Review of BAT for New Waste Incineration Issues

Part 3 New IPPC Considerations

Technical Report
P4-100/TR

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Statement of Use
The study identifies the techniques that nay be used to address the 'new' IPPC considerations, identifies the levels of performance that are achievable by their use, provides benchmarks, and identifies what techniques may be considered as best available techniques (BAT). The information in this document is for use by Agency staff and others involved in the regulation of industrial emissions.

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R&D TECHNICAL REPORT P4-100, PART 3

EXECUTIVE SUMMARY

The study identifies the techniques that may be used to address the 'new' IPPC considerations, identifies the levels of performance that are achievable by their use, provides benchmarks, and identifies what techniques may be considered as best available techniques (BAT). These IPPC considerations include: selection of raw materials, waste minimisation, re-use, recycling and recovery of wastes; noise and vibration, energy efficiency and the risk of accidents and their consequences. These categories form the structure of this report.

The types of plants covered are: municipal solid waste incineration, waste chemical or plastic incineration, hazardous waste incineration, other waste including animal remains and metal container cleaning.

Materials Inputs

The majority of acid gas abatement is achieved with dry and semi-dry processes. Inputs of air pollution control (APC) reagents to these systems are set to increase in order for most processes to comply with the Waste Incineration Directive's 60 mg/m^3 limit for hydrogen chloride.

Further treatment of APC residues to immobilise contaminants will be required by the landfill directive: the increased residue disposal costs will lead to pressure to reduce reagent inputs.

Wet scrubbing systems, which are generally two to four times as efficient as dry or semi-dry systems, are a potential option for all incinerators, though those currently in use have a high water consumption. For municipal waste incinerators with a wet scrubbing system, energy use and carbon dioxide can be reduced if crushed limestone is used in lieu of calcified lime. Wet scrubbing produces half as much solid residue as dry and semi-dry processes, and so reduces the increasing costs of residue disposal. Accordingly, when assessing best available techniques for acid gas removal, a life cycle analysis approach should be taken which should include consideration of the use of wet APC systems featuring closed loops or integral treatment plant.

Notwithstanding the choice of abatement technique adopted, reagent usage should be minimised and continually controlled through linking of reagent dosage rates with appropriate process parameters.

Most incineration installations utilise or intend to utilise ammonia or urea injection as nitrogen oxide abatement techniques. Of these, urea is the least environmentally harmful and is the easiest to handle and contain should a spillage occur. The advantage of using ammonia is that injection is easier than for crystalline urea. Both techniques are BAT if ammonia storage and use is carefully managed.

Selective catalytic reduction may be considered BAT for reduction of nitrogen oxides, as abatement to NO to around 50 mg/m^3 is only possible with this technique. Though this technique is expensive, legislation in some EU countries has led to SCR implementation being necessary: tightening of Europe-wide NO levels is a likely future development.

Materials Recycling and Reuse

The impact of increased recycling on MSW incinerator performance will be minimal. Potential for APC and bottom ash residue lies in the removal of PVC prior to incineration and also from installing a MRF to separate out recyclables.

The majority of municipal waste incinerator operators either currently recycle the bottom ash as aggregate or are seeking to do so. Economics are the key driver for this as operators seek to avoid landfill costs and, in at least one case, create an additional income stream.

Vitrified ash from hazardous waste incinerators can be recycled into building blocks. The imposed barriers to recycling vary greatly from plant to plant, and thus require consideration in the Agency's' Ash Protocol.

APC residues from all forms of incineration plant are currently disposed in landfill, principally as special wastes. In the near future, the Landfill Directive is likely to require pre-treatment of these wastes in order to prevent mobilisation of pollutants including metal elements and chlorides.

Energy Efficiency

Heat recovery to generate electricity is an integral part of operating an energy efficient and economically sound municipal waste incineration facility. Combined heat and power offers the greatest energy efficiency. However, the principal barrier to overcome is economic; the expense of installing infrastructure for exporting heat/high pressure steam needs to be justified against the potential market for this energy. The export of heat to the local community is currently vastly under exploited, due to the initial investment required to involve all stakeholders – long term planning and feasibility assessment is required when installing CHP schemes. Currently, energy is consumed to remove heat in the majority of MSW plants.

At present, UK merchant hazardous waste incinerators only recover low grade heat, typically for the purposes of re-heating stack gases. The rapid quench necessary to prevent dioxin formation prevents CHP use. The nature of the hazardous waste incinerated in the UK requires this quench though energy recovery potential should be investigated on a site-specific basis.

Clinical waste incineration plant in the UK has the potential for both heat recovery and power generation, though many of these facilities do not operate continuously and therefore the potential revenues from exporting energy off-site will not be as favourable.

Due to the lack of information on energy flows within incineration plant, for existing plant we recommend the use of energy auditing as a tool for identification of key energy uses and losses from a plant and identification of savings. For new plant, the energy consumption of plant equipment and the overall process should be identified and evaluated in terms of cost and benefit at the design stage.

Noise and Vibration

Practical measures for reducing noise and vibration are site specific, the best available techniques requiring consideration are: "low noise" equipment, enclosure of the facility, mounting vibrating machinery on separate foundations or damped mountings, careful siting of high noise equipment, minimising noise from vehicle movement and, finally, end of pipe noise abatement measures. For existing plant, identification of key noise sources through a "noise audit" and identification of control measures would minimise overall noise emissions and their impact on the local community.

Accidents and their consequences

All the large incinerator operators are implementing or considering the implementation of an ISO14001 Environmental Management system (EMS), which requires the identification of all the 'environmental aspects' of the plant. As part of this the organisation must also develop formal plans for dealing with accidents and abnormal occurrences and these must be practised at regular intervals.

A significant weakness of these systems is that it is largely left to the operator to decide what constitutes a significant environmental aspect and that stakeholders do not have to be consulted. In addition, the precise methodology by which the organisation uses to determine significance is not specified in the standard and again is left to the operator to determine. Consequently, the operator may undervalue some important aspects.

Accordingly, best practice, may be considered as being:

- Formalised identification of all activities/processes on the site that could give rise to a pollutant release off-site, possibly utilising tools such as fault trees or root cause analysis;
- Formal mechanism using a risk based methodology (potential consequences evaluated together with the likelihood of occurrence), agreed with the regulator, for evaluating significance of these activities/processes in relation to the environment;
- Identification and implementation of controls, both physical (i.e. substitution of reagents with more environmentally benign substances or building of bunds) and systematic (i.e. inspections and/or procedures) to manage these activities/processes;
- Development and practising of emergency response plans; and
- Formal reporting and investigation of accidents and near misses in order to identify causes and preventative actions.

In addition, all activities and processes should also be reviewed, particularly in the light of new knowledge, at regular intervals and all planned new activities and processes for a site should similarly be evaluated.

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1. INTRODUCTION

Technical guidance for waste incineration processes regulated under the integrated process control (IPC) regime was issued by the Environment Agency in 1996 (Environment Agency 1996). This guidance now requires revision to address developments in technology and new considerations brought about by new legislation, notably the change from the IPC regime to the Pollution Prevention and Control (PPC) and the recent EC Directive on the incineration of waste (EC 2000). This study was commissioned to supplement and update current information on best available techniques (BAT) contained within existing guidance in order to assist with the development of future guidance.

The study is presented in three parts:

Part 1 Waste pyrolysis and gasification
Part 2 Techniques for the monitoring and validation of furnace conditions
Part 3 New PPC considerations

This report presents the findings of the Part 3 study. Parts 1 and 2 are reported separately.

1.1 Part 3 study aims

The Environment Agency (the Agency) is responsible for ensuring that all installations with existing IPC permits in England and Wales are phased into the PPC regime by October 2005. New installations and existing installations undergoing a substantial change already require an PPC permit. A key principle of the PPC regime is the adoption of BAT to prevent pollution.

Sectoral guidance documents for use by operators and regulators, BAT Reference Notes (BREFs), are being prepared by the European Commission. However, the BREF note for waste incineration is not scheduled to be published until 2003. This objective of this study is therefore to assist the Agency with the development of interim PPC guidance for the incineration sector.

This report reviews techniques available to address the new considerations brought forward by the PPC regime, identifies the levels of performance that are achievable by their use, provides benchmarks, and identifies those techniques that may be considered as BAT with specific reference to:

- selection of raw materials;
- minimisation, re-use, recycling and recovery of wastes; noise and vibration;
- energy efficiency;
- the risk of accidents and their consequences.

The study comprised a review of all activities covered under Schedule 1, Sect 5.1 Part A(1) of the PPC Regulations including:

- municipal solid waste incineration (for plant >3 tonnes per hour capacity);
- waste chemical or plastic incineration;
- hazardous waste incineration;

- other waste including animal remains (for plant ≥1 tonne per hr);
- the cleaning for re-use of metal containers used for chemical transport.

Pyrolysis and gasification processes are considered in the Part 1 study.

1.2 Methods

The study comprised a review of existing Agency guidance, research papers (published and unpublished) and published literature, supplemented by direct contact the Energy from Waste Association, the Environmental Services Association and numerous Operators in the incineration sector, together with individuals within the Agency. Contact was made via telephone, email, facsimile and through meetings. A list of the individuals and organisations contacted is provided in Appendix 1.

2 SELECTION OF RAW MATERIALS

This section examines the selection of raw materials used in this sector. The term "raw materials" in the context of this study is used to describe the inputs required for incineration operations, excluding the actual waste feed stock. For most incineration plant, the principal material inputs relate to reagent and/or water usage in air pollution control equipment required to ensure that incineration operations comply with permit (authorisation) conditions. The principal material inputs and their purpose are identified in Table 1.

