT range for controlling emission to atmosphere to levels far lower than current limits, with risk values thus resulting largely insignificant with respect to regulatory reference levels and with high reductions in expected risks to older plants with no specific PCDD/F control measures.

Nouwen et al (2001)[66] performed a health risk assessment for local habitants of a residential area of Antwerp in the vicinity of two MSWI. The risk assessment combined chemical, toxicological assessments and model calculations, using historic emissions data for both plants with an emphasis on dioxins. The operational atmospheric transport and deposition model for priority substances was used to calculate the deposition of dioxins in the vicinity of the incinerators.

The observed soil contamination pattern did not correspond to the calculated deposition pattern i.e. lower soil concentrations obtained via deposition modelling than those experimentally observed and soil concentration measurements not corresponding with meteorological statistics, indicating that other sources may contribute at least partly to the local PCDD/F contamination of the area. Dioxin exposure of residents as a function of food consumption behaviour was calculated using a mathematical model combined with other transfer factors and simply residing in the impact area did not result in a meaningful risk. Only if locally produced food was consumed (milk, meat, vegetables), exposure in the area was enhanced compared to the average dioxin exposure estimated for the Flemish population, resulting in the authors suggesting excessive locally produced food consumption should be avoided.

Finally, it was observed that as a consequence of different eating habits and lower body weights, children are subject to significantly higher exposure than adults. There was no evidence for enhanced exposure to genotoxicants based on comparison of chromosomal damage to blood cells of children from the study area to those from a control group.

Cordier et al (2004)[67] assessed the impact of PM emissions containing dioxins and metals on birth defect rates at a regional level in southeast France. The authors state that whilst MSWI has contributed to an increase in the overall load of these emissions, evidence of health consequences on populations at that time was sparse. The study incorporated communities with fewer than 50,000 inhabitants surrounding the 70 incinerators that operated at least one year from 1988 to 1997. Each exposed community was assigned an exposure index estimated from a Gaussian plume model. Poisson models and a reference population of the 2,678 unexposed communities in the region were used to calculate relative risks for congenital malformations, adjusted for year of birth, maternal age, department of birth, population density, average family income, and when available, local road traffic.

They found the rate of congenital anomalies was not significantly higher in exposed than in non-exposed communities. Some sub-groups of major anomalies, specifically facial clefts and renal dysplasia were more frequent in exposed communities. Among exposed communities, a dose-response trend of risk with increasing exposure was observed for obstructive uropathies. Risks of cardiac anomalies, obstructive uropathies and skin anomalies increased linearly with road traffic density.

It concludes that MSWI and road traffic may plausibly explain some excess risk observed, however several alternative explanations may exist i.e. exposure misclassification, ascertainment bias and residual confounding. Old technology MSWI and the persistent pollutants generated by them may be linked to some of the observed effects, if indeed real.

[66] Nouwen, J et al (2001) Health risk assessment of dioxin emissions from MSW incinerators: the Neerlandquarter (Wilrijk, Belgium). Chemosphere 43 909-923

[67] Cordier, S et al (2004) Risk of congenital anomalies in the vicinity of MSW incinerators. Occupational Environmental Medicine 61 8-15

Vinceti et al (2008)[68] analysed rates of spontaneous abortion and prevalence at birth of congenital anomalies in women residing or working near the MSW incinerator in northern Italy, during the 2003–2006 period and who experienced higher levels of exposure to PCDD/F, compared to the remaining municipal population.

In women residing in two areas close to the incinerator plant with increasing exposure to dioxins, they did not detect an excess risk of miscarriage or of birth defects, nor did any indication of dose-response relation emerge. Among female workers employed in the factories located in the exposed areas, they did not observe a higher risk of spontaneous abortion; however, an increase in prevalence of birth defects was noted, although this risk estimate was statistically very unstable.

The authors acknowledge some limitations in the study e.g. the analyses were based on a rather small number of cases, therefore the inherent statistical instability of the risk estimates cannot rule out a possible relation between the exposure under study and 'small' increases in teratogenic risk. However, the study results were generally consistent in both the residential and the occupational cohorts and tended to be similar in each calendar year-specific analyses. The authors did not collect at individual level information about life-style potential confounders such as smoking, diet, occupation and reproductive history, but did however review socioeconomic status information, finding evidence that characteristics of the exposed residents were rather comparable to that of the remaining municipal population, with a tendency towards lower educational attainment in the former group.

