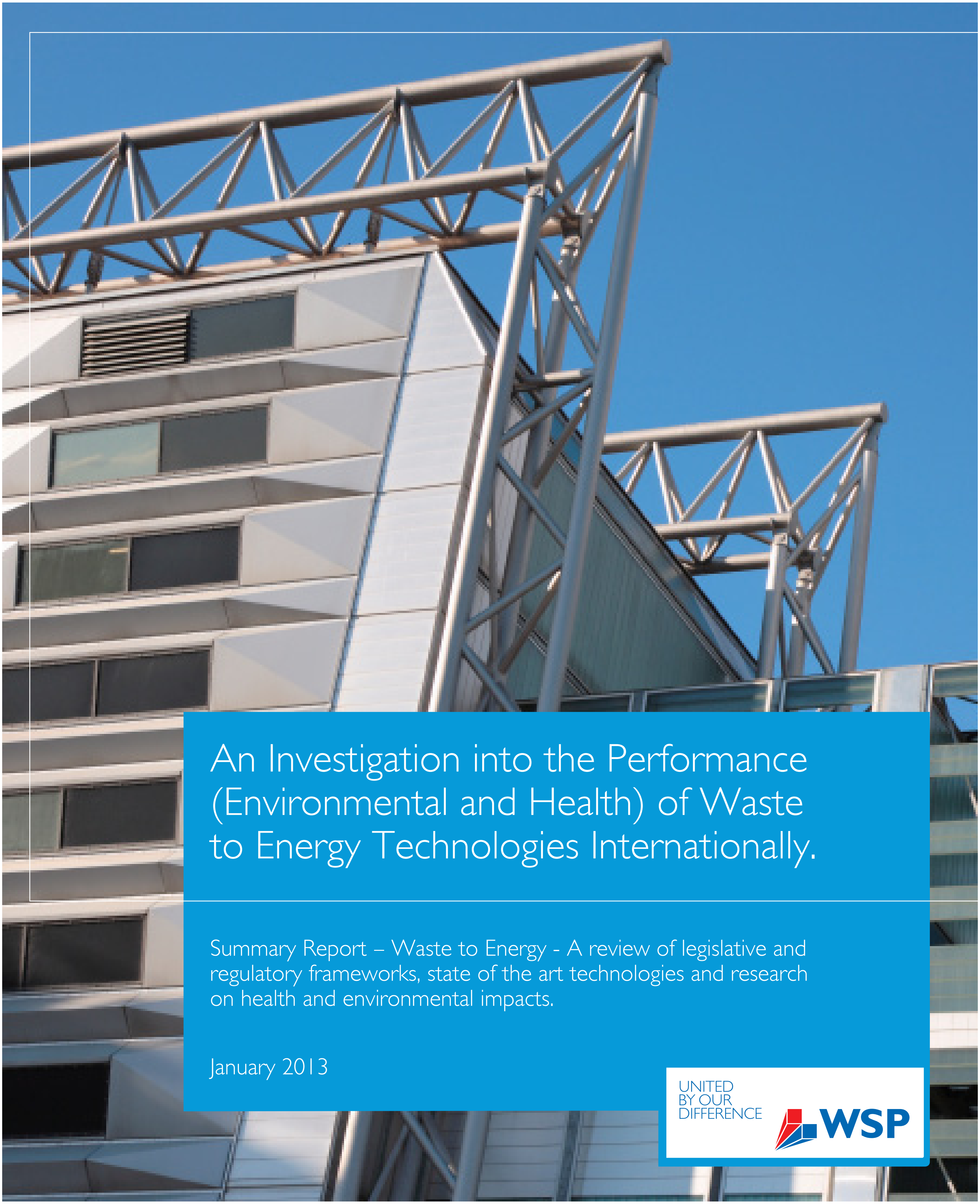


An Investigation into the Performance (Environmental and Health) of Waste to Energy Technologies Internationally.

Summary Report – Waste to Energy - A review of legislative and regulatory frameworks, state of the art technologies and research on health and environmental impacts.

January 2013

UNITED BY OUR DIFFERENCE

WSP

Compiled by WSP Environmental for the Government of
Western Australia Department of Environment and Conservation

Quality Management

Issue/revision	Issue 1	Revision 1	Revision 2	Revision 3
Remarks				
Date	16th January 2013			
Prepared by	Kevin Whiting, Steve Wood and Mick Fanning			
Signature				
Checked by	Michael Berney			
Signature				
Authorised by	Kevin Whiting			
Signature				
Project number	00031427			
Report number				
File reference				

An Investigation into the Performance (Environmental & Health) of Waste to Energy Technologies Internationally

Summary Report compiled by WSP Environmental for the Government of Western Australia 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

Consultants

Kevin Whiting
Senior Techncial Director
Tel: +44 207 7314 4647
Kevin.whiting@wspgroup.com

Mick Fanning
Associate Consultant
Tel: +44 207 7314 5883
Mick.fanning@wspgroup.com

Steven Wood
Principal Consultant
Tel: +44 121 3524768
Steven.wood@wspgroup.com

Summary and Conclusions

This report summarises the findings of three separate studies on the thermal Waste-to-Energy treatment of mixed non-hazardous and low-level hazardous solid waste, predominantly mixed municipal waste. The work incorporates a review of legislative and regulatory frameworks, state of the art technologies and research on health and environmental impacts.

There is now strong policy development within the EU shaping future legislation to ban specific waste categories from landfill disposal and ensure that waste materials that can be recycled are banned from waste-to-energy plants. At regulatory level, bans on certain waste materials being sent for landfill disposal are already established in some countries. This raises parallel debate on the issue of lifecycle assessment for specified waste materials in relation to the respective merits and environmental benefits of processing these at different levels of the waste hierarchy. The outcome of these long term objectives will have an impact on residual municipal waste composition and therefore the design, operational requirements and emission control for waste-to-energy facilities.

In order to showcase real examples of operational WtE plants a collection of fifteen case studies have been produced, which highlight modern state-of-the-art plants and developing technologies. These are presented in detail in the appended full Stage 2 report, but in this report we briefly describe the work carried out and key findings. In terms of air emissions, it can be seen that all the plants considered in the case studies are within EU Waste Incineration Directive limits, with the exception of the Montgomery County plant for HCl and NO_X. This plant does however comply with the local regulatory requirements. In many cases the emissions are more than an order of magnitude below the regulatory limit.

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.

Newer, well-operated Waste-to-Energy facilities i.e. those operated in compliance with the relevant regulations and emission standards seem to be more effective in mitigating potential risks from exposure to emissions. Considerable attention has however 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's Department for Environment, Food and Rural Affairs suggests that whilst emissions 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.

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 for 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.'

List of Abbreviations

AIE	Italian Association of Epidemiology
APC	Air Pollution Control residues
ATT	Advanced Thermal Treatment
BAT-AEL	BAT-Associated Emission Levels
BAT	Best Available Techniques
BREF	Best Available Techniques reference document (EU)
C&I	Commercial & Industrial
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide equivalent
CO	Carbon Monoxide
CV	Calorific Value
DEFRA	Department for Environment, Food and Rural Affairs (UK)
EA	Environment Agency (England and Wales)
EASEWASTE	Environmental Assessment of Solid Waste Systems and Technologies
EIA	Environmental Impact Assessment
EIS	Environmental Impact Statement
EPA	Environment(al) Protection Agency
EC	European Commission
ELV	Emission Limit Values
EU	European Union
FP	Fine Particles
HPA	Health Protection Agency (UK)
IED	Industrial Emissions Directive (EU)
IEH	Institute for Environment and Health (UK)
GHG	Greenhouse Gas
IBA	Incinerator Bottom Ash
LEAP	Energy and Environment Laboratory Piacenza (Italy)
LCA	Life Cycle Analysis
LFD	Landfill Directive (EU)
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
MW	Megawatts
NO_2	Nitrogen Dioxide
NO_x	Nitrogen Oxides
NSPS	New Source Performance Standards (US)
PAH	Polycyclic Aromatic Hydrocarbons
PCB	Polychlorinated Biphenyls
PBDD	Polybrominated Dibenzo-para-dioxins
PBDF	Polybrominated Dibenzofurans
PCDD	Polychlorinated Dibenzo-para-dioxins
PFCDF	Polychlorinated Dibenzofurans
PFR	Persistent Free Radicals
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
UFP	Ultra Fine Particles
VOC	Volatile Organic Carbon
WFD	Waste Framework Directive (EU)
WHO	World Health Organisation
WID	Waste Incineration Directive (EU)
WRATE	Waste and Resources Assessment Tool for the Environment
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 review focusses on the thermal Waste-to-Energy treatment of mixed non-hazardous and low-level hazardous solid waste, predominantly mixed municipal waste. This summary report is divided into three main sections, each summarising the more detailed Stage 1-3 reports provided in the appendices to this report.

Stage One presents the findings of the international literature review encompassing prevailing international legislative and policy context together with scientific understanding with respect to waste-to-energy (WtE) technologies. The review considers how such legislative or policy instruments may affect the feedstock supply, constituents, subsequent storage, management and the handling of waste feedstock. The review also considers 2011 State or National decisions relating to WtE and emissions standards, monitoring and abatement requirements and reference to any associated guidance documents.

Geographies within the scope of this study include:

- Australia, including the States of New South Wales, Queensland, Victoria and South Australia (Section 2);
- European Union (EU) and, in particular, the UK (Scotland, England and Wales), The Netherlands, Sweden, and Germany. Norway is included as part of wider Europe whilst not being an EU member (Section 3);
- Japan (Section 4); and
- USA (Federal and State level) and in particular Florida, Minnesota, New York and California (Section 5).

Stage Two reviews a collection of fifteen Case Studies highlighting modern state-of-the-art plants using the following selection criteria:

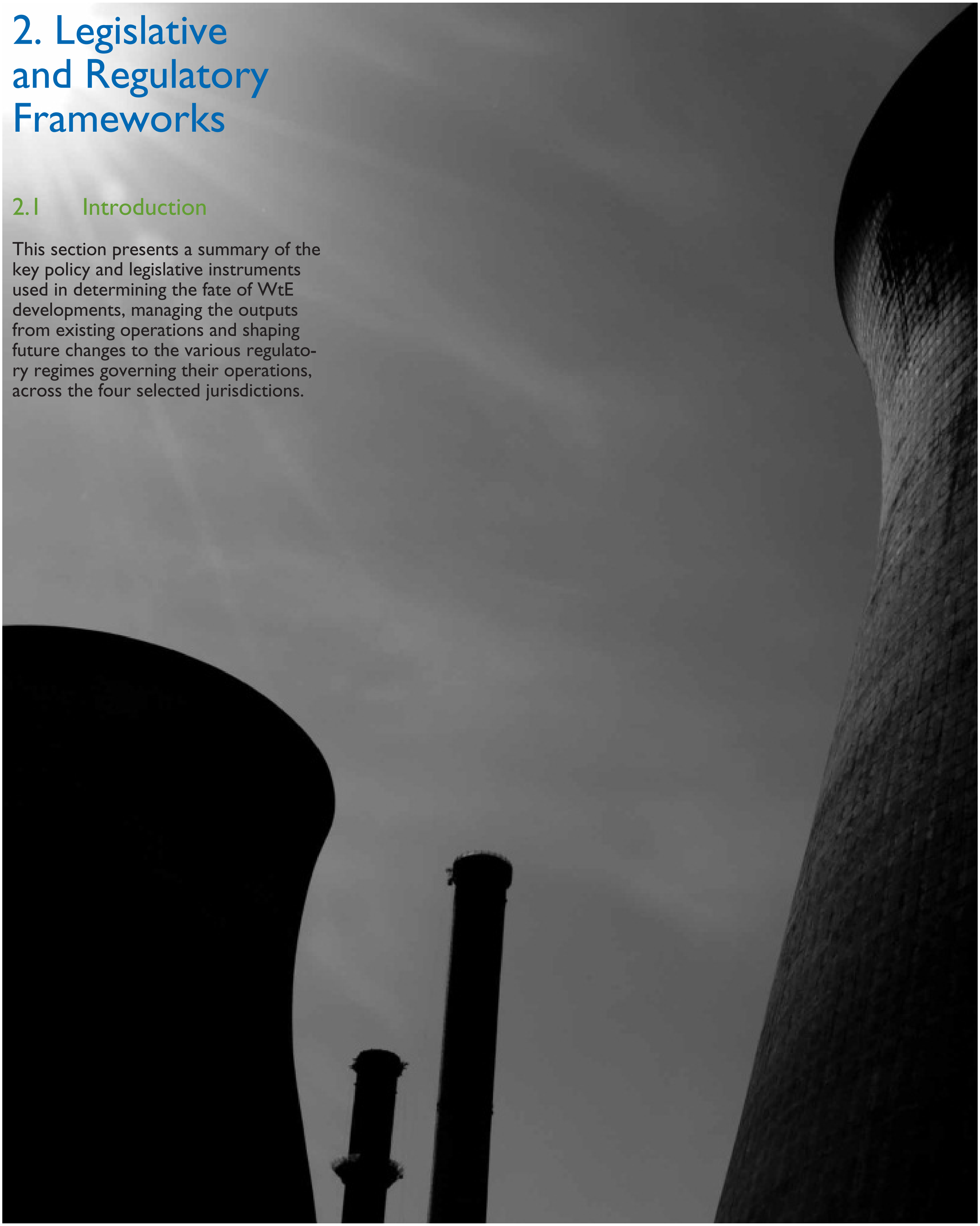
- modern plants with higher than normal thermal efficiency;
- modern plants achieving low environmental impacts;
- plants gaining acceptance via innovative architectural treatments;
- modern plants employing state-of-the-art furnace design;
- modern plants employing alternative thermal technologies, such as fluidised bed and gasification.