Table 1 Principal raw materials consumed in the incineration sector (excluding infrastructure and feed stocks)

Material	**Synonyms**	**Use**
Lime (CaO) Calcium hydroxide ($Ca(OH)_2$) Sodium bicarbonate ($NaHCO_3$) Sodium hydroxide (NaOH)	Dry lime Slaked lime, Hydrated lime Sodium hydrogen carbonate Caustic, Caustic soda	Reagents for neutralisation of acid gases
Water (H_2O)		Make up water for neutralisation reagents Boiler make up water
Ammonia (NH_3) Urea (H_2NCONH_2)		Reagents for reduction of nitrogen oxides (NO_X abatement)

The specific uses of each of the materials identified in Table 1 are discussed in the following sections. Since the abatement issues/techniques are applicable across all facets of the incineration sector, each abatement type is discussed in turn, rather than focussing on each waste incinerator type.

2.1 Abatement of acid gases

Table 1 shows the range of reagents commonly used for acid gas abatement. Sodium based reagents are generally more reactive than those based on calcium. Their use therefore leads to reduced materials handling and, potentially, smaller and less complicated plant. However, the higher reactivity is achieved at increased reagent costs. For small-scale plants the trade-off between capital and operating costs may favour the use of these reagents.

All current IPC regulated municipal solid waste (MSW) incinerators use hydrated lime for acid gas control, either injected dry or as a slurry. Dry lime or sodium bicarbonate is commonly used for smaller scale waste combustion such as clinical wastes. Hazardous waste incinerators commonly use hydrated lime in wet scrubbing systems, or sodium hydroxide during destruction of halogenated wastes since it is regarded as superior to lime for halide removal and dry scrubbing systems are ineffective for removal of the heavier halogens e.g. bromine and iodine.

Sodium bicarbonate is most efficient with respect to acid gas removal at elevated temperatures of around 160^{o}C. However, at such elevated temperatures, activated carbon (injected for mercury and dioxin removal) becomes less effective. Careful consideration is therefore required of injection arrangements, and critically, the temperature at which subsequent particulate abatement is undertaken since this is where most of the reaction between the acid gases and injected reagent occurs.

Current estimated reagent costs are indicated in Table 2.

Table 2 Estimated reagent costs and efficiencies

Reagent	Cost (£/tonne)[2]	Assumed stoichiometry[1]	Effective Cost (£/tonne HCl abated)
Lime (dry injection)	48	4	192
Lime (semi-dry)	48	2	96
Sodium bicarbonate	123	1	123
Sodium hydroxide (wet)	92	1	92

[1] Figures provided in S2 5.0
[2] Estimates derived from Bertin 2000

For MSW incineration using a semi-dry scrubbing process, lime usage to meet current authorised emission limits is typically around 12-17 kg of lime (CaO) per tonne of waste incinerated. The resulting residues are around 17-20 kg per tonne of MSW incinerated. It has been shown that similar reagent consumption rates can be achieved with dry injection of lime through the use of more sophisticated systems, such as two stage lime injection or gas suspension systems.

Clinical waste incineration processes use much smaller and less efficient air pollution control (APC) equipment. Accordingly the reagent consumption rates and resulting wastes are between 2 and 3 times higher.

For hazardous waste incinerators the reagent usage is completely dependent upon the wastes incinerated and the emission limits applied. Sewage sludge incinerators typically dose the flue gases with sodium hydroxide solution at a rate of around 19 kg per tonne of sludge cake incinerated. Data for metal decontamination processes are sparse. However, where scrubbing systems are employed reagent usage will depend upon the nature of the wastes incinerated.

The new EC waste incineration directive (WID) (EC 2000) introduces a 60 mg/m^3 limit for hydrogen chloride based on an half hourly averaging period. It is likely that meeting this limit will be challenging for the vast majority of current plant operating with dry or semi-dry scrubbing systems. One solution is to increase the volume of reagent injected. Another is to install wet scrubbing systems.

For all incineration technologies, wet scrubbing systems are potentially an option. These systems typically employ a mixture of calcium hydroxide and sodium hydroxide in aqueous solution. The advantage of these systems is their relatively high acid gas removal efficiencies (approximately twice as efficient as a semi-dry process) with circa 10 kg of neutralisation agent required per tonne of MSW incinerated and hence half as much solid residue (when compared to dry or semi-dry technologies) produced. In addition these systems, because of their efficiency, can be relatively compact when compared with the large reaction towers/vessels required for dry and semi-dry systems. Also, it is possible with these systems to effectively utilise crushed limestone in lieu of calcified lime and consequently avoid the large emissions associated with the combustion of fuels in lime kilns; typically 114 kg of carbon dioxide are released from fuel combustion per tonne of lime produced. However, these systems are generally not favoured by the industry as, unlike, dry or semi-dry systems, an aqueous effluent can be produced (typically 300 - 450 litres per tonne of MSW) which requires further treatment before disposal.

Wet scrubbing systems are relatively common in continental Europe but their uptake in the UK has been resisted largely on the grounds of the costs of treating the resulting aqueous effluents. However, relatively new technologies have been introduced (e.g. at the Vienna MSW incinerator) that have addressed these issues through the use of closed loop systems. In a closed loop system, scrubber liquor is continuously recirculated via a treatment plant to remove salts (predominantly chloride). Accordingly, water usage is minimised (circa $1m^3$/tonne of waste or less) and a by-product from the treatment plant is crystalline sodium chloride: one use of which could be for road gritting. Figure 1 and Figure 2 respectively demonstrate the key differences between outputs from a reference MSW incinerator fitted with semi-dry abatement plant and wet abatement plant.