The comparable socioeconomic status across the cohorts examined in the study and the expected limited consumption in this urban area of locally-produced foods suggests that dioxin intake through food was very similar in these groups. Overall, the study results provide little evidence of an excess risk of adverse pregnancy outcomes in women exposed to emissions from a modern MSW incinerator.

Vinceti et al (2009)[69] examined the relationship between exposure to the emissions from a MSW incinerator and risk of birth defects in a northern Italy community, using Geographical Information System (GIS) data to estimate exposure and a population-based case-control study design. By modelling the incinerator emissions, they defined in the GIS three areas of increasing exposure according to predicted dioxins concentrations. They then mapped the 228 births and induced abortions with diagnosis of congenital anomalies observed during the 1998–2006 period, together with a corresponding series of control births matched for year and hospital of birth/abortion as well as maternal age, using maternal address in the first three months of pregnancy to geocode cases and controls.

Among women residing in the areas with medium and high exposure, prevalence of anomalies in the offspring was substantially comparable to that observed in the control population, nor dose-response relations for any of the major categories of birth defects emerged. The odds ratio for congenital anomalies did not decrease during a prolonged shut-down period of the plant. The authors did, however find an excess prevalence of chromosomal anomalies in middle exposure area, difficult to interpret since there risk was not increased in the high exposure area, and no association was found in the two previous epidemiologic studies which specifically examined this category of birth defects.

The authors acknowledge some degree of exposure misclassification occurred in the study but conclude that maternal exposure to the emissions of MSWI in this setting, as estimated through a dispersion model, was not associated with excess risk of congenital anomalies in the offspring, although this may not apply to incinerators emitting higher levels of pollutants such as heavy metals or dioxins. Overall, these findings do not support the hypothesis that the environmental contamination occurring around an incineration plant such as that examined in this study may induce major teratogenic effects.

---

[68] Vinceti, M et al (2008) Adverse pregnancy outcomes in a population exposed to the emissions of an MSW incinerator. Science of the Total Environment 407 116-121

[69] Vinceti, M et al (2009) Risk of congenital anomalies around a MSW incinerator: a GIS based control study. International Journal of Health Geographies 8 (8)

Vilavert et al (2012)[70] studied the human health risks associated with the operation of a municipal solid waste incinerator Tarragona (Catalonia, Spain) based on a wide surveillance programme started in 1996. This long-term programme included monitoring of dioxins and furans periodically measured in soil and vegetation samples and in air collected at locations in the incinerator surroundings. In the last survey (2009–2010), mean PCDD/F levels in vegetation, soil and air were 0.06 ng I-TEQ kg−1, 0.58 ng I-TEQ kg−1 and 10.5 fg WHO-TEQ m−3, respectively. Both soil and herbage showed a notable reduction in the PCDD/F concentrations in comparison with the baseline study, with this decrease only being significant for soils. In contrast, PCDD/F values in air remained similar during the whole assessment period. Human exposure to PCDD/Fs was evaluated under different scenarios, and the associated non-carcinogenic and carcinogenic risks were assessed. The hazard quotient was below unity in all cases, while cancer risks were under 10−6, which is lower than the maximum recommended guidelines. The authors conclude that current results clearly show that the MSWI of Tarragona does not produce additional health risks for the population living nearby.

[70] Vilavert et al (2012) Waste Management & Research 30(9) 908–916

4 Review of Key Issues

The decision making process on which technology to choose for the treatment of Municipal Solid Waste (MSW) in any setting is a complex process and one which relies on evidence based evaluation of the main issues. Key considerations when evaluating the environmental or health effects of thermal treatment technologies include direct comparison of potential impact with other waste treatment options, consideration of relative impact when compared to non-waste related anthropogenic activities and specifically for emission to air, the potential relative impact on air quality conditions. Whilst it is accepted all emissions from whatever process should be minimised as far as possible, understanding and recognising the context in which facilities may operate has been an element in the assessment process or regulatory considerations in other jurisdictions.

4.1 Environmental Impact

Comparative Studies

Information relating to airborne emissions from operational incineration plants is well documented, in part because actual emission data is monitored and recorded as a regulatory requirement and because the potential environmental and health impacts of waste incineration have been a high profile area of study for many years. Emissions from landfill operations have also been extensively studied and used as comparison with incineration, irrespective of the difficulties in achieving a 'like for like' comparison.