Stage Three 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.

2. Legislative and Regulatory Frameworks

2.1 Introduction

This section presents a summary of the key policy and legislative instruments used in determining the fate of WtE developments, managing the outputs from existing operations and shaping future changes to the various regulatory regimes governing their operations, across the four selected jurisdictions.



2.2 Australia

The **Council of Australian Governments (COAG) Standing Council on Environment and Water (SCEW)** incorporating the **National Environmental Protection Council (NEPC)**, is the national intergovernmental body that has law-making powers as defined in the **National Environment Protection Council Act 1994 (Commonwealth).**

Included in the Council's Priority Issues of National Significance, as agreed by COAG are:

- Pursuing seamless environmental regulation and regulatory practice across jurisdictions;
- Implementing the National Waste Policy, and
- Developing and implementing a National Plan for Clean Air to improve air quality and community health and wellbeing.

More specifically, the NEPC has two primary functions that are to:

- Make National Environment Protection Measures (NEPMs); and
- Assess and report on the implementation and effectiveness of NEPMs in participating jurisdictions.

NEPMs are broad framework-setting statutory instruments that are agreed on by Australian, State and Territory governments. They outline an agreed consistent national approach for protecting or managing particular aspects of the environment. Each of the State and Territory environment protection agencies have their own legislative frameworks to implement the NEPMs in their respective jurisdiction and are required to comply with the NEPMs.

It should also be noted that COAG has a priority aim to develop and implement a National Plan for Clean Air to improve air quality and community health and well-being.

The National Waste Policy 'Less Waste, More Resources' (2009) provides direction for Australia to produce less waste for disposal and manage waste as a resource to deliver economic, environmental and social benefits until 2020. The associated 2010 Implementation Plan presents the aims, key directions, priority strategies and roles and responsibilities of governments (Federal and State) as outlined in the National Waste Policy: Less Waste, More Resources.

The National Waste Policy discusses the significance of WtE and its relevance to enhancing organic resource recovery and the opportunity to reduce greenhouse gas emissions from landfills. The Policy cites the important role of State and Territory Governments in building on their existing programs, including the need to consider the use of alternative waste treatment technologies, WtE plants and bio-digesters.

National Pollution Inventory

The National Pollutant Inventory (NPI) was developed under the National Pollution Inventory NEPM. The NPI tracks pollution across Australia, and provides the community information about the emission and transfer of toxic substances which may affect them locally.

The NPI is an internet database designed to provide the community, industry and government with information on the types and amounts of certain substances being emitted to the environment. The NPI contains data on 93 substances emitted to land, air and water that have been identified as important due to their possible effect on human health and the environment. The data comes from facilities like mines, power stations and factories, and from other sources such as households and transport.

National Fiscal Drivers

Australia has recently introduced a carbon tax, which came into effect on 1 July 2012. Under the scheme, approximately 500 of the biggest carbon polluters in Australia will be required to pay for pollution under a carbon pricing mechanism. Under the pricing mechanism, the carbon price will be fixed for the first three years, starting at AUS$23 per tonne of carbon dioxide (CO_2). From year four it will be determined by the market.

Most landfills within Australia will be captured under the recently introduced carbon tax scheme so there is an expectation that landfill prices will increase across the board from 1 July 2012. Landfills which generate more than 25,000 tonnes of greenhouse gases a year will pay the carbon tax.

Moreover, landfills in Australia often have waste levies, which are set by each State or Territory.

As an incentive to increase the production of renewable energy, renewable energy power stations can produce large-scale generation certificates, which provide a revenue opportunity for facilities that can demonstrate renewable energy generation.

Renewable Energy (Electricity) Act 2000

The Renewable Energy (Electricity) Act 2000 provides legislative basis for the uptake of renewable energy within Australia. It does this by legislating for the recognition and accreditation of renewable energy producers, liable entities that need to acquire renewable electricity and for the creation, transfer, and use of renewable energy certificates, either when the certificates are small-scale technology certificates (STCs) or large-scale generation certificates (LGCs).

Moreover, section 17 of the act sets out what is an eligible renewable energy source, and while materials or waste products derived from fossil fuels are not eligible renewable energy sources, several biogenic wastes are eligible with respect to obtaining large scale generation certificates for accredited power stations. These eligible renewable energy sources include:

- energy crops;
- wood waste;
- agricultural waste;
- waste from processing of agricultural products;
- food waste;
- food processing waste;
- bagasse;
- biomass based components of municipal solid waste; and
- biomass based components of sewage.

Although this differs somewhat to the Renewables Obligation Certificates (ROCs) employed in the UK, it is functionally similar and aims to achieve the same effect.

The Renewable Energy Target (RET) Scheme is an undertaking that by 2020, 20% of Australia's electricity supply will be sourced from renewable sources.

Carbon Pricing and Clean Energy Legislation

The National Greenhouse and Energy Reporting (Measurement) Determination 2008 (the Determination) supports the aims of the Clean Energy Act 2011 and the National Greenhouse and Energy Reporting Act 2007. In the Determination there are methods for calculating the covered CO_2e from waste incineration. The methods available to estimate emissions include:

- though derived means, using knowledge of the waste inputs and likely oxidising factors for waste inputs entering the incineration process (under 5.53), or
- through direct measurement (under Part 1.3 Method 4) or
- through another emissions calculation method that is consistent with the General principles for measuring emissions (under 1.13 of the determinations).

National Environment Protection Council Act 1994 (NEPC Act)

This Act establishes the NEPC which is a national ministerial body with the responsibility to develop appropriate national legislation to be protective of the environment (media including - air (quality and noise), water, soil and groundwater). This Act is mirrored in all States and Territories.

Ambient Air Quality NEPM 1998

The National Environment Protection Measure for Ambient Air Quality (Air NEPM) was made in 1997 and specifies standards and goals for ambient levels of the 'criteria' air pollutants. The criteria pollutants are ubiquitous in urbanised areas and are general indicators of air quality.

The Air NEPM sets national standards for the six key air pollutants to which most Australians are exposed: carbon monoxide, ozone, sulfur dioxide, nitrogen dioxide, lead and particulates. Under the Air NEPM, all Australians have the same level of air quality protection.

Environment Protection and Biodiversity Conservation Act 1999 & Environment Protection and Biodiversity Conservation Regulations 2000

The Act is the primary Commonwealth legislation directed to protecting the environment in relation to Commonwealth land and controlling significant impacts on matters of national environmental significance. The Act requires assessment and approval of actions that either will significantly affect matters of national environmental significance, or are undertaken by a Commonwealth agency or involve Commonwealth land and will have a significant effect on the environment.

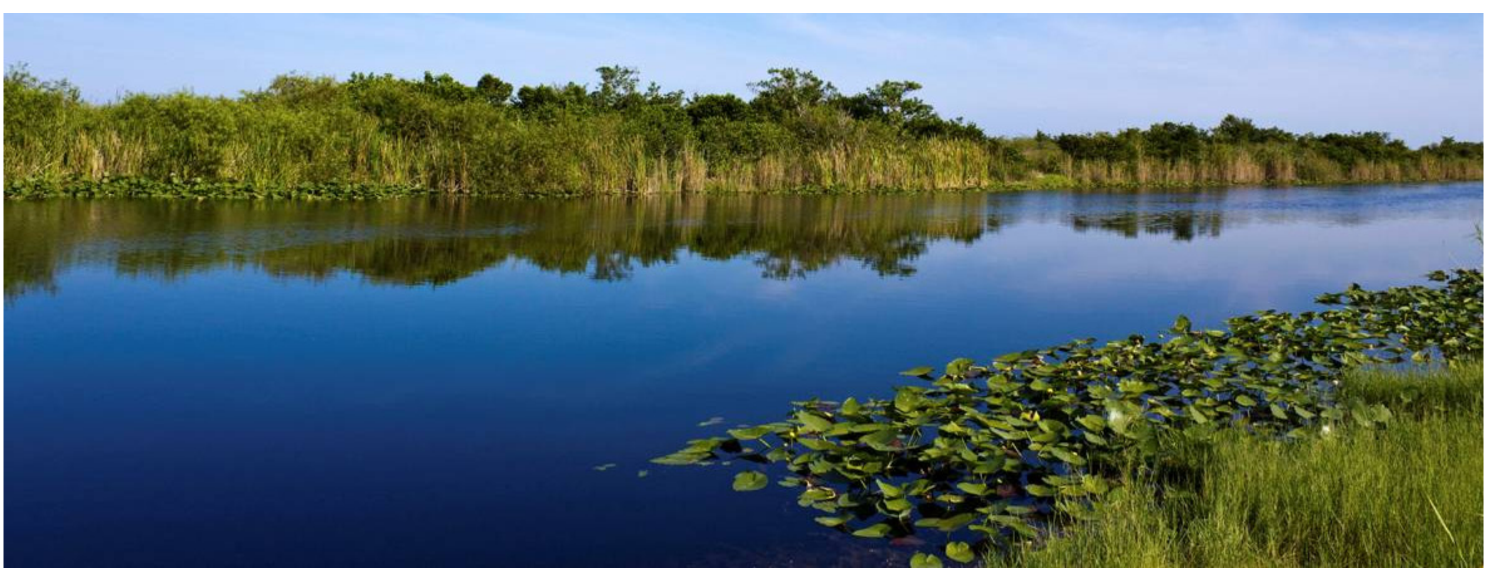
Air Toxics NEPM 2004

The National Environment Protection (Air Toxics) Measure (Air Toxics NEPM) establishes 'monitoring investigation levels' for five specified air toxics. Monitoring data gathered under the Air Toxics NEPM will inform future decisions on the management of these pollutants.

Air Emissions Standards

Australia does not have national air emissions standards applicable to industrial facilities such as WtE plants. Environment protection authorities in individual States and Territories set such standards. Specific air emission targets are generally set for a development as part of the licencing and permitting stage and are site specific with respect to location, adjacent uses and meteorology.

For State level implementation of National Standards, refer to the accompanying Stage 1 report Review of Legislative and Regulatory Frameworks for Waste to Energy Plants.



2.3 European Union (EU) and Wider Europe

EU waste policy aims to coordinate and contribute to increasing resource efficiency and reducing the negative environmental and health impacts over the life-cycle of resources throughout the EU, founded on the basic principles of preventing waste and promoting reuse, recycling and recovery so as to reduce the negative environmental impact.

'Towards a Thematic Strategy on the Prevention and Recycling of Waste' May 2003

The strategy specified a long-term goal for the EU to become a recycling society, seeking to avoid waste as far as possible and to use waste that is generated as a resource. It proposed a combination of measures promoting waste prevention, recycling and reuse in such a way as to produce the optimum reduction in the accumulated impact over the life cycle of resources, including:

- A renewed emphasis on full implementation of existing legislation;
- Simplification and modernisation of existing legislation;
- Introduction of life-cycle thinking into waste policy;
- Promotion of more ambitious waste prevention policies;
- Better knowledge and information;
- Development of common reference standards for recycling; and
- Further elaboration of the EU's recycling policy.

A 2011 review of the strategy concluded that it has played an important role in guiding policy development and improvement and gives specific reference to the simplification of legislation, the establishment and diffusion of key concepts, such as the waste hierarchy and life-cycle thinking, on setting focus on waste prevention, on co-ordination of efforts to improve knowledge and on setting new European collection and recycling targets.

Report on a Resource-Efficient Europe May 2012

In May 2012 the EC published a 'Report on a Resource-Efficient Europe'. As well as proposing an end to waste to landfill, the plans approved by the EU will see a cap set on the amount of recyclable and compostable waste that can be sent for energy recovery via incineration imposed across the continent. The following is an extract form this report on this issue:

'….calls on the Commission to streamline the waste acquis (the accumulated legislation, legal acts, and court decisions which constitute the body of European Union law), taking into account the waste hierarchy and the need to bring residual waste close to zero; calls on the Commission, therefore, to make proposals by 2014 with a view to gradually introducing a general ban on waste landfill at European level and for the phasing-out, by the end of this decade, of incineration of recyclable and compostable waste; this should be accompanied by appropriate transition measures including the further development of common standards based on life-cycle thinking; calls on the Commission to revise the 2020 recycling targets of the Waste Framework Directive; is of the opinion that a landfill tax – as has already been introduced by some Member States – could also help achieve the above ends;…'

Environmental legislation and policy is well established within Europe. The EC is responsible for drafting proposals for new legislation within the EU, managing the day-to-day business of implementing policies and ensuring that the EU Member States abide by the numerous treaties and laws. Member States are obliged to implement EU Directives through national regulations and policy.

Integrated Pollution Prevention Control Directive (IPPC) 2008/1/EC

IPPC defines the obligations with which industrial and agricultural activities with a high pollution potential must comply. It establishes a procedure for authorising these activities and sets minimum requirements to be included in all permits, particularly in terms of pollutants released. The aim is to prevent or reduce pollution of the atmosphere, water and soil, as well as reducing the quantities of waste arising from industrial and agricultural installations, to ensure a high level of environmental protection. It also focuses on the prudent use of natural resources.