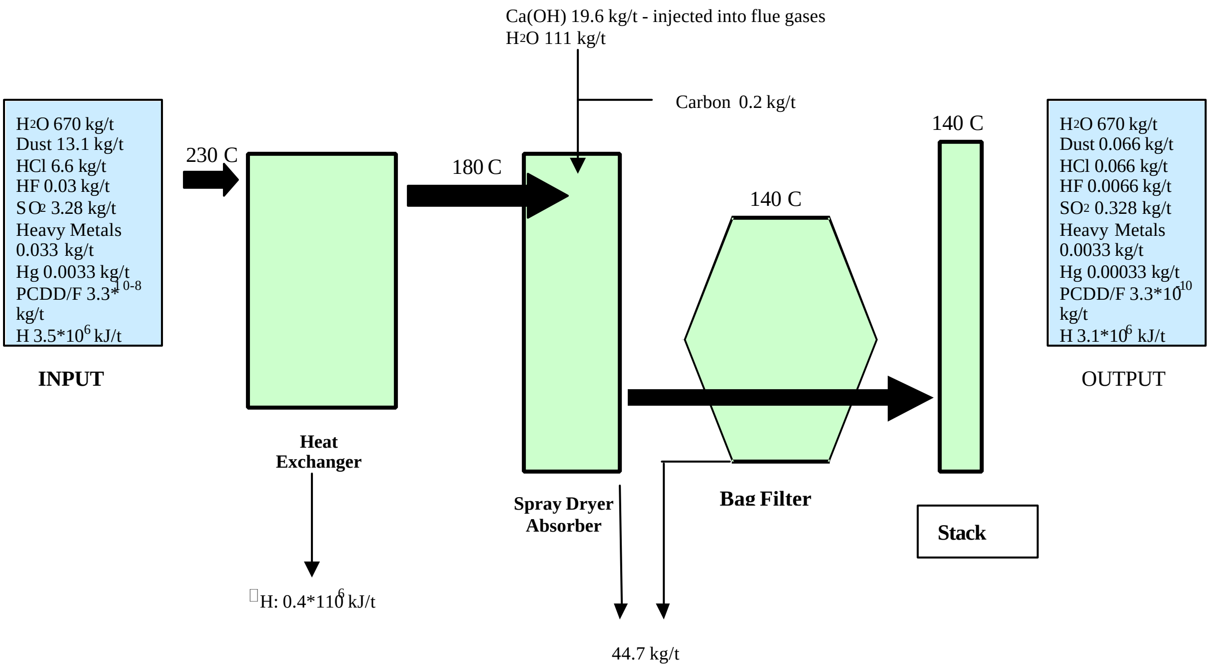

Figure 1 Schematic of inputs and outputs for semi-dry abatement plant

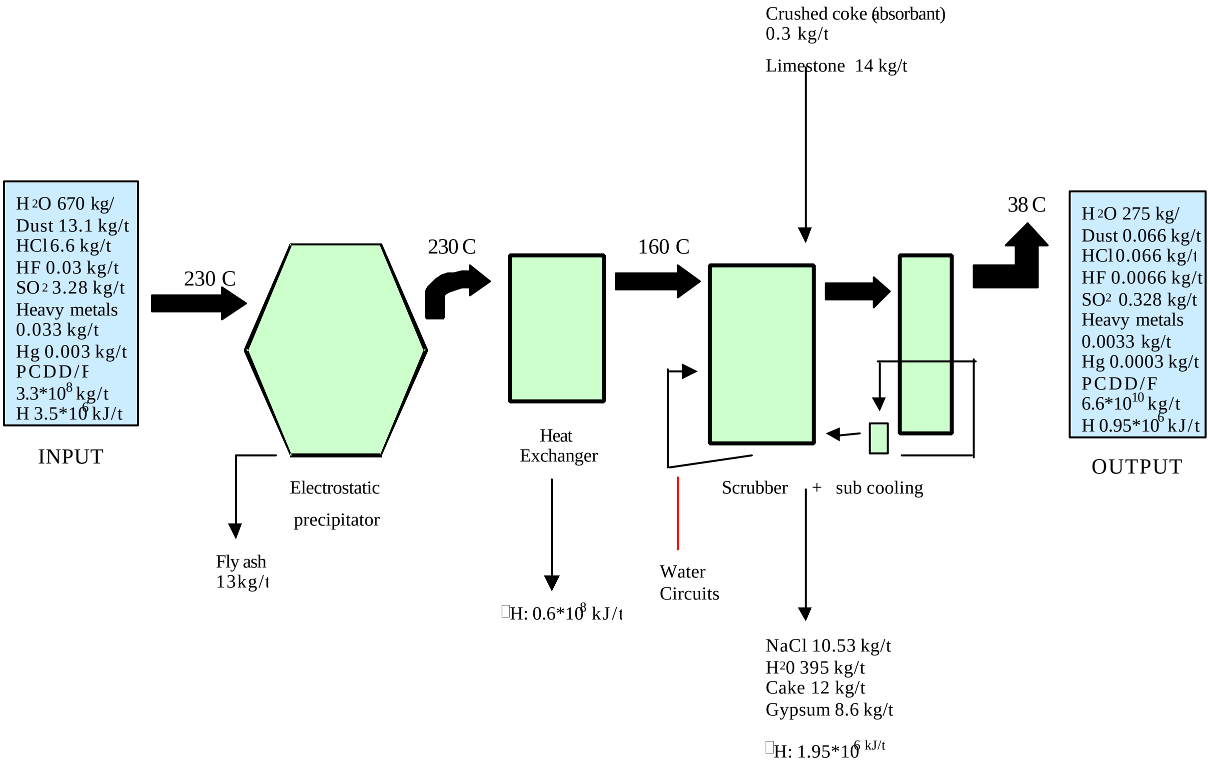

Figure 2 Schematic showing inputs and outputs from wet scrubbing abatement plant

2.2 Abatement of dioxins and mercury

Carbon injection is commonly deployed in the incineration sector for removal of dioxins and relatively volatile heavy metals, principally mercury. The technology is universally deployed across the MSW sector and across most of the clinical waste and sewage sludge sectors. It is likely that the Waste Incineration Directive limits on dioxin and mercury emissions will further enhance the adoption of this technology. Current costs are estimated to be around £1400 per tonne of reagent although actual costs can vary with the quality and performance. However, consumption rates are relatively small at between 0.1 and 0.2 kg per tonne of MSW incinerated. Activated carbon can also be employed in wet scrubbing. A potential alternative has been employed in Europe, with the use of a catalyst for the simultaneous reduction of nitrogen oxides and destruction of dioxins.

For UK merchant hazardous waste facilities hazardous, shock cooling of the furnace gases, using water, is employed in order to prevent dioxin formation.

2.3 Abatement of nitrogen oxides

The WID introduces a limit of 200 mg/m^3 for the emission of oxides of nitrogen. With good combustion control, clinical waste incineration plant should be able to remain within this limit, and hazardous waste incinerators currently operate at NO_x emission levels at around 100 – 150mg/m^3 daily average. Other incinerators, however, are likely to require the addition of abatement systems.

Current abatement technologies are:

- selective non- catalytic reduction (SNCR)
- selective catalytic reduction (SCR)
- flue gas recirculation (FGR)

Selective non-catalytic reduction

SNCR involves the injection of a reagent, usually into the combustion chamber, in order to reduce nitrogen oxides present to nitrogen. The principal reagents used are urea and ammonia. Urea is the most commonly used reagent for NOx reduction in the UK. Ammonia is used in one MSW incineration plant (SELCHP). The urea is supplied in a concentrated granular form which is non volatile and has no odour. Ammonia is volatile and has a highly pungent odour. Ammonia is supplied in aqueous solution (approx. 33% ammonia) and is stored in a bunded tank under pressure. Accordingly, the handling and storage requirements for urea are simpler than those for ammonia and there is less potential for off-site release. Usage rates for ammonia and urea are respectively about 1.9kg (33% solution) and 1kg per tonne of MSW incinerated. Current cost estimates are around £170 per tonne for urea and around £120 per tonne for ammonia (Kemira, Personal Communication 2001).

Selective catalytic reduction

Selective catalytic reduction involves the use of a catalyst to selectively promote the reduction of oxides of nitrogen to nitrogen. The reaction also requires addition of reagent, usually ammonia or urea as the reducing agent. However, the amounts of reagent required are typically 3 to 5 times lower than those required with SNCR systems (CRI catalysts, personal communication 2001). In addition, through modification of the same catalyst, destruction of dioxin can also be achieved.

The catalyst may be arranged in different positions within the waste gas cleaning system but is usually positioned as the last element of the APC system in order that the catalyst is protected from poisoning by heavy metal compounds. Typically titanium dioxide/vanadium pentoxide doped ceramic catalysts are used downstream, and the waste gas requires re-heating to about $180^{o}C$ to $350^{o}C$ as residual sulphur compounds in the flue gases will react with the injected ammonia to form ammonium sulphate which gradually coats and deactivates the catalyst. Accordingly, the catalyst must typically be maintained at or above $180^{o}C$ in order to prevent deposition of ammonium sulphate.

Heating of the flue gases can be achieved by means of gas-fired burners in the waste gas or for lower catalyst temperatures i.e. those $<250^{o}C$, steam heat exchangers are adequate. Calculations undertaken for a "typical" MSW incinerator (ie. assuming a typical flue gas composition of approximately 11% O_2, 10% CO_2 and 21% N_2) indicates that around 78 kWh are required per tonne of waste incinerated to raise flue gas temperatures from around $140^{o}C$ to $180^{o}C$.

Catalyst service lives of three to five years are offered by the catalyst manufacturers. In addition, German experience with catalyst systems installed in hazardous waste incineration facilities has demonstrated catalyst service lives of 10,000 hours without significant decrease in activity. Total costs (operating and capital costs depreciated over the expected catalyst life time) are around 1500 Euros (approx £900) per tonne of NOx abated (Personal communication, CRI Catalysts 2001).

Flue gas re-circulation

FGR is a technique by which a proportion of the cleaned flue gas is re-circulated into the combustion chamber typically replacing 10-20% of the secondary air. The result of FGR is a 15-20% decrease in NOx emissions. However, for mass burn municipal waste incinerators, FGR alone will not enable the WID limit for NOx to be achieved.

2.4 Water usage

The water cycle around a typical mass burn waste incineration facility is provided in Figure 3.

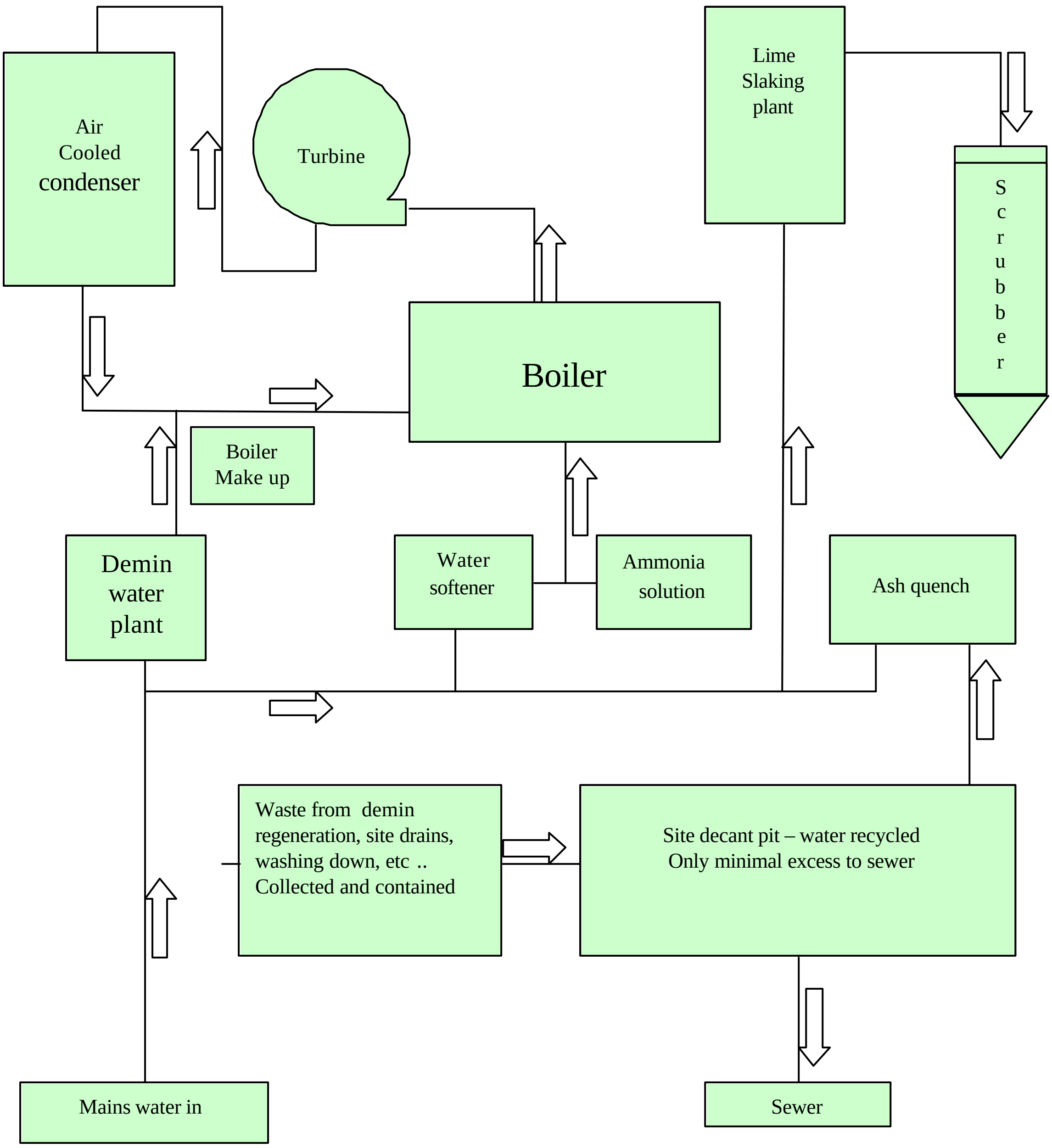

Figure 3 Water cycle for a typical mass burn waste to energy facility (Source: SELCHP 2001)