Emissions data from alternative or complimentary treatment options, some regarded as developing technologies, are not always as comprehensive. In the EU, the development of new BAT-based guidance for some of these treatment options will no doubt further develop the understanding of their emissions profile and be reflected in future permits issued for their operation under the Industrial Emissions Directive. From a decision making perspective, this should enable future comparisons with established treatment technology to be conducted on a more robust basis, centred on environmental impact assessments and life cycle analyses.

This review of published literature has provided some interesting insight on this subject, specifically in relation to the availability of information to enable a robust comparison and how this is then applied to subsequent analysis such as life cycle assessments. The **Rada et al (2005)** study of MSW MBT demonstrates how some treatment options may be considered low impact, when in fact research concludes they may represent an equal impact to other treatment options in relation to certain pollutants. This work also highlighted the variability in the regulation of MBT across jurisdictions and a lack of knowledge on secondary particulates associated with the process (bio-aerosols) and particularly with consideration of ammonia release.

Direct quantitative comparison of emissions and potential environmental impact with other waste facilities or other anthropogenic activities provides one route to support the assessment process for future Waste-to-Energy facilities. Specifically for emissions to air, the relative impact on air quality can also be a useful methodology for determining the suitability of a proposed facility, based on potential environmental impact.

The technical evaluation and preliminary determination document for the Hillsborough Municipal Waste Incinerator provides an example of a significant impact analysis for each specified pollutant to determine if the project could cause an increase in ground level concentration greater than the Significant Impact Level (SIL) for each pollutant. In the case of the Hillsborough assessment, the Department found the applicant's initial PM/PM_{10}, CO, NO_X, and SO_2 air quality impact analyses for this project indicated that maximum predicted impacts from all pollutants were less than the applicable SILs for the area. This methodology provides an alternative approach to determining impact, allowing government organisations the flexibility to set-out the emissions against what would be significant impact levels, ambient concentrations and ambient air standards.

Greenhouse Gases

GHG emissions as a result of waste management activities has been studied and evaluated using a variety of techniques, including LCA. This can be considered in terms of direct and avoided emissions e.g. methane from landfill or CO_2 from transport and incineration for the former, replacing non-renewable fuels or replacing virgin materials for the latter.

The **EEA document (2011)** estimated annual net GHG emissions had reduced by 48 million tonnes CO_{2e} between 1995 and 2008 in the EU, Norway and Switzerland, based on improved MSW management. Within the EU, the **Muhle et al (2010)** study highlighted the impact of different waste management regimes in member states on carbon emissions, with the UK producing five times more than Germany per tonne of MSW, equivalent to removing over 1 million cars from the roads. This difference was attributed to Germany applying tightened waste acceptance criteria for landfill, increased use of WtE and its proven source separation system.

Incineration with energy recovery is considered to generate GHG savings based on the studies reviewed for this report and one of the most efficient processes for treating MSW when heat recovery is achieved.

Dioxins and Furans

Dioxin and furan emissions from the thermal treatment of MSW have decreased significantly over recent decades e.g. pre and post MACT regulations in the US demonstrates a 99.9% reduction. Considerable attention has been given to the difference in emission profiles for dioxins and furans when comparing steady state combustion and operational transients.

Wyrzykowska-Ceradini et al (2011) found operational transients were found to considerably increase levels of PBDD/F and PCDD/F compared to steady state operation, for both raw and clean flue gas.

The **EA (2008)** report also found elevated levels of emissions during shutdown and start-up of conventional mass burn technology which related to waste not being fully established on the grate. The increases in emission concentration and rate were reported as less than one order of magnitude when compared to normal operations and the mass of dioxin emitted during these stages as part of a four day planned outage was similar to the emissions which would have occurred during normal operation in the same period. Consequently, emissions from transient operations during start-up and shutdown procedures did not produce greater amounts of emissions and should not be highlighted as producing a greater level of risk to people in the environs of the plant.

The **DEFRA (2004)** report suggests that whilst emission above prescribed limits is of concern and should be investigated, it is unlikely to have a significant effect on emissions averaged over a long period such as a year.

In **2005**, the **German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety** published a report entitled **'Waste Incineration - A Potential Danger? Bidding Farewell to Dioxin Spouting'[71].** This report provided the following conclusions:

- Emissions of toxic contaminants from waste incineration have been drastically reduced since 1990. Total dioxin emissions from all 66 waste incineration plants in Germany has dropped to approximately one thousandth as a consequence of the installation of filter units stipulated by statutory law;
- Without waste incineration plants, there would be more toxic compounds in the air. The view of the authors of this report is that if fossil fuel-based power generation was used to produce the same electrical output as that from Germany's incinerators, then there would be more toxic compounds and dust in the atmosphere;
- The mercury and lead emissions from all polluters in Germany is one thousand times greater than those produced by WtE plants, and
- Actual measured data for emissions to air from many of the incinerators in Germany is much lower than required by the 17th BImSchV[72] and EU Waste Incineration Directive (WID) regulations.