IPPC manages the activities of significant sites, called 'installations' by regulating and permitting:

- Raw material and energy use;
- How the site operates and the technology used;
- Emissions into air, water and land;
- How any waste produced is managed; and
- Accident prevention.

In order to receive a permit, an industrial or agricultural installation must comply with certain basic obligations and the decision to issue a permit must contain a number of specific requirements, including:

- Emission limit values for polluting substances (with the exception of greenhouse gases if the emission trading scheme applies);
- Any soil, water and air protection measures required;
- Waste management measures;
- Measures to be taken in exceptional circumstances (leaks, malfunctions, temporary or permanent stoppages, etc.);
- Minimisation of long-distance or trans-boundary pollution;
- Release monitoring; and
- All other appropriate measures.

Waste Framework Directive (WFD) 2008/98/EC

European Commission Directive 2008/98/EC (known as the revised Waste Framework Directive) entered in to force in December 2008 and sets out the basic concepts and definitions related to waste management and lays down waste management principles such as the 'polluter pays principle' and the 'waste hierarchy'. It aims to set a framework for waste management in the EU, promoting both reuse and recycling, including energy recovery as a recovery activity within a revised waste management hierarchy and dealing with 'end of waste' classification.

The incorporation of lifecycle thinking in waste management solutions has caused some controversy in some Member States (refer to UK regulatory framework section for a specific example). The EC has recently ruled lifecycle impacts can take precedence over the waste hierarchy for certain materials and has produced detailed guidance, legally binding for all EU Member States. The EC has declared that the rules can be deviated from if it can be proven that following the hierarchy would not be in the 'best environmental interest' of a product's lifecycle.

'For special waste streams Member States are allowed to depart from the waste hierarchy when this is justified by lifecycle thinking on the overall impacts of the generation and management of those specific waste streams.'

In general, it continued, the waste hierarchy should apply 'as a priority order in waste prevention and management legislation and policy' while allowing Member States a 'degree of flexibility'.

The EC is committed to developing end-of-waste criteria for materials such as aggregate, paper, glass, metal, tyres and textiles.

The WFD sets out a range of provisions in relation to recycling and reuse, setting targets for increasing recycling rates for both household and construction and demolition (C&D) waste.

The targets in the Directive are:

- To recycle or prepare for reuse 50% of household waste by 2020; and
- To reuse, recycle or recover 70% of non-hazardous C&D waste by 2020.

It also specifies a requirement to set up separate collection of 'at least the following: paper, metal, plastic and glass', from the household waste stream by 2015 and the separate collection of waste paper, metal, plastic and glass from businesses from January 2015, where technically, environmentally and economically practicable. This has been seen as controversial in its interpretation in some Member States e.g. the UK, where the relevant merits of co-mingled and source-separated recycling collections have been debated at Government level. In June 2012, the EC confirmed this requirement can be met by co-mingled collections of recyclables if high quality recycling is achieved.

R1 Energy Recovery

The EU had considered the incineration of waste in a WtE plant to be a 'disposal' activity and not a 'recovery' (of energy) activity. The revision of the WFD has caused this subject to be discussed at length in Brussels as it is related to the European policies on climate change. Proposals have been made to allow a WtE plant to be considered as a recovery operation if it meets a thermal efficiency index (R1) currently proposed to be 0.6 for existing plants and 0.65 for new plants. This outcome ensures that any new proposed WtE plant that demonstrates an R1 value above 0.65 would be consider a 'resource recovery' plant and therefore sit higher up the waste hierarchy than less efficient plants. Such plants may also be at an advantage when seeking to gain political approval whereas for a project classified as a low efficiency 'disposal' plant may find political approval more challenging to secure.

Typically, the energy efficiency of a WtE plant, based on the ratio of 'useful energy out' to 'energy in', is in the range 18-22% for older plants producing electricity only. Modern plants, particularly at large scale, can meet the criterion on the basis of producing only electricity, due mainly to improved boiler design and enhancements to the high pressure steam cycle, achieving efficiencies in the region 25-27%. These plants readily achieve the R1 criterion of >0.65 and are thereby classified in the EU as recovery operations. There are unique facilities such as the Amsterdam plant discussed in case study of the appended Stage 2 report that has taken steam cycle modification to the extreme and achieve a continuous efficiency of 30%.

The use of Combined Heat and Power (CHP) can dramatically increase the thermal efficiency and help to meet the R1 recovery criterion.

In 2009, the Confederation of European Waste-to-Energy Plants (CEWEP) published its updated Energy Report II (status 2004-07) providing specific data for energy, R1 plant efficiency factor and Net Calorific Value for 231 European Waste-to-Energy plants. It found 'electricity only' plants were achieving the lowest R1 factor of 0.64 as a non-weighted average, and that only 46 out of 75 are reaching the R1 standard i.e. ≥0.6. In contrast, combined heat and power (CHP) plants achieved the highest R1 factors at 0.84 as a non-weighted average, and that 98 out of 115 are reaching the R1 standard.

Landfill Directive

The Landfill Directive aims to prevent or reduce as far as possible negative effects on the environment, in particular the pollution of surface water, groundwater, soil and air, and on the global environment, including the greenhouse effect, as well as any resulting risk to human health, from the landfilling of waste, during the whole life-cycle of the landfill. It supplements the IPPC Directive by setting a variety of technical standards of operation for landfill and sets out a timetable for existing sites to be brought up to standard or close.

The Directive requires, amongst other objectives, that a biodegradable waste strategy is enacted by each member state that achieves the progressive diversion of biodegradable municipal waste from landfill. The Directive set targets for reducing the quantity of biodegradable material sent to landfill to 35% of 1995 figures by 2020.

It also required changes to the way waste was landfilled in the EU, including:

- Certain wastes were banned from landfill;
- All landfill sites were to be classified specifically for inert waste, hazardous waste or non-hazardous waste, the latter category covers most biodegradable waste;
- Outlined standard waste acceptance criteria (WAC) for different classes of landfill;
- Introduced the requirement to pre-treat waste going to landfill (treatment could include sorting); and
- Required the UK practice of co-disposal in landfills of hazardous and non-hazardous waste to end by July 2004.

Waste Incineration Directive (WID)

Whilst the Industrial Emissions Directive (IED) replaces WID as part of the overall recast of the seven specified established waste directives, in advance of Member States' implementation in their respective domestic regulations, this section summarises the requirements of WID since implementation within the EU.

The aim of WID is to prevent or limit, as far as practicable, negative effects on the environment, in particular pollution by emissions into air, soil, surface and groundwater and any resulting risks to human health, from the incineration and co-incineration of waste. It aimed to achieve this high level of environmental and human health protection by requiring the setting and maintaining of stringent operational conditions, technical requirements and emission limit values for plants incinerating and co-incinerating waste throughout the EU.

In order to guarantee complete waste combustion, WID requires all plants to keep the incineration or co-incineration gases at a temperature of at least 850°C for at least two seconds after the last injection of air. If hazardous waste with a content of more than 1% of halogenated organic substances, expressed as chlorine, is incinerated, the temperature has to be raised to 1,100 °C for at least two seconds after the last injection of air. The heat generated by the incineration process has to be put to good use as far as practicable.

For emissions to air, the limit values for incineration plants are set out in Annex V to the Waste Incineration Directive and Table 1 compares the specific WID requirements with those adopted by Member States and Norway.

Table1: Air Emission Limit Values as applied in Europe for waste incineration plants

		Averaging Periods	EU WID/IED	Sweden	Norway	Germany	Netherlands	UK
Particulates	mg/Nm^3	Daily	10	10	10	10	5	10
TOC	mg/Nm^3	min 0.5 max 8hrs	10	10	10	10	10	10
HCl	mg/Nm^3	Daily	10	10	10	10	10	10
HF	mg/Nm^3	Daily	1	1	1	1	1	1
SO_2	mg/Nm^3	Daily	50	50	50	50	50	50
NO_X	mg/Nm^3	Daily	200 /400[1]	200 /400[1]	200	200	200	200 /400[1]
CO	mg/Nm^3	Daily	50	50	50	50	50-150[2]	50
Hg[3]	mg/Nm^3	Daily	N/A	N/A	0.03	0.03	N/A	N/A
		min 0.5 max 8hrs	0.05	0.05	N/A	0.05	0.05	0.05
Cd,Tl	mg/Nm^3	min 0.5 max 8hrs	0.05	0.05	0.05	0.05	0.05	0.05
Metals	mg/Nm^3	min0.5 max 8hrs	0.5	0.5	0.5	0.5	0.5	0.5
Dioxins and Furans[4]	ng/Nm^3	min 6 hrs max 8 hrs	0.1	0.1	0.1	0.1	0.1	0.1

1 - 200 for existing waste incineration plants with a nominal capacity exceeding 6 tonnes per hour or new waste incineration plants, 400 for less than 6 tonnes per hour
2 - 97% of daily average is 50 mg/m^3, all half-hourly average in any 24 hour period is 100 mg/m^3 or 95% of all 10-minute average in any 24 hour period is 150 mg/m^3
3 – WID specifies a min 0.5-max 8hrs averaging period for Hg, Germany also have a daily limit and Norway, who is not within the scope of WID, only have a daily average limit
4 - The emission limit value refers to the total concentration of dioxins and furans calculated using the concept of toxic equivalence in accordance with Annex I.

Member States may interpret and adapt WID to align with their own regulatory requirements e.g. the NO_X and CO emission limit values in the Netherlands.

For emissions to water, the ELVs for incineration plants are set out in Annex IV to the WID and Table 2 compares the specific WID requirements with those adopted by Member States and Norway.

Table 2: ELVs for discharges of wastewater

	Suspended Solids	Hg	Cd	Tl	As	Pb	Cr	Cu	Ni	Zn	Dioxins & Furans
	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	ng/l
EU WID/IED	30-45	0.03	0.05	0.05	0.15	0.20	0.50	0.50	0.50	1.50	0.30
Sweden	30-45	0.03	0.05	0.05	0.15	0.20	0.50	0.50	0.50	1.50	0.30
Norway	30-45	0.03	0.05	0.05	0.15	0.20	0.50	0.50	0.50	1.50	0.30
Germany	30-45	0.03	0.05	0.05	0.15	0.10	0.50	0.50	0.50	1.00	0.30
Netherlands	30-45	0.03	0.05	0.05	0.15	0.20	0.50	0.50	0.50	1.50	0.30
UK	30-45	0.03	0.05	0.05	0.15	0.20	0.50	0.50	0.50	1.50	0.30

Industrial Emissions Directive (IED)

The IED entered into force in January 2011 and aims to reduce emissions from industrial activities with a major pollution potential defined within Annex I to the Directive; for the purpose of this report it specifically includes WtE installations. Operators of industrial installations undertaking the prescribed activities are required to obtain an integrated permit from the competent authority in each EU member country. It is important to note that the emissions limits to be contained in the IED will be identical to those currently defined in the Waste Incineration Directive (WID) and there are currently no specific plans to amend the emissions limits for WtE plants operating in the EU.

The IED is based on several principles, namely an integrated approach, best available techniques, flexibility, inspections and finally, public participation.

The primary aim of the IED is to achieve significant benefits for the environment and human health by reducing harmful industrial emissions. Permit conditions and pollutant emission limit values (ELVs) have to be set on the basis of the application of Best Available Techniques (BAT), as specified in the relevant **BREF** or 'BAT reference document'. Associated Emission Levels (BAT AEL) are the expected range of emissions where BAT is applied. BAT conclusions become the reference point for applying permit conditions, specifying emission limit values less than or no greater than the BAT AELs.

The periodic review of BREFs and developments in BAT may lead to adoption of new technologies or improved abatement. This in turn may require industry to invest in new technology to ensure compliance.

Permits issued by the competent authority in each Member State must provide for the necessary measures to ensure compliance with the operator's basic obligations and environmental quality standards. These measures must comprise at least:

- ELVs for polluting substances;
- Rules guaranteeing protection of soil, water and air;
- Waste monitoring and management measures;
- Requirements concerning emission measurement methodology, frequency and evaluation procedure;
- An obligation to inform the competent authority of the results of monitoring, at least annually;
- Requirements concerning the maintenance and surveillance of soil and groundwater;
- Measures relating to exceptional circumstances (leaks, malfunctions, momentary or definitive stoppages, etc.);
- Provisions on the minimisation of long-distance or transboundary pollution; and
- Conditions for assessing compliance with the emission limit values.

The IED contains certain elements of flexibility by allowing the competent authorities to set less strict ELVs in specific cases, only applicable where an assessment shows that the achievement of emission levels associated with BAT as described in the BAT conclusions would lead to disproportionately higher costs compared to the environmental benefits due to either geographical location, local environmental conditions or the technical characteristics of the installation. The competent authority however, must always document the reasons for the application of the flexibility measures in an annex to the permit including the result of the cost-benefit assessment and as with IPPC before, this is open for examination by the EC.

For State level implementation of National Standards, refer to the Appended Stage 1 main report.

2.4 Japan

Over the last decade, Japan has shifted from a waste management policy to an integrated waste and material management approach that promotes de-materialisation and resource efficiency. Landfill shortage and dependency on natural resources imports have been key drivers of these changes. There has been a considerable push to increase recycling by requiring households to sort waste into various fractions. Individual municipalities are free to establish sorting guidelines, so the level of separation varies quite widely. Waste is typically sorted into around eight fractions, though some municipalities require waste to be sorted into as many as 44 different categories. This leads to variations in the residual waste stream that may be treated via WtE as the recycling rate varies by municipality.