The major users of water are the lime slaking and ash dischargers (quench baths). The water in the slaked lime and injected into the scrubbers evaporates and leaves site via the stack. Normally all waste water goes to the site decant (drainage interceptor) pit and is preferentially recycled to the ash dischargers. Mains water is used to supplement when necessary. Water also leaves the plant as moisture in the bottom ash. With a dry or semi-dry process (as depicted in Figure 3) there is no discharge to sewer during normal operations. Through the use of air condensers around 99% of the steam produced is recycled as condensate. The remainder is lost principally by soot blowing and at continuously flowing sample points. The plant also has a separate foul sewer system and storm water system. Facilities equipped with semi-dry scrubbing plant typically consume around 250-280kg of water per tonne of waste incinerated.

MSW incinerators utilising wet scrubbing techniques can consume around 850 kg of water per tonne of waste incinerated and produce up to 450 kg per tonne of waste water. However, these volumes can be much reduced through the used of closed loop scrubbing circuits and moisture recovery from the flue gases.

Similarly, a hazardous waste incinerator may require large quantities of water for quenching and acid gas scrubbing. The exact quantities of water consumed will be determined by the nature of the wastes incinerated (e.g. combustion of chlorinated wastes will require rapid quenching of the combustion gases). However, the lowest rates in Europe are around 3-4 te of aqueous effluent are produced per tonne of waste incinerated (Personal communication, Shanks 2001).

There is little data concerning water consumption for other incinerator types (e.g. clinical and drum/metal recovery units). However, the principal source of water consumption will be the acid gas abatement equipment and, therefore, will depend on the type of abatement installed and the nature of the wastes incinerated. Most (if not all) clinical waste incinerators employ dry flue gas scrubbing techniques and therefore the water consumption will be relatively low and predominantly linked with bottom ash quenching.

3. RE-USE, RECYCLING AND RECOVERY OF INCINERATOR RESIDUES

3.1 Impact of recycling and water minimisation on incinerator feed stocks

The potential impacts of diverting waste for recycling from the municipal solid waste incinerator waste stream are changes in the moisture content, calorific value and metal content of the waste. The removal of paper, plastic, glass or metal increases the moisture content of the residual waste because these components have lower moisture content than mixed waste. Removal of organic matter reduces the moisture content of the waste stream and thus boosts its calorific value (Atkinson *et al* 1996). However, it has been concluded (Atkinson *et al* 1996) that any variations resulting from recycling schemes will be small and within the daily variations in feedstock already experienced by MSW incinerators.

Removal of dry recyclables may reduce the total ash production by up to 17%, with negligible change in the composition of the off-gas. A potential problem in the removal of dry recyclables could arise from increases in compactibility and cohesiveness leading to air distribution problems. However, these issues could be overcome with purpose-designed grates and waste feeder systems. Removal of metals from the waste stream could extend grate life and glass removal should reduce slag formation. The variations from recycling schemes in the future will be well within the operational design envelope of new generation "mass burn" waste to energy plants, and are therefore not likely to have a significant effect on energy recovery operations in MSW incinerators (Energy from Waste, 1999

The majority of clinical waste arisings are handled by specialist clinical waste collection and treatment companies to specialist incineration plant. However, small amounts of clinical waste are permitted for co-disposal with MSW in newer incinerators, e.g. at Tyseley.

3.2 Ash residues from mass burn MSW incinerator

The majority of MSW incinerators are mass burn machines, where waste is burned on a moving grate in a boiler with no or little pre-processing. Figure 4 indicates the inputs and typical outputs of a mass burn energy from waste plant. The majority of the waste is combusted to bottom ash (around 150 to 300 kg per tonne MSW incinerated) and scrap metal. Typically 20 kg of scrap ferrous metal can be recovered by magnetic separation per tonne of waste incinerated.

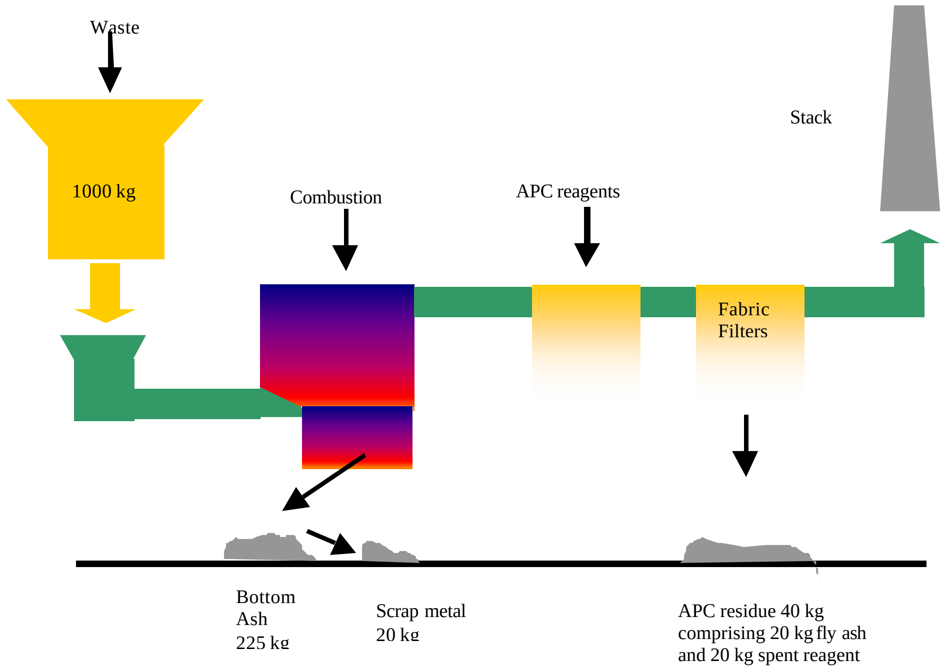

Figure 4 Waste residue streams in a typical UK mass burn EfW combustion facility

Bottom ash or grate ash residues are largely reused. Low cost pre-treatment measures that are often taken include a filtering process to screen oversized components, remove ferrous metal and to allow weathering of the material. These measures improve the chemical integrity and structural durability of the bottom ash prior to disposal or re-use. The practice of solidifying and stabilising bottom ash is not widely used as this requires higher processing costs (CRE 2000).

The fly ash and APC residues represent about 3 to 6% by weight of the input waste and are composed of fine particulate matter and gas cleaning reagents/products (mainly lime, activated carbon and salts). The fly ash itself contains carbon and metal oxides along with organic pollutants which are attached to the particulates in the fly ash. The normal treatment for these residues is to condition them with water and pre-treat them to reduce or immobilise harmful constituents, such as heavy metals. Fly ash and APC residues are pre-treated using solidification and stabilisation prior to landfilling (CRE 2000). This fixing of contaminants reduces the level of leaching when the ash is landfilled.

The most common stabilisation technique involves mixing the ash with Portland cement (CRE 2000). The hydrating reaction of the cement forms a solid material and reduces the mobilisation of heavy metals. The solidified material can then be landfilled. These processes do not effectively immobilise the chloride salts contained in APC residues so this makes re-use of the solidified APC residues unfavourable.

<u>Re-use and recovery of mass burn MSW ash residues</u>

Bottom ash from mass burn incineration has been used as a road sub-base or as aggregates for concrete (Table 3). In Japan, bottom ash has been used in brick manufacture; in the Netherlands as embankment fill, landfill cover and as noise barriers. In the UK, 40% of the bottom ash produced is used in applications such as road construction. The ash is typically graded and is suitable for use as a secondary aggregate for use in sub-base and bitumen or cement bound macadams. This has the potential to recycle around 90% of the ash, with the remaining oversize being used for engineering purposes in the landfill.

In the UK, all fly ash and APC residue is currently sent to landfill as special waste. It may be possible to use these residues following pre-treatment or stabilisation. In the Netherlands, these residues have been used as asphalt filter, in mine reclamation and for top sealing of landfill sites. The fly ash is not considered hazardous in its end use and can be treated the same as normal asphalt (Ballast Phoenix, Personal Communication 2001).