[71] http://www.bmu.de/english/waste_management/downloads/doc/35950.php

Process Residues

The long term environmental impacts of residual solids arising from the thermal treatment of MSW such as IBA and APC residues has been the subject of many studies, with a particular focus on the leaching of pollutants from either landfill sites used for final disposal or from products used in the construction sector e.g. road applications.

The **BSEM 4th report (2008)** suggests that whilst modern abatement equipment delivers improvements to gaseous emissions, this merely transfers the toxic load from gaseous emissions to process residues. There have been well publicised incidents of inappropriate reuse of incinerator residues and in these circumstances, uncontrolled leaching of pollutants could present a risk to the environment and human health. However, when appropriate regulatory control is applied to the management of downstream incineration residuals, such risk is greatly reduced. In the EU, the Landfill Directive ensures hazardous wastes such as APC residues are disposed of in hazardous only landfill sites constructed specifically to prevent escape of leachate. In addition to the controls placed on the construction of these landfill sites, the wastes received have to comply with a specified set of numerical waste acceptance criteria, in part based on meeting certain leaching limit values.

The **AEA Technology (2003)** report on risks associated with the use of processed IBA in road applications found that in the case of matrix bound applications, the leaching potential for IBA was greatly reduced. This was seen as a key environmental advantage as the most significant ecosystem exposure route during the existence of the road was considered likely to be through leaching of metals into local surface waters. It concludes that if used in an appropriate manner, the risks to human health and the environment in hard water areas are likely to be minimal and certainly undetectable in a typical UK situation.

The **Triffault-Bouchet et al (2005)** study found in laboratory IBA leaching and bioassay tests, all three species selected for testing were impaired, with toxicity effects increasing with leachate concentration, with predicted environmental concentration close to the concentration that caused first effects in microcosms. The leachate toxicity was due mainly to the presence of copper.

There is extensive research in the field of IBA upgrading; examples of such processes include curing, weathering, washing with and without additives, carbonation and metal complexation. **Astrup (2007)** found that extended curing along with washing could, in most cases, decrease leaching significantly.

In Japan, slagging gasification processes and the use of plasma melting systems with convention incineration systems produce a vitrified slag which locks the leachable heavy metals within the slag. The Japanese have undertaken extensive leach testing to prove the metals have been immobilised and when the slag is used in construction and civil engineering applications there is no risk to the public.

Scale and environmental impact

In consideration of proposed thermal treatment facilities, the scale of operations or waste treatment capacity is often a key feature of debate in relation to suitability and impact. The **Rada et al (2009)** study suggests the environmental impact of installations dedicated to the treatment of rMSW is not strictly proportional to treatment capacity. A more significant role is played by the qualitative aspects of the rMSW. A combustion plant treating 50,000 tonnes per annum can have an environmental impact similar to that of a combustion plant treating 100,000 tonnes per annum, if the LHV of rMSW treated in the first case is twice as much as the LHV of the second one. As such, environmental performance becomes increasingly related to thermal power rather than specific throughput capacity, in terms of mass input.

[72] Seventeenth Ordinance on the Implementation of the Federal Immission Control Act (Ordinance on Waste Incineration and Co-Incineration

4.2 Health Impact

This review has found extensive research and evaluations attempting to assess the impact of thermal treatment of MSW on human health. Environmental impact studies focus initially on the release to atmosphere on air quality and longer term pollution effects of associated emissions on soil and groundwater. The relationship between environmental and health impact is founded on the fact that pollution of the environment can impact human health by inhalation, skin absorption or ingestion. The **HPA (2009)** note that the majority of non-occupational exposure to dioxins occurs via diet e.g. animal based foodstuffs.

The **DEFRA (2004)** report found that epidemiological evidence at the time made it difficult to establish causality, particularly once confounding factors such as socio-economic variables, exposure to other emissions, population variables and spatial/temporal issues were taken into account. It suggested most data on the possible health effects of incinerator emissions were derived from risk assessments, routinely used to evaluate the potential for both direct and indirect carcinogenic and non-carcinogenic risks from proposed installations.