Japan currently has a surplus of thermal waste treatment capacity. This is a result of two main factors:

- the long-term reliance on incineration for waste disposal; and
- a recent decrease in the volumes of residual waste due to the substantial increase in recycling levels over the previous 10 years.

Fiscal Drivers

There is no national landfill tax. Historically, incineration has been the primary disposal route for waste in Japan due to a lack of space for landfills and the requirement for waste to be disposed of locally, so there is no strong driver to reduce landfill dependence in a country that has limited existing capacity and little potential for future capacity. Additionally, the recycling laws prevent much commercial biodegradable waste from entering landfills.

Regulatory Framework

Waste management in Japan is a responsibility of the Ministry of the Environment. The fundamental principles governing environmental protection are set out in the Basic Environmental Law (1994). Japan has three levels of governance:

- Central government;
- Prefectures; and
- Municipalities.

Each level has different responsibilities relating to waste management. Central government oversees waste management with a duty to collect waste information, promote waste management technology development and provide funding to the prefectures and municipalities to allow them to carry out their duties. The prefectures formalise waste plans and grant licences for waste disposal facilities, and also have the power to set emissions limits. It is then for the individual municipalities within the prefecture to oversee the development of waste infrastructure.

Prior to the 1990s, waste regulation in Japan focussed on disposal and energy recovery whilst recycling was not prioritised. Incineration has historically been the primary disposal route for waste due to limitations on space for landfill in proximity to urban areas as a result of the country's geography. However, the introduction of a raft of new legislation in the late 1990s and early 2000s saw a major shift in policy to increase the recycling rate substantially as well as substantially improving the environmental performance of incineration and WtE facilities.

Permits are issued by the Prefectural Governments and Planning Control is the responsibility of the municipalities.

Basic Law for Promoting the Creation of a Recycling-Oriented Society (2000)

The basic framework law governing waste and resources is the Basic Law for Promoting the Creation of a Recycling-Oriented Society (2000), which came into force in January 2001. This law establishes the basic principles of waste management and sets out roles and responsibilities for national and local government with respect to the management, recovery and disposal of waste. At its core is the promotion of the 3Rs; Reduce, Reuse and Recycle. The law seeks to create a recycling-oriented society, promoting the priority order (the equivalent of the waste hierarchy in the EU Waste Framework Directive.

Waste Management and Public Cleansing Law (2001)

The law was first enforced in 1970 and has been updated numerous times. It is solely applicable to the final disposal of waste, covering the following:

- Proper waste disposal;
- Regulations for setting up waste disposal facilities;
- Regulations on waste disposal businesses;
- Establishment of criteria for waste disposal;
- Measures to control improper disposal; and
- Development of facilities through participation of the public sector.

Of note is that the incineration of waste without thermal energy recovery is considered a disposal operation. As such this law was relevant to many incineration plants prior to the introduction of the Basic Law for Promoting the Creation of a Recycling-Oriented Society, as the emphasis was strongly on incineration as a volume reduction and disposal process rather than an energy recovery operation. Many plants were small scale serving individual municipalities and the generation of electricity or recovery of heat was uneconomic. However, given the increasing emphasis on recycling and recovery, modern WtE plants are incentivised to recover energy (as well as recycling ash) an activity classed as 'thermal recycling', particularly the use of plasma melters to vitrify the bottom and fly ash from incineration plants to be recycled into construction applications. Hence modern WtE is not considered to be a disposal activity and this law therefore does not apply to WtE.

Law for Promotion of the Effective Utilisation of Resources (2001)

The law was first enforced in 2001 and includes the following:

- Prevention and recycling of
- by-products;
- Utilisation of recycled resources and parts;
- Self-collection and recycling of used products; and
- Promotion of effective utilisation of by-products.

The law is essentially a framework providing guidance to ensure minimisation, re-use and recycling of waste.

WtE Regulatory Framework

The regulatory regime governing environmental impacts from WtE plants in Japan is set out in the Japan Environmental Governing Standards (JEGS) 2010. There are a number of important definitions in the JEGS, and in many cases the definitions differ from the equivalent term in the EU and other regions:

- Municipal Solid Waste – includes 'any household, commercial/retail or institutional waste'; and
- Commercial and Industrial Solid Waste – limited to industrial wastes such as waste oils, sludges, construction and demolition residues etc.

The differences are important as there are different emissions limits depending on the type of feedstock being treated.

National air emissions limits are provided in Chapter 2 of the JEGS and these standards set out the minimum emissions levels that all new and existing incineration plant (and other industrial facilities) must achieve. There is no legislation that applies specifically to incineration as there is in the EU.

Certain emissions limits vary depending on a range of factors, including:

- Age of the plant;
- Feedstock (in particular whether the plant treats Municipal Solid waste or Commercial and Industrial Solid waste);
- Treatment capacity; and
- Technology type.

To enable comparison of JEGS emission limit values with EU WID, the values from JEGS (expressed as parts per million) have been converted to mg/Nm^3 and all concentrations normalised to an 11% oxygen basis. A summary is provided in Tables 3, 4 and 5.

Table 3: Air Emission Limit Values

Incinerator Type		Existing Municipal Waste Combustion Plant		New or substantially modified Municipal Waste Combustion Plant		Commercial and Industrial Waste Incineration Plant
Rated Capacity	Units	35-250 tpd	>250 tpd	35-250 tpd	>250 tpd	All units
Particulate	mg/Nm^3	50	19	17	17	50
Opacity		10%	10%	10%	10%	10%
NO_X (expressed as NO_2)	mg/Nm^3	None	Depends on technology	723	217	561
SO_2	mg/Nm^3	155	58	60	60	40
Dioxins/Furans	ng/Nm^3	89.0	21.4	9.3	9.3	0.3
Cadmium	mg/Nm^3	0.07	0.03	0.01	0.01	0.00
Lead	mg/Nm^3	1.14	0.31	0.14	0.14	0.03
Mercury	mg/Nm^3	0.06	0.06	0.06	0.06	0.33
HCl	mg/Nm^3	287	33	34	29	71

Table 4 Carbon Monoxide Emission Limit Values

<table>
<tr><th>Incinerator Type</th><th></th><th colspan="2">Existing Municipal Waste Combustion Plant</th><th colspan="2">New or substantially modified Municipal Waste Combustion Plant</th><th>Commercial and Industrial Waste Incineration Plant</th></tr>
<tr><td>Rated Capacity</td><td>Units</td><td>35-250 tpd</td><td>>250 tpd</td><td>35-250 tpd</td><td>>250 tpd</td><td>All units</td></tr>
<tr><td>Fluidised Bed</td><td>mg/Nm3</td><td colspan="4">137</td><td rowspan="9">214</td></tr>
<tr><td>Fluidised Bed, mixed Fuel (wood/ RDF)</td><td>mg/Nm3</td><td colspan="2">274</td><td>274</td><td>137</td></tr>
<tr><td>Mass burn rotary refractory</td><td>mg/Nm3</td><td colspan="2">137</td><td colspan="2" rowspan="2">137</td></tr>
<tr><td>Mass burn rotary waterfall</td><td>mg/Nm3</td><td colspan="2">342</td></tr>
<tr><td>Mass burn waterfall and refractory</td><td>mg/Nm3</td><td colspan="2">137</td><td colspan="2">137</td></tr>
<tr><td>Mixed fuel fired (pulverized coal/ RDF)</td><td>mg/Nm3</td><td colspan="2">205</td><td colspan="2">205</td></tr>
<tr><td>Modular starved-air and excess air</td><td>mg/Nm3</td><td colspan="2">68</td><td colspan="2">68</td></tr>
<tr><td>Spreader stoker, mixed fuel fired (coal/RDF)</td><td>mg/Nm3</td><td colspan="2" rowspan="2">274</td><td colspan="2" rowspan="2">205</td></tr>
<tr><td>Stoker, RDF</td><td>mg/Nm3</td></tr>
</table>

Table 5: Dioxin Emission Limit Values

Capacity (tonnes per hr)	Units	New	Existing
=>4	ng TEQ/Nm^3	0.1	0.7
2-4	ng TEQ/Nm^3	0.7	3.6
<2	ng TEQ/Nm^3	3.6	7.1

A full version of the JEGS emission limit values for air and water is provided in the appended full Stage One report.

It is noteworthy that the national emissions limits are in many cases substantially less stringent than for WID. For example small plants can emit 50 times the level of dioxins/furans than an equivalent plant in the EU.

For 'existing' plants the dioxin/furan limits are higher still (note 'existing' plants are defined in the JEGS as those plants constructed prior to December 1997, 'new' plants are those constructed after this date).

The JEGS include two emissions limits tables specifically apply to incineration plant. However, plants must also comply with other emissions limits in a range of other tables, leading in many cases to several emissions limits for the same pollutant. It is assumed that the figures in the incineration-specific tables take precedence.

However, the JEGS allow Prefectural Governments who plan to construct waste treatment facilities to decide on emissions limits in accordance with emission regulation of local government and/or agreement with communities.

Air Emissions Limits - Regional

The national emissions limits are a baseline minimum in the absence of more specific limits that may be set at a regional level. Prefectural governments are free to set their own, more stringent limits specific to their jurisdiction. This results in significant differences across the country, with more heavily urbanised areas typically setting stricter limits than more rural prefectures. For example, predominantly urban Saitama Prefecture has a very strict dioxin limit, 50 times lower than the much more rural Aomori Prefecture. An implication of this is that certain WtE technologies may be appropriate in one prefecture but not in another due to an inability to comply with the emissions standards.

The differences between emissions limits in each prefecture results in a complex picture nationwide. Data for all 47 prefectures could not be obtained, but a sample of emission limits in four prefectures is provided in Table 6.

Table 6: Example of Emission Limit Variation by Prefecture

Pollutant	Unit	Prefecture			
		Kanagawa	Saitama	Miyagi	Aomori
Dust	g/Nm^3	0.005	0.02	0.02	0.01
SO_X	ppm	10	10	50	20
NO_X	ppm	30	50	60	150
HCl	ppm	10	10	50	50
CO	ppm	30 (4hr average)	30 (4hr average)	30 (4hr average)	30 (4hr average)
Dioxins	ng/TEQ/m^{3}N	0.05	0.005	0.01	0.1
Capacity of plant	tonnes/day	525	265	230	60

Municipal Solid Waste - Local Government Responsibility

Incineration has historically been used to dispose of a far greater proportion of waste than in most countries. In 2008, 74% of all waste produced in Japan was thermally treated, with just 2% sent to landfill. This is primarily a result of a lack of available land for landfills near urban areas (a high population in a relatively small habitable area). Municipalities are required to dispose of their waste within their own boundaries where possible, though several neighbouring municipalities may partner to develop a common waste treatment plant if there are insufficient waste arisings.

The requirement to treat waste at a local municipality level (i.e. individual cities, towns and villages) has resulted in the construction of a very large number of relatively small scale incineration plants, typically based on grate combustion technology. In 2008 Japan had 1,269 waste incineration plants for the treatment of 35.7 million tonnes of Municipal Solid Waste, the average size of which is well below that of the average Europe plant (less than 30,000 tonnes per year). Japan is one of the few countries with an overcapacity of incineration plant as recycling rates have increased substantially since the turn of the century.

Historically energy recovery was not a high priority for incineration plant in Japan. Only relatively recently has the focused changed from waste disposal (volume reduction) to energy recovery (or 'thermal recycling').

2.5 United States

The regulatory framework applicable to WtE operations in the US is at best complex. At the federal level (which covers all States, territories, and protectorates), there is no single body of laws that regulate WtE siting, construction, and operation. Instead, each aspect is governed by a series of laws and regulations that must be taken into consideration during all phases of selecting a facility location, constructing the facility, operating the facility, and closing down the operation at end of life.

The USEPA has identified the potential environmental impacts having the most significance with respect to WtE facilities to include air emissions (nitrogen oxides, sulfur dioxide, CO_2, and trace amounts of mercury compounds [and potentially other metals] and dioxins/furans), water use (for cooling water and steam generation), water discharges (cooling water, wastewater, and storm water runoff), solid waste generation (ash and other residue), and land resources (resulting from the physical location and operation of the plant and related ash landfill). There are individual federal laws that address each of these impacts and others that regulate specific aspects of facility operations such as management of the MSW fuel source and hazardous materials that may be used in the process.

Many of the federal laws require participation by the states with respect to enforcing federal regulations within each state including developing and implementing matching programs at the state level. States (many, but not all) also have promulgated laws that go well beyond the federal regulations and include stricter compliance criteria. For example, many states have passed regulations requiring the application of stricter air quality criteria to emissions than the federal government has included in the Clean Air Act. At the state level, there are also a number of additional laws that are applicable to WtE facilities to address regional issues including water use, groundwater protection, geological concerns (e.g., site stability), storage tank registration and testing, contingency planning, and emergency preparedness. Some states have developed a fairly comprehensive approach to regulation and permitting of WtE facilities and power generating facilities in general, while others have no formalised program.

In the US, there are also individual municipalities within the states that have enacted local environmental laws that would apply to and potentially further restrict WtE operations. The most significant of these municipal laws tend to be found in larger cities, such as New York (which has a robust set of environmental regulations that apply to various activities conducted within the city limits), Los Angeles, and Chicago, although many smaller cities and counties also have laws and ordinances that are applicable to WtE operations including those governing such issues as land use, water rights, occupancy permits, permits to operate, noise limits, control of odours, traffic-related impacts, water discharges, storm water impacts from construction activity, and operation of pollution control equipment.