The costs of utilising ash residues dictate whether the ash is sent for disposal in landfill or treated and then used in an application as a substitute for raw materials. Site specific cost evaluation is required for residue utilisation. This involves acquiring a permit for ash re-use, extensive testing on the ash, transportation and finally the cost offset from diversion from disposal to landfill and from replacing the natural material. The costs of treatment for fly ash and APC residue to render it safe enough for use are far higher than for the less contaminated bottom ash. Accordingly, at present fly ash and APC residues are not put to any use in the UK.

The use of ash residues in products is governed by the required performance of the end product. The key performance characteristics are:

- The properties of the ash residues (including standard engineering criteria)
- The potential for environmental impact during product application lifetime

An example of the above is that alkali metals and chlorides in ash residues need to be limited for concrete and cement applications since they give rise to loss of strength and risk of corrosion in reinforcement bars (Energy from Waste March 2000). **Table 3 Mass burn incinerator residues and potential fates**

Residue	**Weight produced when 1 tonne MSW consumed**	**Composition**	**Recovered**
Bottom Ash	150 – 300 kg	Grate ash (heterogeneous material) Grate riddlings (fallen through grate)	1) Ferrous metal magnetically separated from quenched bottom ash and sold for scrap (metallurgic industry) 2) Used in road construction (base course/asphalt pavement /embankment) 3) Building construction (construction material/ filling material/interlocking blocks/concrete blocks)
Fly Ash	10-30 kg	Particulate matter from flue gas stream prior to APC (electrostatic precipitator dust and cyclone dust)	1) Civil engineering (asphalt filler/mine reclamation/landfill site top-seal, concrete)
Air Pollution Control (APC) Residue	10 – 30 kg	Scrubber residue and/or bag house filter dust (may be combined with fly ash prior to disposal)	1) Potential for use as grout in coal mines

(Source: Adapted from: Energy From Waste 2000)

Alternatively, vitrification may be used to both stabilise and solidify incinerator ash residues. There are many techniques for vitrifying ash residues developed to laboratory and pilot scale. However, there are no plants using this technique in North America or Europe on a commercial scale. The only known large-scale application is vitrification of fly ash from mass burn incinerators in Japan (CRE 2000). The advantages and disadvantages of the technique are provided in Table 4.

Table 4 The advantages and limitations of vitrifying residues

Process description	Advantages	Disadvantages
Vitrification is a thermal process achieved by melting the material with additives to form an homogenous glass phase, which immobilises heavy metals and other substances	♦ After vitrification the leachability of the residue is substantially reduced and the material is highly resistant to aqueous, chemical and thermal attack. ♦ Vitrification can be applied to fly ashes with a variety of compositions, including those with high variability in the concentration of heavy metals ♦ Large reduction in residue volume ♦ Low dust generation ♦ Established technique ♦ Number of uses for end product ♦ Glass forming additives are inexpensive	♦ Gaseous emissions (e.g. Cl, SO_2, Hg etc) and other volatiles previously trapped in the residue. ♦ Secondary treatment of gaseous emissions is required before release to the atmosphere ♦ High energy requirements to heat the residue, therefore the technique can be expensive ♦ Complex technique, requiring specialist equipment and trained personnel

(Source: CRE 2000)

The high cost of the process is a barrier to market penetration (costs are incurred in high-energy consumption, circa 0.6 kWh/kg of filter dust, off gas treatment and complexity), though a number of novel vitrification processes have been reported to be economically viable alternatives to landfill.

The main disadvantage of vitrification is that the high temperatures result in the release of volatile metals into the off-gases (CRE March 2000). The other problem is that melting and fusion processes do not effectively incorporate halogens, sulphur or carbon, thus gaseous emissions of Cl and SO_2 are experienced.

New techniques under development are the PermaVIT Vitrification process, which is a method for transforming non-hazardous and hazardous residues into a chemically durable construction material. The TDR vitrification process is another that is promising: the bottom ash or fly ash is melted into a glassy material, resistant to leaching when cooled (CRE March 2000). The glassy product can be used as construction aggregate or fill material, thus avoiding the cost of landfilling.

<u>Case study: Ballast Phoenix</u>

Ballast Phoenix are the only major bottom ash recycling company in the UK, handling some 130,000 tonnes of ash per year. This case study highlights the costs and processes involved for bottom ash.

Ballast Phoenix's charges vary depending on the amount of ash taken away, with lower charges per tonne levied for larger quantities. In order to be competitive, the rates charged for bottom ash disposal are lower than landfill rates. Ballast are currently disposing of bottom ash from three major MSW incinerators and are currently discussing the feasibility of options with a number of other Operators.

The bottom ash is delivered to the treatment site in bulk by tippers provided by incineration companies. The ash processing involves purely mechanical treatment (no heat input is required). Firstly, the ferrous component is separated out and the metals are sold to specialist sorting companies. Secondly, the non-ferrous component is separated out and any un-combusted material, of which there is usually minimal amounts, are collected and returned to the incineration or are sent to landfill. If there is a significant quantity of un-combusted material a charge may be levied against the incinerator company, however, this is extremely unusual as each incinerator Operator will be authorised with a specified maximum carbon in ash content, typically 3%.

The remaining ash is sized to customer requirements e.g. 0-10mm, 0-20mm and 20-30mm size. Finally, the graded ash is delivered for use in road construction and fill material. The ash is subject to strict quality control (Ballast Phoenix apply the provisions of the Environment Agency's draft policy document) prior to its re-use.

Figure 5 Bottom ash processing plant (Courtesy of Ballast Phoenix- Recycling Industrial Residues)

One company, SELCHP, has formed a joint venture with Hanson to recycle incinerator bottom ash. The ash is graded and blended before sale as aggregate. This operation provides SELCHP with an income stream displacing former costs of disposal.

Ash residues from fluidised bed MSW incinerator

In the fluidised combustion plant, a drum sieve is used to separate the bottom ash from the bed material (usually sand) to allow the sand to be recycled to the bed. As little as 20kg of bottom and boiler ash is generated per tonne of waste incinerated (Figure 6), ie. an order of magnitude less than that produced by a mass burn incinerator, but this is dependent on the extent of waste processing and inert material removal prior to combustion. However, the sieve is not completely efficient and some sand escapes, so the bottom ash can contain a high proportion of sand. The bottom ash and boiler dust may be combined, as may the flue-gas cleaning residues and the cyclone dust, prior to disposal.

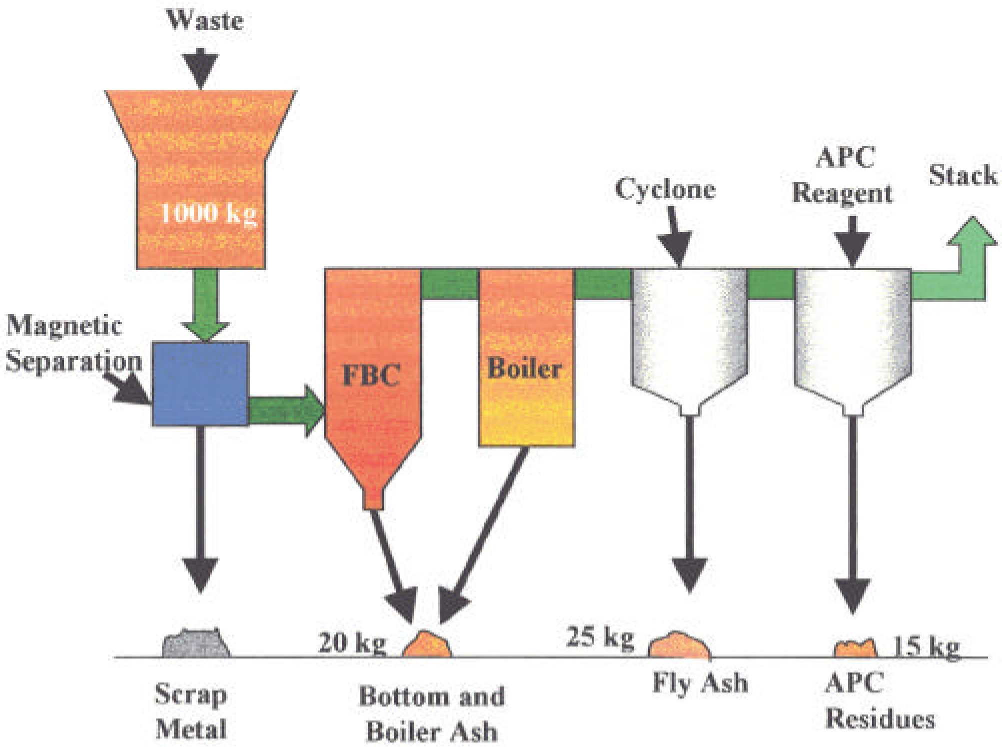

Figure 6 Waste residue streams for a fluidised bed incinerator (Source: Energy from Waste Association, 2000)

Table 5 Fluidised bed combustor residues (Source: Energy from Waste 2001)

Residue	**Description and Composition**	**Quantity produced**
Boiler Ash	Removed from fluidised bed – contains high proportion of sand particles	Amounts of residue produced from fluidised bed plant are lower than those from mass burn plant as non-combustibles are separated from the waste stream prior to combustion
Fly Ash	Particulate matter removed from flue gas stream (cyclone dust)	
APC Residues	Scrubber residue and / or bag house filter dust	

3.3 Ash residues from hazardous waste incineration

The methods for the treatment of hazardous waste residues are described in Table 6. The table summarises the costs involved, energy required and metals that can be recycled. Although there are many options in development or available, the costs and energy requirements indicate it is only currently viable to recycle the hazardous waste slag. APC residue and fly ash are normally sent to landfill, often after a treatment to stabilise the leachable compounds.