Giusti (2009) also suggested epidemiological studies dealing with the impact of waste management activities on human health are usually observational rather than experimental. Most studies at the time were based on old types of waste facilities, especially in the case of incinerators. It concludes that the overwhelming majority of epidemiological studies have not managed to prove convincingly and unequivocally that excess risk of contracting specific illnesses is associated with waste facilities.

Particulate Matter

In any assessment of PM in emissions from MSW WtE plants and impacts on human health, the issue of context and relative impact requires careful consideration. In the UK, **DEFRA NAEI (2009)** shows a source contribution of fine particles of 0.042% from MSW incineration, with road traffic at 29%. This was observed by **Buonanno et al (2009)** in a study on the size distribution and number concentration of particles in the stack of a MSW incinerator, where in comparison to vehicular contribution, it showed a negligible emission in terms of the total number of particles.

There has been much debate about whether it is the mass concentration of PM that should be assessed in relation to health impacts, especially for fine and ultrafine particles, or whether it is the particle numbers that could potentially have a greater impact.

In its position statement of **2009**, the **UK HPA** acknowledge that both long-term and short-term increases in exposure to can damage health and that no thresholds of effect can be identified for either the effects of long-term exposure or for the effects of short-term increases in concentrations. From this they suggest that any increase in particle concentrations should be assumed to be associated with some effect on health. However they suggest the critical step in the assessment of health effects lies in estimating the size of the effect.

They confirm that nanoparticles make a large contribution to the number of particles per unit volume of air, with those of less than 500nm in diameter dominating the number concentration of ambient particles. From this, it might be correctly suggested that if an incinerator or other specified source produced many nanoparticles, changes in local mass concentrations (PM10 and PM2.5 to a lesser extent) would not reflect the increase in numbers of particles in the air. It suggests that although the evidence is as yet weak in comparison with that relating to mass concentrations, particle numbers will link with some effects on health better than mass concentrations. It goes on to state that no generally accepted coefficients that allow the use of number concentrations in impact calculations have yet been defined.

Carcinogens, Mutagens and Teratogens

In the US, substantial reduction in emissions over time from WtE facilities is largely attributed to the strict air pollution regulations imposed by the USEPA, the New Source Performance Standards (NSPS) under the federal Clean Air Act (CAA), including a dramatic decline in dioxin emissions. The CAA has changed significantly over time based on the US EPA's continuous research on health effects associated with exposure to emissions from a wide variety of source, including MSW combustor facilities. The US EPA's substantial body of research on the potential toxicity attributable to exposure to PM, carbon monoxide, nitrogen and sulphur oxides, metals, dioxins, furans, and PAHs has been used as the basis for setting both its National Ambient Air Quality Standards and the NSPS for specific types of facilities.

The extensive work undertaken by **Fatima Reis et al (2007)** in biomonitoring of residents local to two Portuguese incinerators concluded in relation to PCDD/F in blood and human milk, source control of these pollutants appeared to be effective as the difference in concentrations between exposed and control groups was insignificant.

Lonati et al (2007) evaluated incremental lifetime health risks due to PCDD/F emitted from MSWI. The preliminary evaluation finds that potential for plants equipped with flue gas treatment units included in the BAT range for controlling emission to atmosphere to levels far lower than current limits, with risk values thus resulting largely insignificant with respect to regulatory reference levels and with high reductions in expected risks to older plants with no specific PCDD/F control measures.

The **Cangialosi et al (2008)** case study on risk assessment included determination of stack emissions for selected persistent pollutants, evaluation of pollution transport in environmental media, exposure and dose assessment and health risk assessment. It concludes MSWI emissions based on this study show individual risk well below maximum accepted levels and very small incremental cancer risk compared with background levels.

The **Forastiere et al (2011)** health impact assessment concluded that past exposures from incinerators were likely to cause a sizeable health impact, especially for cancer, in Italy and England. However, the current impacts from landfill and incineration is characterised as moderate when compared to the impact of other sources of environmental pollution e.g. traffic or industrial emissions.

Dioxins in the food chain and exposure risk was studied by **Nouwen et al (2001)** in their health risk assessment for local habitants of a residential area of Antwerp in the vicinity of two MSWIs. It concluded that if locally produced food was consumed (milk, meat, vegetables); exposure in the area was enhanced compared to the average dioxin exposure estimated for the Flemish population, resulting in the authors suggesting excessive locally produced food consumption should be avoided. It was also observed that as a consequence of different eating habits and lower body weights, children are subject to significantly higher exposure than adults. There was no evidence for enhanced exposure to genotoxicants based on comparison of chromosomal damage to blood cells of children from the study area to those from a control group.