National Environmental Policy Act (Federal Law)

The National Environmental Policy Act (NEPA) was passed in 1969 and requires an environmental review to be conducted before any major federal action is undertaken. Each federal agency has developed its own program for compliance with NEPA requirements and the USEPA plays a significant role in the NEPA process both for its own activities as well as for those of other agencies. Given the wide applicability of NEPA, it has been broadly interpreted over the years and may be applicable to any project that requires federal involvement such as the licensing of a power generation facility by the Federal Energy Regulatory Commission. The NEPA process is overseen by the federal Council on Environmental Quality and involves preparation of an Environmental Assessment (EA) and, if warranted, preparation of an Environmental Impact Statement (EIS).

The purpose of the EA is to determine whether the proposed project is likely to have a significant impact on the environment. There is an opportunity for public involvement and comment during preparation and review of the EA and input is generally sought from applicable federal, state, and local agencies that have an interest in the project. Upon completion of the review, there is either a Finding of No Significant Impact or a determination that an EIS must be prepared.

The EIS involves a more detailed and rigorous evaluation of the potential environmental impacts of the proposed project and generally follows a more formal review process. It can be a lengthy process requiring the development of significant supporting studies and reports. There is an opportunity for public review and comment at both the draft and final EIS stage and participation by interested stakeholders is encouraged throughout. The final decision regarding the EIS is published in a Record of Decision (ROD) and any requirements for mitigation of potential environmental impacts are included in the ROD.

Resource Conservation and Recovery Act

The regulatory framework for managing solid and hazardous wastes is established by the **Resource Conservation and Recovery Act (RCRA)**, which was originally passed in 1976 and significantly amended in 1984. For solid (non-hazardous) waste, which by definition includes MSW, the RCRA regulations cover:

- Requirements for state permit programmes;
- Guidelines for thermal processing of solid wastes;
- Guidelines for storage and collection of solid wastes;
- Guidelines for source separation for materials recovery;
- Procurement guideline for products containing recovered materials;
- Prior notice of citizen suits;
- Identification of regions and agencies for solid waste management;
- Guidelines for development and implementation of state solid waste management plans;
- Criteria for classification of solid waste disposal facilities and

practices; and
- Criteria for MSW landfills.

Within the RCRA regulations, there are specific requirements that govern the design and operation of both non-hazardous and hazardous waste management facilities. Individual States are encouraged by the USEPA to adopt State non-hazardous and hazardous waste management and permitting programmes that meet the minimum regulations established under RCRA. Currently, 50 States and territories have been authorised by the USEPA to implement baseline RCRA programmes.

Many States are also authorised to implement other parts of RCRA, including Corrective Action, but there is substantial variability among the States with respect to which parts of RCRA each is authorised to implement, and enforce. In cases where a State does not have an equivalent rule, the responsibility for enforcement under RCRA reverts to the federal level. As a result, it is possible to have solid waste management requirements for a site that are enforced jointly by a State regulatory agency and the USEPA.

Clean Air Act

The Clean Air Act (CAA), originally passed in 1970, is the comprehensive federal law that regulates air emissions from stationary and mobile sources. Among other things, this law authorises the USEPA to establish National Ambient Air Quality Standards (NAAQS) to protect public health and welfare and to regulate emissions of hazardous air pollutants.

One of the goals of the CAA was to set and achieve NAAQS in every state by 1975 to address the public health risks posed by certain widespread air pollutants. The setting of these standards was coupled with directing the states to develop state implementation plans (SIPs), applicable to appropriate industrial sources in each state, to achieve these standards. The CAA was significantly amended in 1977 and 1990 primarily to set new goals (i.e., dates) for achieving attainment of NAAQS since many areas of the US had failed to meet the original deadlines.

Although many sections of the CAA are potentially applicable to WtE facilities, Title I, Part A, Section 129 (added to the CAA in 1990) is specific to solid waste combustion and includes requirements pertaining to emissions standards (including numerical limits as performance standards or emission guidelines), control methods and technologies, facility monitoring, operator training, and permits. Under Section 129, the USEPA is required to establish New Source Performance Standards (NSPS) for new units and emission guidelines (EG) for existing units pertaining to particulate matter, opacity, sulfur dioxide, hydrogen chloride, oxides of nitrogen, carbon monoxide, lead, cadmium, mercury, dioxins/furans, and dibenzofurans. Both the NSPS and EG under Section 129 use a Maximum Achievable Control Technology (MACT) approach.

The NSPS are federal regulations that apply directly to all new sources, i.e., new municipal waste combustor (MWC) units that start up after the effective date of the NSPS must comply with the federal NSPS. The EG establish requirements for limits to be included in SIPs; once the SIPs are approved by the USEPA, they become federally enforceable. In accordance with Section 129, SIPs must have emissions limits that are at least as protective as the EG, but may be more restrictive.

It is important to note that the USEPA initiated the rulemaking process to establish NSPS or EG for most solid waste combustor units in the mid-1990s. Many of the rules have been amended several times or stayed by judicial authority pending the outcome of litigation brought by various interested parties. For large MWCs, the most recent version of the final rule for NSPS and EG was issued in May 2006; in March 2007, the USEPA announced that it was reconsidering certain aspects of the final rule (not including the emissions limits). For small MWCs, the most recent versions of the final rules for NSPS and EG (issued separately) were issued in December 2000. For CISWI, the most recent version of the final rule for NSPS and EG was issued in March 2011; since then, the USEPA has delayed the effective dates for the rules and indicated that it is reconsidering certain aspects of the final rule. For 'other' solid waste combustor units, the final rule for NSPS and EG was issued in January 2007.

Of recent and growing interest within the CAA are the regulatory initiatives developed to address greenhouse gas emissions from mobile and stationary sources. In 2009, the USEPA issued a finding under the CAA that six key greenhouse gases pose a threat to public health and welfare – carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride. As a result, several actions were either proposed or completed by the USEPA to implement the CAA requirements for greenhouse gases for stationary sources that include: emissions reporting and establishing greenhouse gas emissions thresholds that define when permits under the New Source Review/Prevention of Significant Deterioration and Title V Operating Permit programs are required (currently subject to the final Greenhouse Gas Tailoring Rule).

Emission Limit Values for Air and Water

Under the CAA, there are several sets of emissions standards that may apply for specific hazardous air pollutants. The final rules for NSPS and EG for large combustors existing and new, small combustors existing and new, and Commercial and Industrial Waste Incinerators (CISWI) all apply different limits, including general modifying criteria.

For water discharges under the CWA, there is not a single set of effluent criteria that will apply. The NPDES permit programme and industrial wastewater discharge limits are state and location-specific and are driven by the specific discharge activity and nature of the discharge.

For State level implementation of National Standards, refer to the Appended Stage 1 main report.

2.6 Conclusion

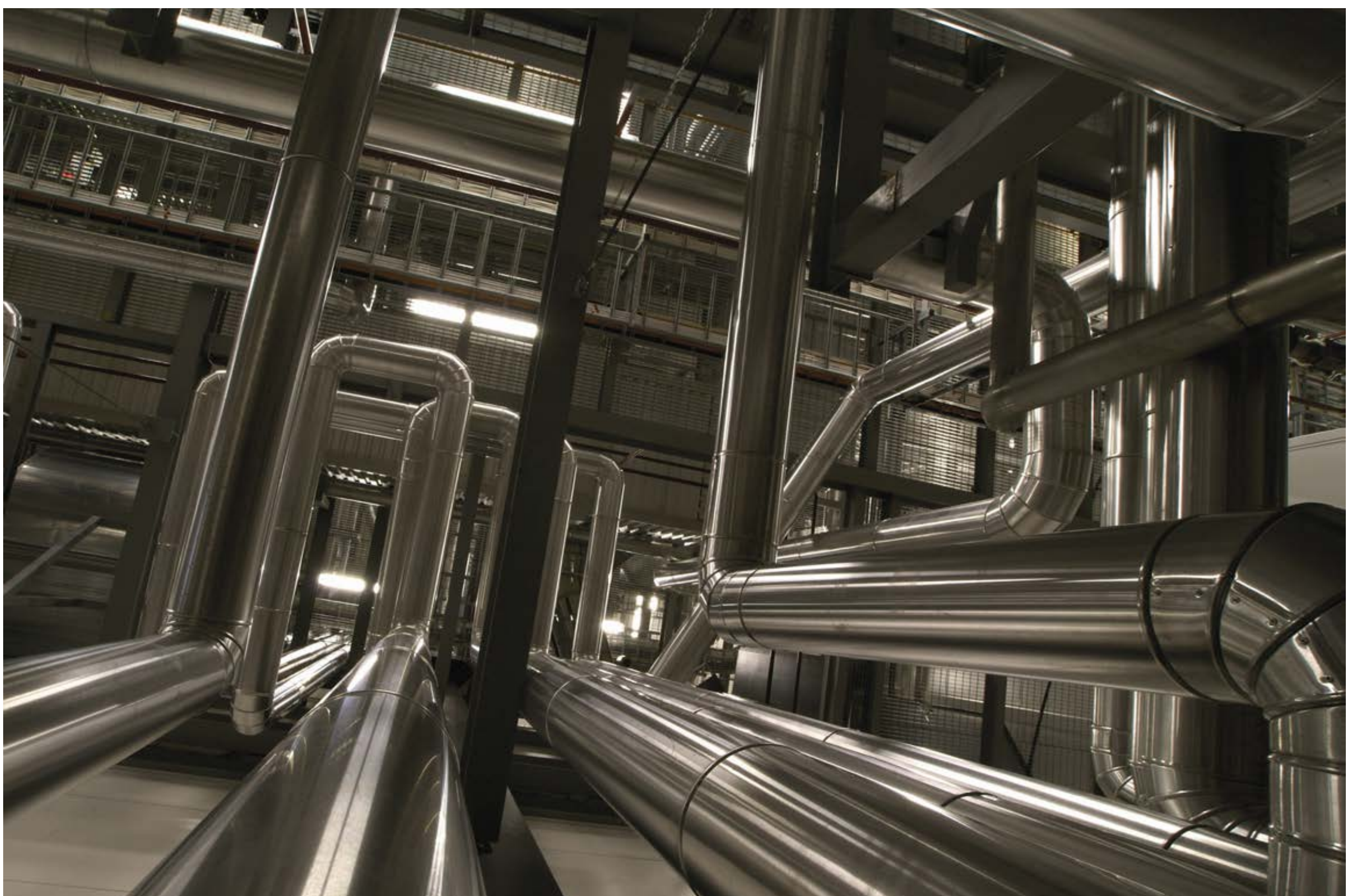
This section summarises the key policy and legislative instruments relating to waste-to-energy plants across four separate geographies. It finds a complex and varied set of strategies within each, at Federal, State and Local Authority levels, to ensure the maximum level of resource efficiency is achieved whilst retaining a detailed focus on protection of human health and the environment.

At policy level, the implementation of fiscal drivers for change, such as environmental taxes, has been successful in achieving their objectives to varying degrees. For example, a landfill tax with on-going incremental increases, on the whole, appears to be a successful incentive to divert waste from landfill and in the longer term support investment of alternative processing technologies. Other environmental taxes such as the incineration tax in Norway was introduced, amended and later withdrawn.

There is now strong policy development within the EU shaping future legislation to ban specific waste categories from landfill disposal and ensure that waste materials that can be recycled are banned from waste-to-energy plants. At regulatory level, bans on certain waste materials being sent for landfill disposal are already established in some countries. This raises parallel debate on the issue of lifecycle assessment for specified waste materials and respective merits and environmental benefits of processing these at different levels of the waste hierarchy. The outcome of these long term objectives will have an impact on residual municipal waste composition and therefore the design, operational requirements and emission control for waste-to-energy facilities.

The introduction of the new recovery status given to waste to energy processes in the EU meeting specified thermal efficiency requirements (R1 energy recovery criterion) is resulting in tangible changes in the way certain waste fuels are being managed, to include increasing cross border activity.

Emissions control and regulation also varies across the selected geographies. Notably national air emission limit values in Japan are, in many cases, substantially less stringent than those under the EU Waste Incineration Directive. However, the Japanese national environmental regulations allow Prefectural Governments who plan to construct waste treatment facilities to decide on emissions limits in accordance with emission regulation of local government and/or agreement with communities, which may, in theory, be more stringent than the national requirement.



3. State of the Art Facilities

3.1 Introduction

This section presents a summary of the Stage Two report provided in the appendices to this report.

The utilisation of waste as a resource for the recovery of materials and energy is becoming an increasingly attractive option for local and national governments worldwide to allow diversion of large volumes of residual solid municipal solid waste (MSW) which cannot be recycled or composted from landfill to meet current and future obligations under relevant regulations, such as the EU Landfill Directive (discussed in Section 2). Waste to Energy (WtE) also offers the significant potential to contribute to the mitigation of climate change as part of Local and Regional Government energy strategies and policies to meet CO_2 reduction targets. Selection of the optimal WtE technology will require careful consideration of technical, environmental, regulatory and economic issues when evaluating life cycle costs and the impacts of WtE technologies.