The hazardous waste incinerator has a variety of waste inputs ranging from those with a high chlorine content to those with a high metals content, or both. The temperature at which the combustion is carried out is generally selected by the Operator to reflect the waste characterisitics. A higher, slagging temperature, is used for the majority of wastes as this gives more complete combustion and produces a vitreous residue (instead of an ash) in which any remaining hazardous compoenets are effectively immobilised. In the UK this vitreous residue is currently sent to landfill as non-special waste, although one Operator (Cleanaway, Ellesmere Port) deliberately adds sand and waste green bottle glass (to around 15% of the total kiln input) to the kiln in order to enhance the slagging process and slag quality. This has found use in building block manufacture.

However, when treating wastes high in volatile metals, for example arsenic, an Operator may run the incinerator at the lower, "ashing" temperature in order to reduce volatilisation. In these circumstances, the bottom ash must be landfilled as special waste at additional cost.

The APC residues from hazardous waste incineration in the UK comprise scrubber liquors and wet Electrostatic Precipitator (EP) residues. These produce a solid cake that is sent to landfill as non-special waste. Significant APC residues are produced as there is a three stage wet scrubber and five EP precipitators although the actual quantities of residue produced will depend upon the nature, particularly the halogen content, of the wastes incinerated (Shanks, 2001 Personal Communication).

Table 6 Process comparison for residue treatment from MSW and hazardous waste incineration (data based on 1 tonne of MSW fly ash input material)

Treatment Process	Costs	Process Complexity	Resource Requirement	Comments
Storage in underground caverns of disused salt mines	Low	Low	Energy 100 kWh Wastewater 70kg	Residue still environmentally hazardous and left for future generations to deal with. Least suitable option although low cost.
Solidification process with cement / china clay	Medium	Multiphase	Energy 600 kWh Wastewater 2000-3500kg Water consumption 2500-3750kg Material 450-500kg	Only partially adequate because of its high volume increases and limited compliance.
Chemical pre-treatment and subsequent immobilisation	Low	Single phase	Energy 160 kWh Water consumption 170kg Material 155kg	Low cost, compliance and low use of resources means that this process seems to be the best option (based on this criteria).
Acid washing with heavy metal recycling	Medium	Multiphase – still being developed.	Energy -78-100 kWh Wastewater 7000-18000kg Water consumption 7750-18400kg Material 400-500kg	These processes represent an interim form of processing and partial recycling. The benefits may not be proportionate to the costs and materials deployment plus there are technical problems that exist. Frequently not complying.
Oxidative metal processing	High	Hi-tech multiphase	Energy 3500 kWh Wastewater 5900kg Water consumption 6000 kg Material 300kg	The end product is only useful as a building material or cement additive (and is not environmentally harmful). These benefits may not be proportional to the process costs. Processes still be developed.
Reductive melting process	High	Hi-tech multiphase	Energy 2600 kWh Wastewater 2600kg Water consumption 2700kg Material 300kg	
Catalytic reduction	Medium	Hi-tech multiphase	Energy 3000 kWh Material 560kg	Process being developed and costs still to be proven on large-scale implementation.
HSR process	Low	Hi-tech multiphase	Energy 2400 kWh Wastewater 2600kg Water consumption 2700kg Material 300kg	Process being developed and costs still to be proven on large-scale implementation.

Source: International Directory of Solid Waste Management 1999/2000

NB. Compliance notes are based on Swiss regulations.

3.4 Sewage sludge incineration

The bottom ash from sewage sludge incineration is frequently sent to landfill. However, the industry is developing processes to enable the ash to be used in bricks and hence avoid landfill charges. The sewage sludge incinerators are fluidised bed systems so the ash will contain a high proportion of the bed sand (see above for MSW FBC ash). It may also have a high metal content if the sewage sludge has a high industrial component, which could severely limit the re-use potential of the bottom ash.

4. NOISE AND VIBRATION

Most of the sources of noise and vibration for incineration plant of all types are similar to those encountered in many other industrial processes, ie. fans, pumps, motors etc. Accordingly, in order to avoid repetition of existing Agency Guidance, this section only the key sources of noise typically encountered in/from incineration plant are identified together with options to ameliorate the noise impact. These sources and potential remedies are presented in Table 7.

Table 7 Key sources of noise from incineration plant

Source	Potential remedial actions
Vehicle movements for waste deliveries and removal of residues off site	Landscaping of site, earth barriers etc Attenuated reversing bleeper (warning bleeps volume adjusts to a set level above background noise) Clear access and egress to and from the site to reduce or eliminate vehicle manuoevering Restricted times for vehicular access to the site e.g. daylight hours only
Boilers (where fitted)	Enclosed plant and fit vents etc with baffles. Roller doors etc where fitted should be kept closed as much as possible to restrict noise
Burners (air intakes)	Enclosed plant or silencers fitted to intakes
Vibrating motors e.g. shaker tables/conveyors	Enclosed plant and motors etc set into separate foundations
Induced and forced draught fans	Enclosures with baffles fitted to air intakes Attenuators/baffles fitted within id fan exits ducts
Steam turbine/generator sets (where fitted)	Anacoustic enclosures within an enclosed plant. Generator set mounted on own separate foundations
Air condenser fans	Sound barriers e.g. walls, landscaping Site away from noise sensitive locations
Compressed air - bag filter pulsed cleaning	Sound barriers e.g. walls/enclosures, landscaping Position away from noise sensitive locations
Emergency safety valves	Attenuators/silencers fitted to valve exits

Case studies

- Addenbrookes Hospital, Clinical Waste incinerator. Complaints about noise emitted from the stack. Subsequent investigation by the Operator identified the noise source as the induced draught fans. Noise from the fans was being transmitted through the incinerator exhaust gas ducting to the stack where the noise was subsequently transmitted at a high elevation from the top of the stack. The problem was resolved once the Operator installed noise attenuators (baffles) in the id fan exits.

- Stoke-on-Trent MSW incinerator. The Operator received complaints from local residents during the commissioning phase of the project to build a new MSW incineration facility. The complaints related to the use of the boiler emergency steam release valves during testing. In response, the Operator has fitted silencers to the valve exits.

5. ENERGY EFFICIENCY

This section outlines some of the best available techniques for incinerators in terms of energy efficiency, one of the key requirements of the IPPC Directive. Energy efficiency will need to be addressed in the future throughout the incineration process in order for compliance of the Directive. Within this section the available techniques are outlined and illustrated through the use of case studies to assess energy efficiency in specific operations.

5.1 Energy efficiency techniques

The following techniques can reduce energy consumption and hence reduce both direct (heat and emissions from on-site generation) and indirect (emissions from a remote power station) emissions.

- Energy recovery is an important consideration as part of an incineration plant as it can significantly improve overall thermal efficiencies (e.g. from 22% to 75%) and provide heating and power, displace fossil fuels and provide an income stream for the incinerator Operator. However, there are a number of reasons why combined heat and power (CHP) schemes may not be applicable as an option for integration into the operations of an incinerator – see IPPC Paper and Pulp guidelines.
- Insulation of the incineration furnace is important to maintain temperatures for full waste combustion, and as a result, improve energy efficiency. As set out in the EPA (1990), temperatures must be maintained to at least 850^{o}C throughout the combustion process (1100^{o}C in the case of hazardous wastes).
- The type of combustion technology used can significantly impact on the thermal efficiency achieved. Thermal efficiency should be a consideration in plant selection. . Boilers need to be installed and maintained to ensure that there is an efficient heat exchange between the heat input and feed water, and to ensure that there is no air leakage which may depress thermal efficiency.
- Energy efficiency may be improved through using exhaust heat to preheat feed water, raising its temperature before it runs through the boiler or by preheating combustion air.
- Generation of steam or hot water needs to be ‘delivered’ efficiently to ensure that there are no significant losses in the transfer process. Site position and layout may be an important factor to ensure that efficient transfer can take place and significant heat losses do not occur.
- Plant utilisation needs to be maximised as far as possible to maintain energy efficiency and to reduce requirements for start-up and support fuels. Maintaining capacity relies on an adequate supply of waste to the plant, and waste supply management is therefore an important feature of maintaining energy efficiency.
- Treatment of waste prior to the process of incineration can be important in enabling more efficient combustion and hence reduce the need for supplementary firing. This will be largely dependent on the type of waste going into the incineration process, i.e. its calorific value or moisture content.
- In all waste incinerators, the water used in the boiler must be purified using a demineralisation process – any ions remaining in the water will corrode the boiler at the high operating temperatures. Demineralisation can be carried out using ion-exchange softening or membrane processes. Using membranes requires very high pressures and thus consumes more electricity than ion exchange (Shanks 2001, Personal

Communication). However, membrane technology is often used as it has lower investment costs.

Options for energy recovery from incineration of waste are important and any decision not to recover energy needs to be justified. The following case studies outline some of the benefits of recovering energy from waste, particularly economic and environmental benefits. For both of these factors, cost assessment considerations need to apply.

Case Studies

The following case studies identify how energy efficiency within the incineration process can be improved. Case studies 1 and 2 concern incinerators that use bubbling fluidised bed technologies. Case study 3 assesses the integration of CHP into an incinerator while case study 4 looks at clinical waste incineration.