Further Studies

In its conclusions, the **DEFRA 2004** report found that health effects in people living near waste management facilities were either generally not apparent, or the evidence was not consistent or convincing. They acknowledge however, that a few aspects of waste management have been linked to health effects in local people, but more research would be required to know whether or not these are real effects. They also investigated the health effects of emissions of some important airborne pollutants from waste management facilities and whilst acknowledging the data was of moderate or poor quality, found that these emissions are not likely to give rise to significant increases in adverse health effects.

The **Health Protection Agency (2009)** position statement, '*The impact on health of emissions to air from municipal waste incinerators,* concludes the following:

‘*While it is not possible to rule out adverse health effects from modern, well regulated municipal waste incinerators with complete certainty, any potential damage to the health of those living close-by is likely to be very small, if detectable. This view is based on detailed assessments of the effects of air pollutants on health and on the fact that modern and well managed municipal waste incinerators make only a very small contribution to local concentrations of air pollutants. The Committee on Carcinogenicity of Chemicals in Food, Consumer Products and the Environment has reviewed recent data and has concluded that there is no need to change its previous advice, namely that any potential risk of cancer due to residency near to municipal waste incinerators is exceedingly low and probably not measurable by the most modern techniques. Since any possible health effects are likely to be very small, if detectable, studies of public health around modern, well managed municipal waste incinerators are not recommended.*’

The position statement also referred to the **DEFRA 2004** report as the most extensive available in this field and states that since the evidence base had not changed significantly between 2004 and 2009, it would be an inefficient use of resources to repeat this work when applications to build and operate individual incinerators are being considered. It does, however, acknowledge that like all scientific findings, it may be subject to revision if new datasets were to emerge. It should also be noted the document only concerns the health effects of emission to air.

References

1. Burnley, S J et al (2011) Energy implications of the thermal recovery of biodegradable municipal waste materials in the United Kingdom. Waste Management 31 (9-10),1949-1959
2. Rada, EC et al (2005) Some research perspectives of emissions from MBT of MSW in Europe Environmental Technology 26 1,297-1,302
3. Bioenergy Producers Association (2009) Evaluation of Emissions from Thermal Conversion Technologies processing MSW and Biomass.
4. Eschenroeder, A. and von Stackelberg, K. (1999) Health Risks of Landfilling versus Combustion of Municipal Solid Waste: An Illinois Comparison. Air & Waste Management Association's 92nd Annual Meeting, St. Louis, Missouri.
5. El Hanandeh, A et al (2010) Life-cycle assessment of MSW alternatives with consideration of uncertainty: SIWMS development and application. Waste Management (30) 902-911
6. Fruergaard, T et al (2011) Optimal utilization of waste-to-energy in an LCA perspective. Waste Management 31 572-582
7. Morselli, L et al (2005) Tools for the evaluation of impact associated with MSW incineration, LCA and integrated environmental monitoring systems Waste Management 25 191-196
8. Rada, EC et al (2009) Trends in the management of residual municipal solid waste. Environmental Technology 30 (7) 651-661
9. Exponent (2004) Former Municipal Solid Waste Incinerator, Human Health and Ecological Risk Assessment. Prepared for City of Sitka, Sitka, AK.
10. Weitz, K.A., Thorneloe, S.A., Nishtala, S.R., Yarkosky, S.; Zannes, M. (2002) The Impact of Municipal Solid Waste Management on Greenhouse Gas Emissions in the United States. Journal of the Air & Waste Manage. Assoc. 52: 1000-1011.
11. European Environment Agency (2011) Waste Opportunities. Past and future climate benefits from better municipal waste management in Europe
12. Muhle, S et al (2011) Comparison of carbon emissions associated with municipal solid waste management in Germany and the UK. Resources, Conservation and Recycling 54 (11) 793–801
13. Pavlas, M et al (2010) Waste to energy – An evaluation of the environmental impact. Applied Thermal Engineering 30 (16) 2326–2332
14. Papageorgiou, A et al (2010) Assessment of the greenhouse effect impact of technologies used for energy recovery from municipal waste: A case for England. Journal of Environmental Management 90 (10) 2999-3012
15. Psomopoulos, CS. et al (2009) Waste to Energy: A review of status and benefits in USA. Waste Management, 29 1718-1724
16. Wyrzykowska-Ceradini, B et al (2011) PBDDs/Fs and PCDDs/Fs in the raw and clean flue gas during steady state and transient operation of a municipal waste combustor. Environ Sci Technol Jul 1;45(13) 5853-60
17. Investigation of Waste Incinerator Dioxins During start-up and shutdown operating phases, AEA Technology 2008
18. UK DEFRA (2004) Review of Environmental and Health Effects of Waste Management: Municipal Solid Waste and Similar Wastes. DEFRA Publications.
19. Environmental and health risks associated with the use of processed IBA in road construction, EA Technology 2003
20. Astrup, T (2007) Pretreatment and utilisation of waste incineration bottom ashes: Danish Experiences Waste Management 27 1452-1457