Waste to Energy is the generic term given to a process by which the energy stored in waste (chemical energy) is extracted in the form of electricity, heat and/or a fuel for use in a decentralised energy generation plant. A number of technologies are commercially available and have been deployed, especially in Europe, Japan and the USA. These represent a number of fundamentally different technologies under two main groups: e.g. biological processing of biodegradable waste and thermal technology of residual waste, including direct combustion (incineration), Advanced Conversion technologies (ACT - gasification and pyrolysis) or recovery of secondary fuel for subsequent energy recovery Solid Recovered Fuel (SRF) from Mechanical Biological Treatment (MBT) processes and biofuels from syngas produced by gasification processes). Maximising recycling and recovery from MSW and Commercial & Industrial (C&I) waste will have both environmental and economic impacts on WtE technologies and considerable technological developments have been taking place within the WtE space to optimise the performance of state-of-the-art facilities.

Thermal conversion processes can be divided into three different categories; combustion, gasification and pyrolysis with each process being dependent on the concentration of oxygen. Combustion takes place in an environment with an excess of oxygen, gasification is a partial oxidation process requiring an oxygen concentration slightly below the stoichiometric level (the stoichiometric air (oxygen) requirement is the exact amount of oxygen needed to balance all of the chemical reaction equations to convert the Carbon in the fuel to Carbon Dioxide and Hydrogen to water). Pyrolysis occurs in the absence of oxygen.

In order to showcase real examples of operational WtE plants a collection of fifteen case studies have been produced, which highlight modern state-of-the-art plants and developing technologies. These are presented in the appended full Stage 2 report, but in this chapter we briefly describe the work carried out and key findings.

3.2 Summary of Case Studies

WSP has selected plants suitable as state-of-the-art case studies using the following selection criteria:

- modern plants with higher than normal thermal efficiency;
- modern plants achieving low environmental impacts;
- plants gaining acceptance via innovative architectural treatments;
- modern plants employing state-of-the-art furnace design; and
- modern plants employing alternative thermal technologies, such as fluidised bed and gasification.

WSP has chosen to include two case studies that include more than one technology in order to provide the reader with a fuller understanding of current technical developments whilst still including interesting operating plants with innovative design elements:

- a review of the status of slagging gasification technologies in Japan; and
- a review of the status of plasma gasification technology developments.

Table 7: Plants used for case studies and reasons for inclusion

	Plant name	Country	Why included
1	AEB, Amsterdam	The Netherlands	The largest plant in the Netherlands. The most recent two lines added to the original four line facility employs a reheat Rankine steam cycle and produces electricity with a total **thermal efficiency of 30%**.
2	Lakeside, London	UK	A recently commissioned **merchant incinerator** developed by a major UK waste management company and located near to Heathrow Airport. The plant **processes residual MSW and C&I waste** and is the only plant supplied to date by a Japanese supplier.
3	Spittelau, Vienna	Austria	This is a relatively old conventional moving grate combustion plant. However, it was the first facility that used **architectural treatment to gain public acceptance**.
4	Allington, Kent	UK	One of the l**argest fluidised bed MSW incineration plants in the world**. The plant was supplied by Lurgi Lentjes with technology licensed from the Ebara Corporation of Japan. Ebara has supplied more than 100 such plants in Japan.
5	Issy les Moulineaux, Paris	France	The newest and largest incineration plant in France. The plant is built on the side of the River Seine in the centre of Paris and the **building only has a vertical profile of 27 metres** as 30 metres of the plant is below ground. The roof is flat and covered with grass and shrubs and the exhaust stacks only protrude 5 metres above the building roofline.
6	Reno Nord, Aalborg	Denmark	Modern incinerator in **CHP mode and providing district heating to the local city**.
7	Sarpsborg II	Norway	The **newest gasification plant** using the Energos two stage gasification/combustion process, which operates with **very high thermal efficiency** by sending all steam to an adjacent industrial customer.
8	Zabalgarbi, Bilbao	Spain	**High efficiency plant** linked to an adjacent combined cycle plant. The steam from the combustion plant is passed to the adjacent power plant and converted to electricity at higher efficiency.
9	Brescia	Italy	New plant in Italy operating with **high thermal efficiency**.
10	Riverside, London	UK	The newest and largest combustion plant in the UK using state-of-the-art grate combustion technology and **high steam pressure and temperature**. The majority of the MSW is delivered to the site by barge via the River Thames.
11	Mainz	Germany	The new third line installed at this existing combustion facility operates with **high efficiency** due to integration with and adjacent gas turbine plant.
12	Lahti II	Finland	Metso Power has supplied many fluidised bed combustion plants via companies it has acquired over the years – Tampella Power, Gotaverken Miljo and Kvaerner. The company has developed a **CFB gasification plant for RDF fuels** that is operating in Finland. This plant has been included as a Case Study because it is the first large scale commercial gasification plant supplied by a large well capitalised company.
13	Montgomery County, Maryland	USA	Relatively old plant refurbished with the newest Martin grate and the **LN deNO$_x$ technology.**
14	Slagging Gasification	Japan	**A review of slagging gasification in Japan**. There are currently 122 operating slagging gasifiers processing MSW with more under construction. This review describes the processes supplied by the leading Japanese companies.
15	Plasma Gasification	Various	**A worldwide status review of plasma gasification** technologies currently being marketed and close to commercialisation.

Summary of Findings

The full case studies can be found in the Stage 2 report, each of which contains a comprehensive review of the plant covering the following aspects:

- Overall plant description
- Process details
- Plant performance
- Emissions
- Visual impact
- Operation and reliability; and
- Economics

Though it is impossible to adequately summarise each case study in this summary report, a brief overview of each plant is provided in Table 8.

Table 8: Summary of case studies

	Plant name	Summary
1	AEB, Amsterdam	The newest two lines of the Amsterdam moving grate combustion plant really are state-of-the-art. Not only does the process produce electricity with a net efficiency of >30%, the highest of any WtE combustion plant in the world, but the plant also maximises recovery of materials for re-use in society such as bottom ash and fly ash, as well as producing calcium chloride and gypsum as secondary by-produces of the flue gas cleaning process. The annual availability is reported to be >90%.
2	Lakeside, London	The Lakeside plant was developed by Grundon as a merchant facility and processes both residual MSW supplied by local Councils and C&I waste obtained from the market by Grundon's waste management The plant employs innovative architecture and best-practice energy recovery techniques. We understand from the operators that the plant is performing well and meeting its regulatory requirements with respect to environmental impact.
3	Spittelau, Vienna	The Spittelau plant is a relatively old plant, but is notable for using extensive architectural treatment to help the plant gain public acceptance. Public perception and acceptance of WtE plants is very important, and innovative architecture can be one means of helping to overcome this hurdle.
4	Allington, Kent	The Allington plant is the largest fluidised bed combustion plant outside of Japan, which although it suffered from some initial teething problems has operated successfully for the past few years and met most of its environmental objectives. The plant has a very low building profile thanks to the fact that most of the fluidised bed combustors and boilers have been sunk 30 metres into the ground.
5	Issy les Moulineaux, Paris	The ISSEANE plant is a major feat of engineering. The plant is sunk about 30 metres into the bank of the River Seine with all the associated hydrogeological challenges of building the plant there. The exhaust gas chimneys protrude only 5 metres above the building but in order to do this the plant has had to guarantee emission limits to air of 50% of the WID values for all pollutants. It is truly a state-of-the-art WtE facility.
6	Reno Nord, Aalborg	The Reno Nord plant is a state-of-the-art example of a waste processing facility that delivers hot water into the district heating network of the area. The electrical conversion efficiency is 27% but the combination of that with the heat utilisation means the total efficiency of the plant is >40%.
7	Sarpsborg II	The two stage gasification/combustion process developed by Energos has been accepted as a gasification process by the UK regulator Ofgem. The plant supplies steam 'over-the-fence' to a heat customer, and so operates with very high thermal efficiency despite no electricity being generated. The low steam conditions (pressure and temperature) that would are not an issue.
8	Zabalgarbi, Bilbao	The Bilbao combustion facility is an example of a modern plant utilising the exhaust heat from an adjacent gas turbine power plant to perform reheating of the steam produced by the heat recovery boiler and operate with a thermal efficiency >40%.
9	Brescia	The Brescia WtE facility is a true state-of-the-art plant with low emissions and high efficiency power production. The architectural look of the plant is also extremely modern.
10	Riverside, London	The Riverside WtE plants has been 18 years in development, facing significant opposition and having to be subjected to two Judicial review processes before it was finally constructed. The plant is an example of a modern state-of-the-art facility design and constructed by one of the leading companies – Hitachi Zosen Inova (formerly Von Roll Inova). The majority of the waste is delivered to the plant in barges via the River Thames. The plant operates with increased steam conditions (72bar and 427°C) and the boiler has been designed specifically to produce steam at these conditions without the significant boiler fouling and failure that would have been experienced in the past. The plant operates with a relatively high thermal efficiency of 27%.
11	Mainz	The Mainz WtE plant is another example of a modern German plant producing high efficiency power and meeting stringent emission limits.
12	Lahti II	The CFB gasification plant developed by Metso Power for the processing of RDF/SRF is a high efficiency, state-of-the-art development; which, in our opinion will change how gasification is perceived and utilised within the context of the waste management industry.
13	Montgomery County, Maryland	Although the Montgomery County Resource Recovery Facility in Maryland, USA is a relatively old plant it has been included as an example of a plant that has undergone a significant retrofit with modern moving grate combustors added to improve efficiency and equipment to significantly improve the de-NO_X capability of the plant. The plant achieves good emission control (in A USA context) and meets the local regulatory requirements. The facility has undergone a significant health impact assessment.

Table 9: Summary of Technical Parameters for plants used for case studies

Facility	Commenced Operations	Throughput Capacity	Process Type	Boiler Type	Steam Pressure (bar)	Steam Tempera-ture (°C)	Gross Power	Overall Efficiency	Gas Cleaning System	Waste Processed	Plant Resi-dues	Fate of Residues
AEB, Nether-lands	1969, upgraded 1993 and 2007	1.37Mt	Moving grate	Horizon-tal	130	440	66MWe	30.6%	SNCR, ESP and Wet and dry scrubbers	House-hold, C&I	Bottom Ash Fly Ash	Sand-lime bricks, concrete Asphalt concrete
Lakeside, UK	2010	410,000t	Mass burn	Horizon-tal	45	400	37MWe	Not available	Flue gas recircula-tion (FGR), SNCR and Semi-dry scrubbing	MSW, non-hazardous C&I	APC resi-dues Bottom Ash	Landfill after treatment Construc-tion
Spittelau, Austria	Original 1969, 2nd generation 1986	250,000t	reverse-acting grate	Vertical	34	245	6MWe 60MWt	Not available	ESP, Scrubber (wet), SCR and EDV	Municipal; non-haz commer-cial	APC resi-dues Bottom ash	Deep mine disposal Landfill Engineer-ing
Allington, UK	2008	500,000t	Rotating fluidised bed	Horizon-tal	65	420	43MWe	Not available	ESP and Dry Scrub-bing	Non-haz MSW, Commer-cial and Industrial	Bottom Ash APC resi-dues	Construc-tion industry Landfill after treatment
ISSEANE, France	2007	460,000t	Water-cooled grate	Horizon-tal	50	400	52MWe	30% electrical (theoreti-cal) See Note: 1	ESP and SCR DeNOX System	Residual MSW	Bottom ash Fly ash	Recycled Landfill after treatment
Reno Nord, Denmark (Line 4)	2005	160,000t	Moving grate	Horizon-tal	50	425	18MWe and 43MWt	27% electrical (theoretical) See note 2	Three-field electro-static filter, wet and dry scrub-bers and AFM's	MSW	Bottom Ash Fly Ash	Construc-tion industry Not speci-fied
Energos, Norway	Sarpsborg II 2010	78000t	Staged combus-tion	Horizon-tal	23	217	32MWt	Not available	Semi dry cleaning system	Residual C&I waste	Bottom Ash APC resi-dues	Landfill Landfill
Zabalgarbi, Spain	2004	250,000t	Moving grate	Horizon-tal	100	330	99.5MW e	42% See Note 3	SNCR and wet scrubber	MSW	Bottom ash Fly ash	Construc-tion industry Storage
Brescia, Italy	1998 (household waste) 2004 (biomass)	800,000t	Moving reverse thrust grate	Vertical	72	450	Up tp 100MW e and 150MWt	>27.0% electrical	SNCR, activated carbon and dry lime scrubbing	2 lines MSW, 1 line biomass	Bottom Ash APC resi-dues	Construc-tion material Deep mine disposal
Riverside, UK	2012	670,000t	Moving grate	Horizon-tal	72	427	66MWe	27.0%	Semi dry cleaning system	MSW	Bottom Ash APC resi-dues	Construc-tion Landfill
Mainz, Germany (Line 3)	2008	110,000t	reverse-acting grate	Vertical	42	420	See Note 4	See Note 4	SNCR and Wet (pre) and dry scrubbers	Residual MSW	Bottom ash APC resi-dues	Used in landfill and road construc-tion as substitute materials for virgin aggregates Infilling old salt mines
Lahti II, Finland	2012	250,000t	Circulating fluidised bed	Vertical	121	540	50MWe and 90MWt	31% thermal efficiency based on waste NCV	Gas cooling & filtration by ceramic filter; dry APC system and NOx control using SCR	SRF	Bed Ash Filter (Fly) Ash	Landfill Treated as Hazardous

Table 9: Summary of Technical Parameters for plants used for case studies. Continued....