<u>DERL Energy from Waste Facility - Case Study (1):</u>

The bubbling fluidised bed boilers, as used at this facility, are each sized at a maximum continuous rating to match the gross incoming waste stream of 8 tonnes per hour at an assumed gross calorific value (10 MJ/kg of waste). This rating is set to the stream of waste to maximise throughput. The fuel feed system is overfed to ensure there is always enough fuel going in to the boilers (important in maintaining efficiency). The boilers use an advanced combustion zone (ACZ) design which enables thermal efficiencies of 89% with typical steam conditions (40 bar and 400 degrees C) – see case study details for technical details concerning the ACZ. The lower furnace area is refractory lined to achieve uniform temperatures (and thereby increasing process efficiency) and reduce slagging.

Electricity production is generated at 10.5MW, in-house demand being 2.2MW. The mass and energy balance is as follows:

Category	TPA	GWh
MSW	74400	133
Commercial	15120	38.8
Special Dry	720	3.5
Civic	7080	13.9
Industrial	8520	29.5
Rubber Tyres	1320	9.8
Special Liquid	3120	20.9
Clinical	9720	34.6
Bulky Items	744	1.5
Spill-over ferrous	423	0.8
Spill-over non-ferrous	77	0.2

NB. Figures are based on availability of at least 7500 hours / annum, and the processing of 120000 tonnes per annum.

Lidkoping Waste-to-Energy Plant - Case Study (2):
As in the above study, the boiler technology is bubbling fluidised bed (BFB). The maximum capacity of this plant is 82MW. 70,000 tonnes of fuel are combusted every year, producing 200 GWh district heat. 120 GWh was delivered from waste (household 60% and industrial 40%) in 1998 - (77 GWh from bio fuels and 3 GWh recovered from industries). Waste is baled when there is an excess so that it can be used when levels are lower, maximising energy recovery during the year.

Sand is initially heated up in the boilers to 600 degrees C using oil burners. Furnace walls are protected with bricks until the level of the arches to prevent cooling (and maintain furnace temperature) and protect against erosion.

Average heat value for all waste streams has been determined to 3.1 MWh/tonnes (or 11.2 MJ/kg). The calculated overall efficiency of the solid fuel plant is 88%.

Integration of waste incineration with CHP- Case study (3):
This study outlines the benefits of integrating waste incineration with CHP. The system is made up of a gas turbine (for CHP), incinerator, waste heat boiler (fed by both incinerator and gas turbine) and an economiser. The waste heat boiler provides heat recovery rates of 5.9 MW for the turbine and 1.5 MW for the incinerator. The incinerator in this case is a 750 kg/h, dual fuel two-stage pyrolytic incinerator. Exhaust gases from the primary chamber pass up to the secondary chamber, where they are fully combusted in the presence of additional combustion air. A duel fuel burner is situated in the secondary chamber in order to ensure temperatures are maintained. All steam produced by the waste heat boiler is utilised, with around 96% of the total available economiser output.

Energy cost savings of £690,810 were achieved during the 1990/1991 monitoring period. The CHP system has an overall efficiency of 70% (and therefore a loss of 30% primary energy). An overall saving of 118,950 GJ/year has been achieved by the installation of this integrated system. A total of 1883 tonnes was incinerated. With energy savings of 12400 GJ/year from saved fuel used in combustion and 5140 GJ/year through energy recovery from waste, there has been an average energy recovery of 2.7 GJ/te of waste.

Waste burning boilers for clinical incineration - Case study (4):
This system has been designed with the objective of producing useful energy in the form of steam or hot water. The waste fired boiler is basically of 3 pass wet back design with a vertical annular arrangement of tubing. The combustion process involves both gas (or oil) and combustible waste. The difficulty of unknown and varying calorific value of the waste is overcome by controlling the supply of natural gas in response to combustion temperature. In the primary burner, hot gases rise upwards – a secondary gas burner ensures that high temperatures are maintained and combustion complete before the gases reach the top of the chamber (as mentioned in the previous case study).

During the monitoring period, the calorific value of the waste was 14 MJ/kg and the thermal efficiency of the boiler was 75%. The cost of waste disposal in the plant is £200 per tonne (not the normal rate of £250). This is including the cost of the gas for supplementary firing. The economic effectiveness under these conditions is 2.5. Thus, each unit of energy purchased produces 2.5 units of energy output.

5.2 MSW incineration

All the current IPC authorised MSW facilities feature heat recovery systems; a steam turbine/alternator set for electricity generation and, in some cases (notably Coventry and Nottingham) district heating. The production and sale of electricity from these facilities is integral to maintaining the economic viability of their operation. An illustration of the energy flows around a typical facility is presented in Figure 8. Typically, overall thermal efficiencies for electricity only production are around 18%, with most of the energy losses (around 60%) being accounted for by the low-pressure steam exiting the turbine and entering the condensers. Some of this energy can be recovered through bleeding off low pressure steam close to the turbine exit, for example for use in district heating schemes. Although the removal of some steam from the turbine will result in a small drop in electrical output, as energy is effectively removed from the system, this would be more than off-set by the energy recovered for heating purposes. The efficiency of such CHP schemes can be around 60%. With fluidised bed machines, an electrical efficiency of 21% may be achievable.

As well as producing energy it is also consumed around the plant, for example in fans and the APC equipment. Data for the distribution of energy around the plant are sparse. However, an estimation of the energy consumption around a typical waste to energy plant, featuring a steam turbine, is provided graphically in Figure 7.

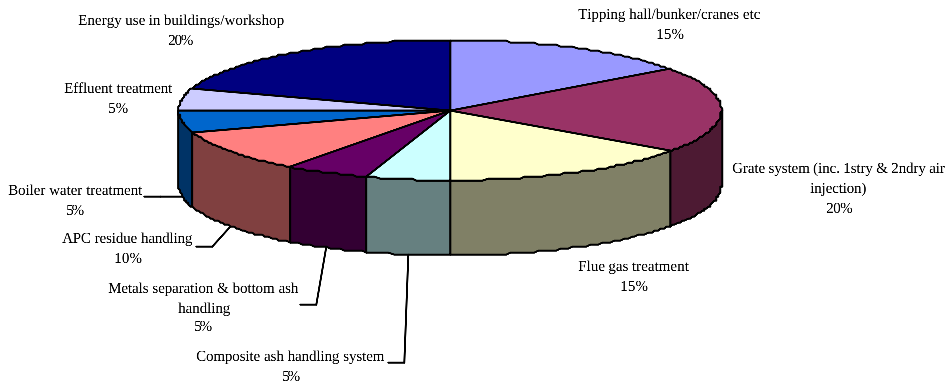

Figure 7 Estimated distribution of energy consumption in a mass burn MSW incineration facility (Source: Courtesy of ONYX UK Ltd)

MSW incinerators also require fuel for start up of the incinerator. In general, the burners are fired up on oil but are ignited by gas. Once the incinerator has reached the required operating temperature the burners are no longer used unless the temperature in the furnace falls below the required operating parameters e.g. due to a large batch of low calorific value waste entering the grate. This is avoided through careful mixing of the waste to ensure that the waste feed fed on to the grate is as homogenous as possible. Auxiliary fuel use generally accounts for less than 1% of the energy input of a typical MSW incineration plant.

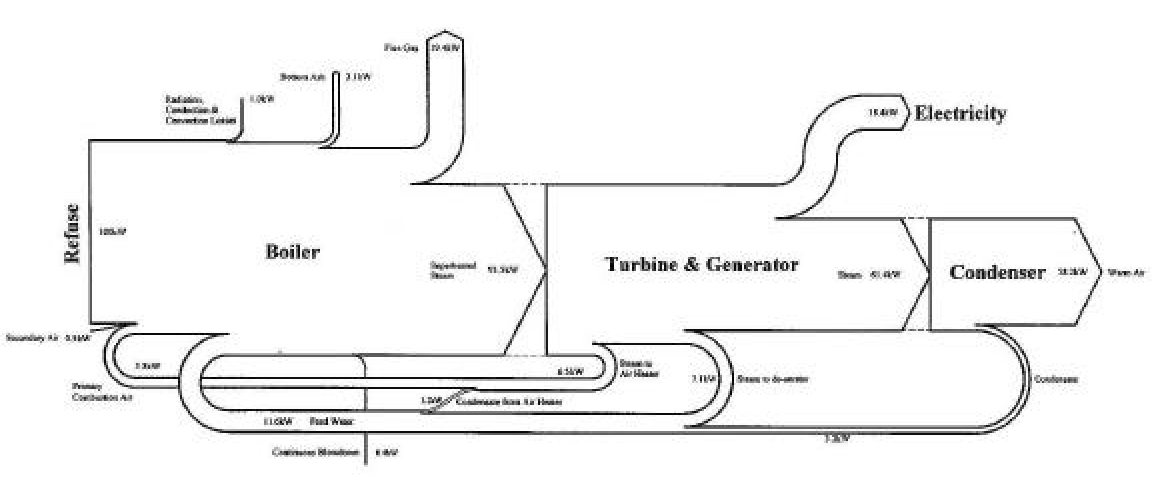

Figure 8 Energy flows of a model waste to energy facility

5.3 Hazardous waste incineration

The hazardous waste incinerators in the UK generally only employ low grade heat recovery as they need to rapidly quench the furnace gases in order to reduce or prevent dioxin formation from the incineration of chlorinated wastes. Energy is generally recovered to provide re-heat for the flue gases after abatement in order to ensure an invisible plume and that the plume is hot enough to achieve adequate dispersion. Figure 9 indicates estimated energy flows around a typical UK hazardous waste incineration facility.