21. Astrup, T et al (2011) Incinerator performance: effects of changes in waste input and furnace operation on air emissions and residues. Waste Management and Research 29 57-68
22. Triffault-Bouchet, G et al (2005) Ecotoxicological assessment of pollutant flux released from bottom ash reused in road construction. Aquatic Ecosystem Health & Management 8 (4) 405-414
23. Water Research Centre (2012) Assessment of Hazardous Classification of IBA
24. British Society of Ecological Medicine (2008) 2nd Edition The Health Effects of Waste Incinerators
25. Fruergaard, T et al (2010) Life-cycle assessment of selected management options for APC residues from waste incineration Science of the Total Environment 408 4672-4680
26. Demidova, O et al (2005) Risk assessment for improved treatment of health considerations in EIA Environmental Impact Assessment Review 25 411-429
27. Roberts, RJ et al (2006) Waste incineration - how big is the health risk? A quantitative method to allow comparison with other health risks. Journal Public Health, 28 (3) 261-266
28. Bridges, O et al (2000) A generic comparison of the airborne risks to human health from landfill and incineration of MSW Environmentalist 20 (4) 325-334
29. Moy, P et al (2008) Options for management of municipal solid waste in New York City: A preliminary comparison of health risks and policy implications. Journal of Environmental Management 87 73-79
30. Saffron, L et al (2003) Human health impact of WM practices: A review of literature and an evaluation of the evidence, Management of Environmental Quality 14 (2) 191-231
31. Cocarta, DM et al (2009) A contribution for a correct vision of health impact from municipal solid waste treatments. Environmental Technology 30 (9) 963-968
32. Glorennec, P et al (2005) Public health benefits of compliance with current EU emissions standards for municipal waste incinerators: A health risk assessment with the CalTox multimedia exposure model. Environment International 31 693-701
33. Committee on Health Effects of Waste Incineration; Board on Environmental Studies and Toxicology; Commission on Life Sciences; National Research Council (2000) Waste Incineration & Public Health, National Academies Press, Washington DC, 312 pp.
34. Giusti, L et al (2009) A review of waste management practices and their impact on human health, Waste Management 29 2227-2239
35. Health Effects of Waste Combustion Products (1997) Page Bros, Norwich ISBN 1 899110 09 7
36. Hu, S W et al (2001) Health Effects of Waste Incineration: A Review of Epidemiologic Studies Journal of the Air & Waste Management Association 51 1100-1109
37. Porta, D et al (2009) Systematic review of epidemiological studies on health effects associated with management of solid waste. Environmental Health 8:60
38. Franchini, M et al (2004) Health effects of exposure to waste incinerator emissions: a review of epidemiological studies. Ann Ist Super Sanità 40(1) 101-115
39. Waste processing and health. A position document of the Italian Association of Epidemiology (AIE) Ann Ist Super Sanità (2008) 44 No.3 301-306
40. Environmental Services Association (2012) Review of health effects of EfW facilities
41. Dellinger, B et al (2008) Combustion byproducts and their health effects. Env Eng Science, 25 (8) 1108-1114
42. Buonanno, G et al (2009) Size distribution and number concentration of particles at the stack of a MW incinerator. Waste Management 29 749755
43. Buonanno, G et al (2010) Dimensional & chemical characterisation of particles at a downwind receptor site of a WtE plant. Waste Management 30 1325-1333

44. Buonanno G, et a (2011) Chemical, dimensional and morphological ultrafine particle characterization from a waste-to-energy plant Waste Management 31 2253-2262

45. Aboh IJK, et al "EDXRF characterisation of elemental contents in PM2.5 in a medium-sized Swedish city dominated by a modern waste incineration plant," X-Ray Spectrometry Volume 36, Issue 2, pages 104–110