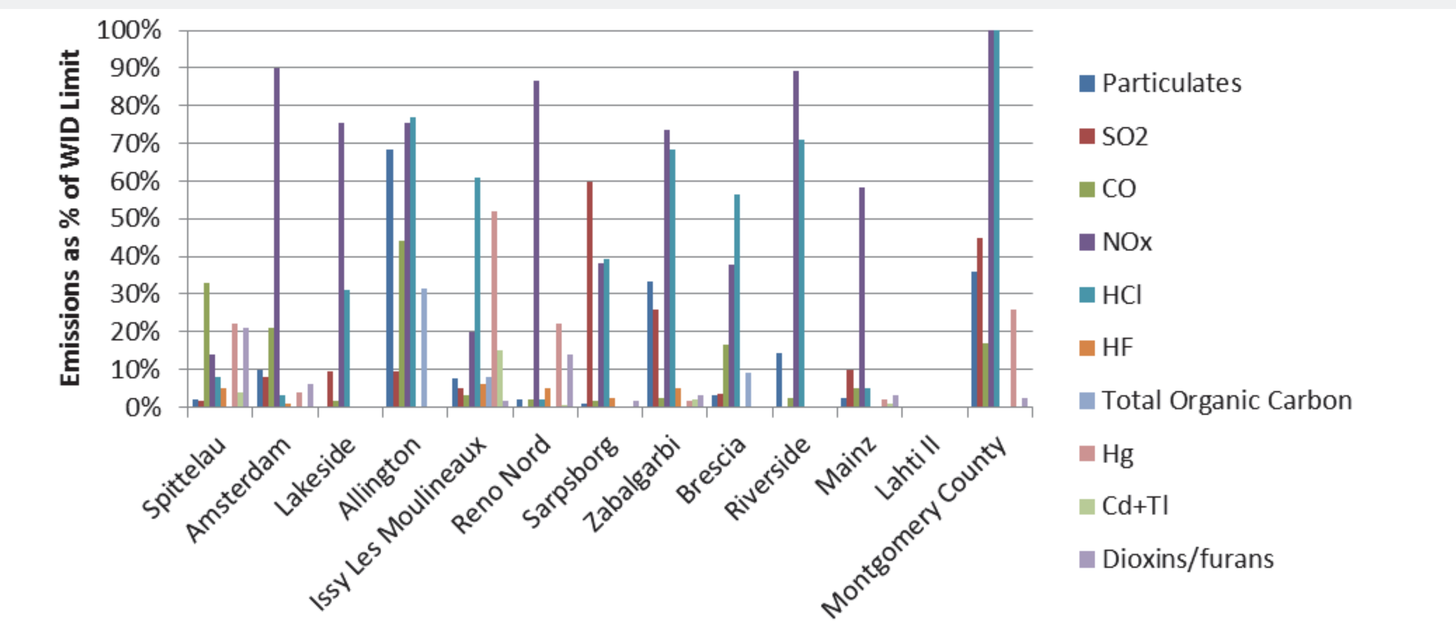
Facility	Commenced Operations	Throughput Capacity	Process Type	Boiler Type	Steam Pressure (bar)	Steam Tempera-ture (°C)	Gross Power	Overall Efficiency	Gas Cleaning System	Waste Processed	Plant Resi-dues	Fate of Residues
Montgom-ery County, USA	1995	573,000t	Reverse-reciprocating stoker	Not known	59.6	443	63MWe	Not available	LoNOX system, Semi-dry scrubbers and Thermal DeNOx	MSW	Bottom ash	Landfill Engineer-ing
											Fly ash	Landfill
Shin-Moji, South Korea	2005	216,000t	Fixed bed	Vertical	39.2	400	23.5MW e	23%	Dry scrub-ber and SCR	Industrial waste	Fly ash	Recycled
											Vitrified slag	Re-used
Sagamiha-ra, Near Tokyo	2010	160,000t	Fluidised bed gasifier and melting furnace	Vertical	40	400	10MWe	Not available	dry scrub-bing system and SCR	MSW	Vitrified slag	re-used
Fukuyama, Near Hiroshima	2004	92400	Slagging updraft gasifier	Vertical	60	450	20MWe	30%	Dry scrub-bing system and SNCR	Pelletised RDF	Melted slag	Recycled
											Metal	Recycled
Plasma gasification technology	There are no large scale commercial plasma gasification plants currently operational.											

It is assumed metals will be extracted from bottom ash for recycling

Note 1: Annual average gross electrical efficiency estimated at around 10% due to high level of heat export - thermal efficiency of around 40%
Note 2: High level of heat export means electrical efficiency lower in practice, but overall efficiency high (actual figure unknown), estimated >40%
Note 3: The efficiency achieved is only possible because the WtE plant provides steam to an on-site natural gas fired combined cycle plant
Note 4: The conversion of the steam to electrical energy is carried out in the neighbouring 400 MW combined cycle power plant (CCPP) owned by Mainz-Wiesbaden AG

A comparison of the emissions performance relative to emission limits in the EU WID is provided in Figure 1.

Figure 1: Summary emissions performance for plants reviewed in case studies



Note: Lahti II yet to release emissions data

It can be seen that the air emissions from all the plants considered in the case studies are within WID limits, with the exception of the Montgomery County plant for HCl and NOx, however this plant complies with the local regulatory requirements. In many cases the emissions are more than an order of magnitude below the regulatory limit.

3.3 Maximising Efficiency of Steam Cycle WtE Plants

The steam conditions in a WTE combustion plant have typically been limited to 40bar, 400°C in most plants to avoid serious corrosion problems due to the high moisture content and plastics content of the waste; consequently, in conventional modern plants electrical efficiency is usually limited to around 22-25% (gross).

In the last decade we have seen the introduction of a range of technologies designed to increase the electrical efficiency of WTE plants, particularly in Europe and the USA. This has been driven by the desire to increase revenue from electricity sales, and legislative requirements to demonstrate high efficiency to secure premium prices paid for electricity generated from renewable (or partly renewable) sources.

There are a number of means by which the efficiency can be increased and these techniques have been developed by WTE suppliers, particularly for large scale moving grate combustion processes. The main techniques can be summarised as follows:

- Advanced combustion control – the use of enhanced process control will maximise combustion efficiency to ensure maximum burn-out of the organic waste content, reduced excess air levels; and optimum oxygen levels can be achieved using flue gas recirculation;
- High steam pressure and superheat temperature – increasing steam pressure and temperature will increase the enthalpy of the steam and allow greater energy to be recovered in the steam turbine. Extreme care with the boiler design needs to be taken to protect the superheaters and increase the overall thermal efficiency of the plant. Locating the superheater tubes in the furnace can also boost steam temperatures beyond that usually possible. The tubes require considerable protection (Inconel) to avoid major corrosion problems, and may be located behind protective tiles;
- Reheat cycle – using a reheat cycle can increase the efficiency by several percent. Steam from the outlet of the high pressure stage of the turbine is sent back to the boiler where it is heated back to the original temperature, before being expanded in the low-pressure stage. This is a relatively high cost option, so the balance between cost and benefit of increased electricity generation has to be considered carefully;
- Reduced boiler exit temperature – the boiler exit temperature is established by sizing of the economiser and is typically set well above the dewpoints for hydrochloric and sulphuric acids and moisture. Preventing condensation of acid gases reduces corrosion and preventing condensation of moisture prevents agglomeration of particulate on the boiler tubes. However, keeping the exhaust gas temperature well above the dew points means that energy recovery from the flue gases is reduced. Careful control and reduction of this temperature has been employed on recent plants to maximise energy recovery with additional corrosion protection provided in the economisers;
- Reduced steam condenser pressure – the condenser temperature has a strong influence on the plant efficiency, the lower the condenser temperature, the greater the pressure drop across the turbine which increases power generation. Water cooled condensers can create the lowest temperatures but air cooled condensers are used where no water cooling source is available. However a review of ocean temperatures in Singapore indicate that the warmer water temperatures may not provide a significant improvement in power cycle efficiency and will not offset the increased maintenance effort of a pumped once-through ocean water cooling system;
- Integration with fossil fuelled fired power plant (external superheating) – there are some plants in Europe that are integrated with a gas turbine Combined Cycle Gas Turbine (CCGT) system using the high temperature exhaust gases from the GT to provide additional heat. This can help boost the efficiency of energy recovery from the combustion of waste; and
- Combined Heat & Power (CHP) operation – the recovery of heat as well as electricity can produce the greatest increase in efficiency. Steam can be extracted from the turbine and used directly for process heating in industry or used to produce hot water for a district heating network.

All of the above techniques come at a cost, and there will always be a balance between additional capital, operational cost and increased revenue from electricity (and potentially heat) sales. A number of the plants considered for case studies in the Stage 2 report incorporate one or more of the innovations in the list above.

3.4 Alternative Thermal Treatment Technologies

Our review has also considered the status of two technologies about which there is growing interest; slagging gasification (which has been developed almost entirely in Japan), and plasma gasification. Two case studies are devoted to these technologies and a brief summary is provided in this section.

Slagging Gasification

Many commentators consider gasification of waste to be unproven - they could not be more wrong. The Japanese have embraced gasification technologies for the processing of residual waste and waste derived fuels. Much of the interest around the world in waste gasification over the last fifteen years has originated with political decision makers seeking an alternative to incineration that achieved the following objectives, in order of political priority:

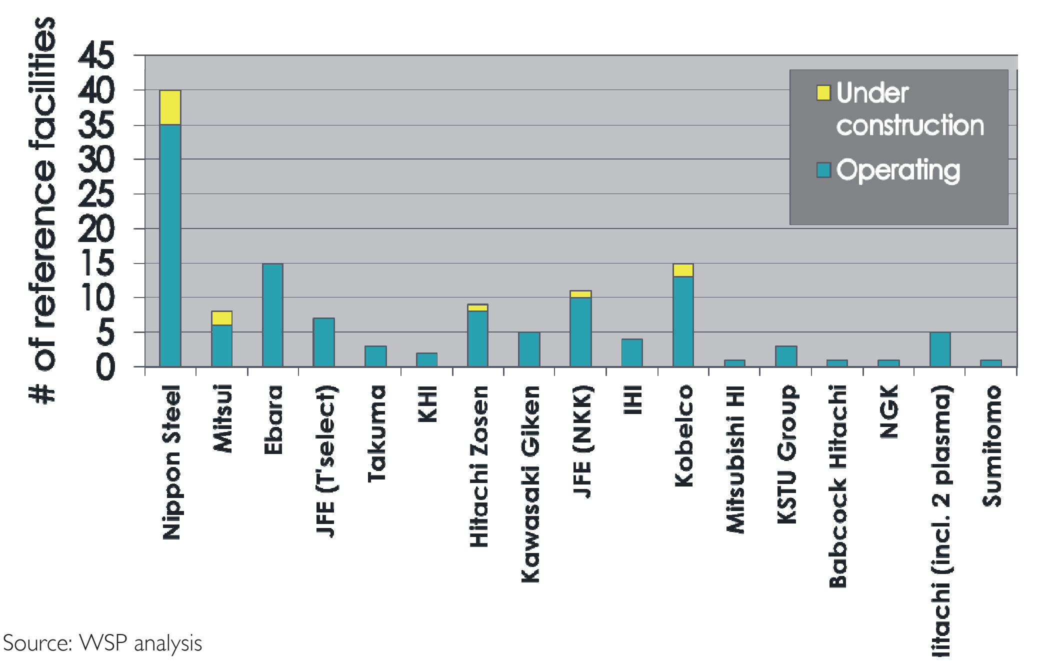
- produced demonstrably low emissions – particularly of dioxins;
- provided better resource recovery, in the form of materials and energy that could be re-used; and
- is fully proven at commercial scale.

Over the last few years, the perception has arisen in Europe, Australia and parts of North America that gasification has failed against these objectives, principally because of the poor operational track record of gasification processes developed by smaller lowly capitalised companies. Waste gasification technologies developed in Japan are proof that this is a misconception. In WSP's view, the majority of the processes operating in Japan deliver on each of those three key objectives:

- the reference plants have low emissions, particularly of dioxins;
- they do recover materials which have found viable and useful applications; and
- they are proven and therefore 'bankable' at least in a Japanese context, although it should be noted that the leading suppliers of slagging gasification technologies are actively seeking opportunities outside of their home markets.

The full Stage 2 report provides an overview of the current situation of slagging gasification and brief technical reviews of the leading companies. Figure 2 shows the leading companies and the number of plants currently operating and in construction.

Figure 2: The number of waste slagging gasification processes in Japan



Source: WSP analysis

The above chart shows that there are 122 operating waste slagging gasification plants processing 6,9 million tonnes per year of MSW/RDF. There are also nine plants under construction which will process a further 1 million tonnes per year of MSW/RDF.

Slagging gasification has taken off in Japan owing primarily to legislative and commercial drivers that require maximum diversion of waste (and the by-products of waste such as ash from thermal treatment) from landfill, due to the scarcity of void space. Such drivers are not present in many other countries at present, but this may change in future as legislative measures make landfill an increasingly unattractive option.

Plasma Gasification

Although plasma gasification is often hailed as the next technology to convert waste to electricity without the need to employ incineration technologies there are no large scale plants using this technology in operation at present. We have chosen to produce a summary of the current status of the plasma gasification of waste but have included descriptions of processes that WSP considers the nearest to commercial operation and not all processes that are currently being promoted.

Unfortunately, there are no commercially operating plasma gasification plants that could be considered state-of-the-art and therefore we are providing a review of the current status of plasma gasification, which will allow the reader to understand where the technology sits within the panoply of WtE technologies.

A plethora of plasma gasification processes have been marketed over the past few years as alternatives to incineration for treating residual MSW and SRF/RDF and our in-house database includes 55 such plasma gasification processes. These processes vary considerably in the level of provenness, scale, credibility of supplier, costs and hence 'bankability' (the ability to secure project finance on normal commercial terms).

WSP has used its in-house knowledge to identify the most credible processes and suppliers who could develop a fully commercial process within five years, and an analysis of each process can be found in the Stage 2 report.

Driven by the size of the commercial opportunity some plasma process developers are anxious to compete directly with incineration for mass processing of municipal solid waste. Below we discuss six key challenges associated with such applications:

- heat transfer;
- scale and modularity;
- heterogeneity;
- relatively low calorific value;
- relatively high moisture content; and
- high ash content.

Aside from these technical aspects there are also questions whether plasma processing of MSW is economically viable and whether potential customers can be convinced about its operational availability. Thus, when considering large-scale MSW applications there are technology risks and economic uncertainties. At the present time there is insufficient evidence available to allow a definitive judgement - either way - about the applicability of plasma processes for processing MSW.

4. Recent Health and Environmental Impact Studies

4.1 Introduction

This section presents a summary of the Stage Three report provided in the appendices to this report. It summarises a review of literature published over the last 15 years encompassing potential environmental and health risks associated with emissions from Waste-to-Energy plants, processing predominantly municipal solid waste. This focuses necessarily on incineration as there is limited available information on the environmental or health impacts on alternative advanced thermal treatment technologies.

4.2 Assessing the Impacts of MSW Thermal Treatment

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.

Comparison with other waste processing options

A 2011 paper written for the Waste Management Journal 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 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 was 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 presented 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. Whilst the authors acknowledged certain limitations with the assessment e.g. the findings in this study were highly dependent on the composition of the waste streams. However, 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.

A 2009 paper written for Environment Technology Journal considered trends in the management of residual municipal solid waste and the environmental and health impacts of installations dedicated to the treatment of residual MSW. The scale of operations (treatment capacity) was not considered to be proportional to their potential environmental impact. The authors consider a more significant role is played by the qualitative aspects of the residual MSW. 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.

A paper published in the US Journal of the Air & Waste Management Association (2002) evaluated potential greenhouse gas (GHG) emissions associated with various MSW management practices, using a LCA approach to track GHG emissions over time. The authors reported a substantial reduction in GHG emissions resulting from improvements in the 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.

A 2011 report published by an EU Agency used a life-cycle approach to assess GHG emissions in the EU, Norway and Switzerland and concurred with the general findings of the previous 2002 US paper. It concluded that improved MSW management was deemed to have cut GHG emissions by 48M tonnes of CO_2e between 1995 and 2008, due mainly to landfill diversion and increases in recycling, but also attributable in part to waste as an energy source or secondary material and subsequent savings in virgin materials or fuels.

The National context in relation to policy and approach to waste management has been demonstrated to have a potential significant effect on GHG emission outcomes. A paper published in Resources, Conservation and Recycling (2011) compared carbon emissions associated with MSW management in Germany and the UK. The analysis indicated that the carbon emissions associated with MSW management in the UK are approximately five times higher than that for Germany, equating approximately to removing 1.2 million cars from the roads in England and Wales. Whilst acknowledging the use of assumptions and approximations, 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 major reasons for the difference.

Using a simple methodology based on calculating primary energy savings resulting from export of energy, a 2009 paper published in Engineering Transactions concluded that thermal treatment of MSW with heat recovery represents one of the most efficient ways of treatment. The energy generated in WtE plants contributed to primary energy savings and a consequent reduction in GHG emissions.

Comparison with other industrial non-waste processing options

A US University publication (2009) evaluated emissions from thermal conversion technologies processing MSW and biomass and assessed 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. Results from the analysis indicated that pyrolysis and gasification facilities currently operating globally with waste feedstock met each of their respective air quality emission limits. In the case of dioxins/furans and mercury, every process evaluated met the most stringent emission standards worldwide. The report stated that the environmental implications of these technologies are critically important to their feasibility and that information at the time (2009) suggested they can be operated in a manner that presents no greater threat to human health or the environment than other common industrial processes.

Air Impact Assessments

A US State Environmental Protection Agency regulates major air pollution sources in accordance with Its 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. In their technical evaluation and preliminary determination for a specific new development 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 showed ground-level increases less than the SILs, the applicant was exempted from conducting any further modelling. If the modelled concentration's from the project had exceeded the SILs, then additional modelling including emissions from all major facilities or projects in the region (multi-source modelling) would have been required to determine the proposed project's impacts compared to the AAQS or PSD increments.

In this case 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.

Risk Assessment Process

Another key consideration in evaluating potential health effects of thermal treatment technologies based on published literature and academic studies is to assess any the limitations associated with these works. The following is an excerpt from a 2008 report published by a UK Independent School of Medicine:

Typically decisions are 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.

In 2004 a UK Government Agency report suggested 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.

One such study published in the Journal of Public Health (2007) assessed the health risks associated with waste incineration and used a quantitative method to allow comparison 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 acknowledged 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 found that 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 also 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.

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 US-government sponsored public-private study of health effects associated with waste incineration in the US and internationally published in 2000 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 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.'

A review of waste management practices and their impact on human health published in Waste Management Journal (2009) 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.'

The UK Government Agency 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 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.'

A paper published in the Management of Environmental Quality (2003) 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.

4.3 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.

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. A 2009 paper published in the Waste Management Journal reviewed the status and benefits of WtE as applied in the US and presented data on dioxin emissions from WtE between 1987 and 2002 i.e. pre and post Maximum Achievable Control Technology Regulations (MACT), demonstrating a 99.9% reduction in air emissions over this period.

A 2007 paper published in the Chemosphere Journal evaluated incremental lifetime health risks due to PCDD/F emitted from MSWI, for the resident population in the area of specified plants. 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 flue gas treatment (selective non-catalytic reduction, electrostatic precipitators, dry system absorption with injected activated carbon and fabric filters), and older plants in northern Italy using flue gas treatment not specifically designed to remove trace organic pollutants (electrostatic precipitators and wet scrubbers).

The preliminary evaluation found the distribution functions for PCDD/F stack concentrations for plants equipped with BAT flue gas treatment were far lower than the current WID emission limit value, with associated risk values largely insignificant with respect to regulatory reference levels (10-6). The authors also note that plants not equipped with BAT flue gas treatment also showed reductions in expected risks, even with no specific PCDD/F control measures.

A 2011 US EPA publication 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 a UK Agency publication based on the investigation of waste incinerator dioxins during start-up and shutdown operating phases reported elevated emissions during shutdown and start-up relating to the waste was not being fully established on the combustion 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.

In 2004 a UK Government Department published a review of environmental and health effects of MSW and similar wastes management. The report 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 for environmental and health effects. On this issue 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.'

Dioxins are highly toxic and can cause reproductive and developmental problems, damage the immune system, interfere with hormones and also cause cancer.

Dioxins are persistent environmental pollutants and they are known to accumulate in the food chain, mainly in the fatty tissue of animals. It is estimated that greater than 90% of human exposure is through food, mainly meat and dairy products, fish and shellfish. A 2009 UK Government Agency publication stated that inhalation of dioxins was a minor exposure route and estimated that less than 1% of UK dioxin emissions arise from MSWI, suggesting 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.'

A health risk assessment of dioxin emissions from MSW incinerators in the Neerlandquarter of Belgium was published in Chemosphere in 2001. The authors 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.

A long-term Portuguese University study 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. 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.

One study focussed on dioxin/furan body burden determined 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.'

Dioxin/furan body burden by PCDD/F levels in human milk was also studied. This paper investigated differences between exposed and non-exposed subjects under study and possible covariates of the dioxin levels in human milk. The authors acknowledged 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.'

A 2008 case study published in Waste Management Journal used a risk assessment approach to assess air pollution from a MSWI plant in Italy. The authors noted 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;
- 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.

Whilst the previous studies focussed on residents living in the vicinity of the incinerators, another paper published in Industrial Health (2003) focussed on occupational exposure and 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.

4.4 Particulate Matter

Particulate matter arises from a variety of sources including traffic emissions, agricultural, domestic and industrial processes including MSWI. It is commonly categorised by size i.e. average diameter of particles as follows:

- PM_{10} - 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.
- $PM_{2.5}$ - 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
- $PM_{0.1}$ - particles smaller than 100 nm in diameter (often referred to as ultrafine particles).

A UK Trade Association published a report in 2012 reviewing research into the health effects of Waste-to-Energy facilities. In a section on process emissions, the authors provide a quantitative context for assessing the impact of PM by referring to a UK Government Agency 2009 dataset providing the following source contribution for UK emissions of fine particles ($PM_{2.5}$):

- MSW Incineration 0.042%;
- Road traffic 29%;
- Residential combustion 14%, and
- Electricity generation 5.5%

The authors discuss the relevance of nano or ultrafine particles ($PM_{0.1}$) in relation to concerns with regard to their effects on health and suggest it is plausible that risks to health associated with particulate matter are more closely linked with numbers of particles rather than mass of particles.

In 2009 the Waste Management Journal published a paper on size distribution and number concentration of particles at the stack of a MW incinerator, observing 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 × 105 and 2 × 105 particles/cm^3 and on average relatively stable from one test to another. The authors observed that particle size $PM_{2.5}$ 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 $PM_{2.5}$.

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 2010 study, the same authors investigated the dimensional and chemical characterisation of particles at a downwind receptor site of a WtE plant, specifically evaluating seasonal concentrations and size 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 × 103 +/-3.7 × 102 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.

A further study by the same authors (2011) 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 × 107 particles/cm^3 and 2.0 × 103 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.

An International Congress on Combustion By-products and their Health Effects was held in Italy 2007. A summary document based on the proceedings 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, 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.

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

The 2008 UK Independent School of Medicine 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 (PM_{10}). The authors suggest modern baghouse filters only remove 5-30% of $PM_{2.5}$ (particles with a diameter less than 2.5 microns) and virtually none of the $PM_{0.1}$ (particles with a diameter less than 0.1 microns).

In its evaluation of this report, a UK Environmental Consultancy made the following comments in relation to the comments on particulates:

'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 PM_{10} 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. $PM_{2.5}$ 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.'

A UK Government Agency published a position statement in 2009 and acknowledged 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 some effect on health. However, they suggest the critical step in the assessment of health effects lies in estimating the size of the effect.
The position statement responds to the claim that PM_{10} 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 PM_{10}.

'PM_{10} 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. $PM_{2.5}$ 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 PM_{10} includes $PM_{2.5}$ and that $PM_{2.5}$ cannot exceed PM_{10} in any given sample of air.'

It also responds to the claim that PM_{10} or $PM_{2.5}$ does not include nanoparticles present in the air, once again claiming this is incorrect.

'Nanoparticles are efficiently collected by $PM1_0$ and $PM_{2.5}$ samplers but make only a small contribution to the results expressed as PM_{10} or $PM_{2.5}$. 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 $PM_{0.1}$ (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:

PM_{10} 20 µg/m^3
$PM_{2.5}$ 13 µg/m^3
$PM_{0.1}$ 1-2 µg/m^3'

The Agency confirmed 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 (PM_{10} and $PM_{2.5}$ 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.

A 2010 study carried put by a consortium supported by an Italian 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.'

4.5 Other Emissions to Air

In addition to particulate matter and dioxins/furans, other potential pollutants found in emissions to air include 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.

A 2009 US paper suggests the implementation of the Maximum Achievable Control Technology (MACT) regulations decreased mercury emissions from waste-to-energy plants in the US 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 previous dioxin/furan exceedance discussions, mercury levels in emissions may also fluctuate during periods of abnormal operating conditions e.g. bag house failure.

4.6 Solid 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 (IBA)
In 2003 a UK Consultancy carried out a study entitled 'Environmental and Health Risks Associated with the Use of Processed Incinerator Bottom Ash in Road Construction'. The commission was part funded under the terms of the Landfill Tax Credit Scheme. 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.'

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. A 2007 summary paper provides an overview of these projects and found that no single process ensured compliance with Danish limit values on leaching at the time, however extended curing along with washing could, in most cases, decrease leaching significantly.

A paper published in Aquatic Ecosystem Health & Management journal (2005) presented 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.

Air Pollution Control Residues

The UK School of Medicine report states that 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.

4.7 Conclusions

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 on-going 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.

About Us

WSP and GENIVAR is one of the world's leading professional services firms. We have 14,500 employees based in more than 300 offices across 35 countries. Our expertise ranges from land remediation to urban planning, from engineering iconic buildings to designing sustainable transport networks and from developing the energy sources of the future to enabling new ways of extracting essential minerals.

Find out more at www.wspgroup.com

Our specialist environment and energy business helps organisations around the world manage risks and maximise opportunities related to sustainability, climate change, environment, energy and health & safety. Whether its environmental permitting for mining operations; climate adaptation plans for cities; GHG mitigation and sustainability strategies for corporations; or geotechnical designs for new developments, we will help to create competitive advantage for our clients.

Find out more at www.wspenvironmental.com

Registered Address

WSP Environment and Energy Ltd
WSP House70 Chancery Lane,
London WC2A 1AF
www.wspenvironmental.com

UNITED BY OUR DIFFERENCE