46. Laursen J, et al "Urban PM2.5 aerosol source identification by factor analysis of elemental composition related to meteorological data," IOP Conf. Series: Earth and Environmental Science 6 (2009)

47. UK Health Protection Agency (2009) The Impact on Health of Emissions to Air from Municipal Waste Incinerators

48. Enviros Consulting (2006) Evaluation of the 4th Report of the British Society for Ecological Medicine

49. Florida Department of Environmental Protection Department, technical evaluation and preliminary determination for the Hillsborough County Resource Recovery Facility (2006) http://www.dep.state.fl.us/air/emission/construction/hillsborough/369tebact.pdf

50. Macleod, C et al (2006) Modelling human exposure to APC residues released from landfill in England and Wales Environmental International 32 (4) 500-509

51. Cernuschi, S et al Emission of fine and ultrafine particles from stationary combustion plants. Final Summary 2010

52. Vilavert, L et al (2011) Levels of chemical and microbiological pollutants in the vicinity of a waste incineration plant and human health risks: Temporal trends. Chemosphere 84 (10) 1476–1483

53. Miyake, Y et al (2005) Relationship between distance of schools from the nearest municipal waste incineration plant and child health in Japan European Journal of Epidemiology 20 1023-1029

54. Aatamila, M et al (2011) Odour annoyance and physical symptoms among residents living near waste treatment centres. Environmental Research 111 164-170

55. Fatima Reis, M et al (2007) Determination of dioxins and furans in blood of non-occupationally exposed populations living near Portuguese solid waste incinerators. Chemosphere 67 S224-S230

56. Fatima Reis, M et al (2007) Biomonitoring of PCDD/Fs in populations living near Portuguese solid waste incinerators: Level in Human Milk. Chemosphere 67 S231-S237

57. Fatima Reis, M (2007) Human exposure to heavy metals in the vicinity of Portuguese solid waste incinerators - Part 1: Biomonitoring of Pb, Cd and Hg in the blood of general population. International Journal of Hygiene and Environmental Health 210 439-446

58. Fatima Reis, M (2007) Human exposure to heavy metals in the vicinity of Portuguese solid waste incinerators - Part 2: Biomonitoring of lead in material and umbilical cord blood. International Journal of Hygiene and Environmental Health 210 447-454

59. Fatima Reis, M (2007) Human exposure to heavy metals in the vicinity of Portuguese solid waste incinerators - Part 3: Biomonitoring of Pb in blood of children under the age of 6 years. International Journal of Hygiene and Environmental Health 210 455-459

60. Kumagai, S et al (2003) Exposure evaluation of dioxins in municipal waste incinerator workers. Industrial Health 41 167-174

61. Cangialosi, F et al (2008) Health risk assessment of air emissions from a MSW incineration plant - a case study Waste Management 28 885-895

62. Forastiere, F et al (2011) Health impact assessment of waste management facilities in three European countries. Environmental Health 10:53

63. Federico, M et al (2010) Cancer incidence in people with residential exposure to a municipal waste incinerator: an ecological study in Modena (Italy), 1991-2005, Waste Management 30 1362-70

64. Knox, A et al (2000) An Overview of Incineration and EFW Technology as Applied to the Management of Municipal Solid Waste, International Journal of Epidemiology 29 391-397

65. Lonati, G et al (2007) Health risk analysis of PCDD/F emissions from MSW incineration: comparison of probabilistic and deterministic approaches Chemosphere 67 S334-S343
66. Nouwen, J et al (2001) Health risk assessment of dioxin emissions from MSW incinerators: the Neerlandquarter (Wilrijk, Belgium). Chemosphere 43 909-923
67. Cordier, S et al (2004) Risk of congenital anomalies in the vicinity of MSW incinerators. Occupational Environmental Medicine 61 8-15
68. Vinceti, M et al (2008) Adverse pregnancy outcomes in a population exposed to the emissions of an MSW incinerator. Science of the Total Environment 407 116-121
69. Vinceti, M et al (2009) Risk of congenital anomalies around a MSW incinerator: a GIS based control study. International Journal of Health Geographies 8 (8
70. Vilavert et al (2012) Waste Management & Research 30(9) 908–916
71. http://www.bmu.de/english/waste_management/downloads/doc/35950.php
72. Seventeenth Ordinance on the Implementation of the Federal Immission Control Act (Ordinance on Waste Incineration and Co-Incineration