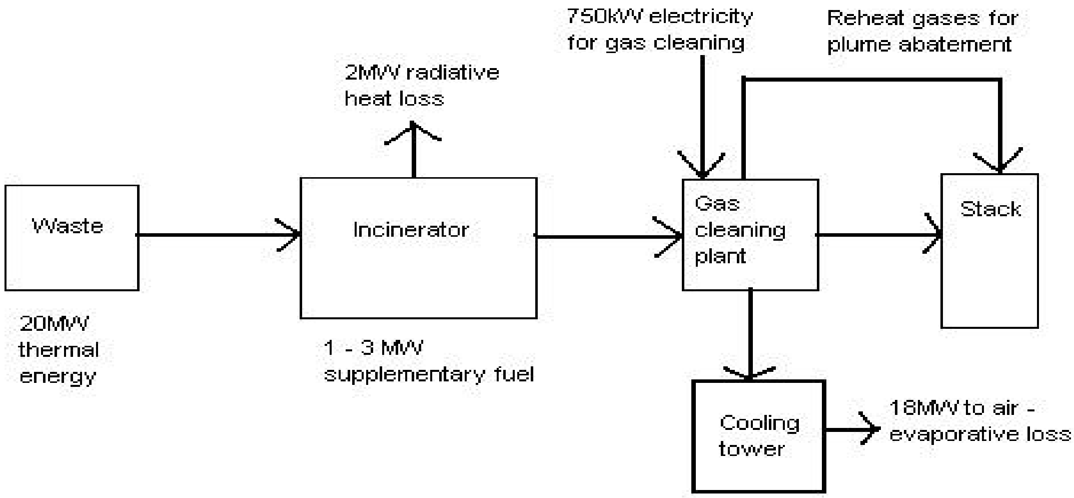

Figure 9 Energy flows within a hazardous waste incinerator (Source: Shanks 2001)

An additional complication regarding the use of energy recovery systems in merchant hazardous waste incinerator plant, is their need to incinerate a wide range of wastes. These wastes can contain high proportions of inorganic salts and halides which can deposit in heat recovery systems such as boilers in form of slags or sinter leading to decreasingly boiler efficiency and potential destruction of the boiler.

Additional fuel is often required in the incineration of hazardous waste to achieve complete combustion. The calorific value of the waste determines how much supplementary fuel is required. 50 to 60% of the electricity consumed powers the fans for pushing the gas through the plant and to the recirculating pumps. In order to make a 5% overall energy saving (10% electricity saving), inverter control should be installed for the fans and there should be speed control for the 3 phase motor used to regulate the power (Shanks 2001, Personal Communication).

Some hazardous waste incinerators in continental Europe generate electricity from the heat from combustion to give them 10 to18% conversion into electricity. One potential solution to the issue of dioxin formation is the use of a catalyst for dioxin destruction. Such catalysts are already deployed in European plant and can perform the dual function of destruction of oxides of nitrogen and dioxin destruction. In addition, if dioxin destruction only is required, catalyst operating temperatures as low as 120°C are adequate, hence additional re-heating of stack gases over and above that required to avoid a visible plume is not required. However, as the catalyst is an end-of-pipe abatement device and therefore does not prevent dioxin formation an additional issue with catalyst equipped plant is that the boiler dusts and APC residues can contain elevated levels of dioxin.

5.4 Clinical waste and animal remains incineration

There are some clinical waste incinerators in the UK that recover energy from the process, usually in the form of heat. It is unclear whether the animal remains incinerators also recover heat. Many clinical waste incinerators situated within hospitals already recovery energy in the form of steam for space heating and/or laundries although they do not generate electricity. For those plant situated remotely from hospital sites (i.e. merchant operators) the issues will be similar to those for MSW incineration, however, most if not all of these plant do not recover any energy.

5.5 Drum Incinerators

Little data is available on these processes. However, the data that are available indicate these are largely batch (i.e. non-continuous) processes and do not recover energy.

6. WASTE INCINERATION ACCIDENT ISSUES

Many of the potential accidents or hazards associated with an incineration plant also apply to other sectors, such as the movement of heavy vehicles, and are covered in existing Agency Guidance (i.e. S6.01). Specific issues relevant to incineration plant are outlined in Table 8.

Table 8 Waste incineration accident issues

Aspect	**Consequence of release**	**Controls**
Waste storage and handling	Litter Contaminated land Release of pathogens, odours etc	Secure storage Containment e.g. sealed floors, bunds Refrigeration of wastes Constant mixing of wastes in the refuse pit (municipal) Sprinkler and water cannon systems mounted over waste pits etc.
Residues management	Contaminated land Damage to aquatic systems Potential releases to air e.g. ammonia	Liquid reagents stored within bunds Ammonia stored in pressurised silo – during delivery displaced gas returns to delivery vehicle Storage silo level monitoring with warning and high level alarms. Contained site drainage systems linked to interceptors or treatment plant.
APC equipment failure e.g. Power failure Reagent shortage Blockages or damage to APC equipment	Release of particulate material and untreated combustion products. Acid gases to air including dioxins to local surroundings	Use of emergency back up generators to ensure fans are able to operate and avoid or minimise use of emergency vent systems (EVS). Low level alarms fitted to reagent storage silos/vessels. Predictive/continuous monitoring of key parameters e.g. fabric filter pressure drop, and feed back to control room/multi-stage alarms.

7. ANALYSIS AND DISCUSSION

7.1 Selection of raw materials

Abatement of acid gases

The current selection criteria for acid gas scrubbing reagents are cost and performance. The most common reagents are lime (CaO) or hydrated lime ($Ca(OH)_2$) employed in dry or semi-dry scrubbing processes.

The most significant acid gas, with respect to difficulty of control within authorised limits, is hydrogen chloride (HCl). The half-hourly average value for HCl in the WID is $60mg/m^3$, hence peaks or spikes of HCl for short periods of time that are significantly above this level could result in breach of permit conditions. Large HCl spikes are common in municipal solid waste incinerators, clinical waste incinerators and hazardous waste incinerators. Best available techniques currently used to minimise reagent usage are the injection of alkali reagent altered in response to increased HCl in the flue gases. However to be effective, response time would need to be almost immediate. This has proved difficult, as the sample times are too long to make it fast enough. In practice, for the dry and semi-dry acid gas abatement systems commonly employed, these must be continually over-dosed with alkaline reagent in order to compensate for occasional peak levels of HCl from high chlorine content wastes (e.g. plastics).

The cost of the excess reagent is significant, and the unreacted lime or sodium bicarbonate will make the APC residues alkaline and thus more problematic for disposal, particularly with respect to the mobility of chloride and metals within the residues. In addition, as the reagent dosage rate increases so will the quantity of dry APC residues increase. These residues are currently disposed of as special waste, attracting a disposal charge of around £50 per tonne. In future, as the Landfill Directive is implemented, it is probable that these wastes will require stabilisation and leach testing before they can be disposed.

Accordingly, the extra cost involved in extra-dosing of reagent could make the option of wet scrubbing more economically competitive than dry systems. A comparative cost study for semi-dry and wet scrubbing systems has been reported for a Brussels incineration plant with four combustion units, each burning 20 tonnes of MSW per hour (European Commission, 1996). These costs are reproduced in Table 9.

The costs provided in Table 9 should be regarded with caution as the data relate to a study carried out in 1989 considering only the acid gas scrubbing equipment for a specific incineration plant. However, the figures do provide a useful comparison.

Table 9 Comparative acid gas abatement costs (all figures converted to pounds sterling, 2000)

Parameter	**Semi-dry**	**Two stage wet scrubbing**
Capital Costs		
Investment	£14.5 M	£13.5 M
(of which for water treatment)	£0	£0.76 M
Amortisation over 20 years	£1.23/tonne	£1.13/tonne
Operating Costs		
Reagents	£2.35 /tonne	£0.48/tonne
Water	£0.69/tonne	£0.01/tonne
Electricity	£1.05/tonne	£1.25/tonne
Residue disposal	£2.07/tonne	£1.28/tonne
Maintenance	£1.41/tonne	£1.32/tonne
Staff	£0.69/tonne	£0.69/tonne
Total cost (amortisation and operating costs)	**£9/tonne**	**£7/tonne**

(Source: European Commission, 1996)

Hazardous waste incinerators commonly employ wet scrubbing techniques although these are generally open systems. For example, the Cleanaway Plant at Ellesmere Port operates a single pass wet scrubber where water is used only once in the scrubber before discharge to the Mersey estuary. Shanks Waste use a recirculating system at their Pontypool plant where water is recirculated via a treatment plant until the chloride content prohibits further use and is consequently discharged to the local river at a rate of around $350m^3$ per day. The differences in approach taken by the two plants are a consequence of the differing chloride contents permitted in their effluent discharges. Theoretically, both plants could use a closed loop system with chloride recover. However the nature and value of the resulting residues should also be considered i.e. if the final residues were of low or no value then they would be landfilled and the potential for leaching of pollutants from these residues should be considered.

Abatement of dioxins and mercury

The abatement of mercury and dioxins are primarily achieved through the addition of activated carbon into the waste gas stream prior to particle abatement. These systems are reliable and highly effective for removal of volatile metals and dioxins. However, the resulting residues are highly concentrated in both toxic organic species and heavy metals creating a problem for disposal. One approach is to use wet scrubbing as discussed above together with activated carbon to absorb dioxins and other additives to facilitate destruction of dioxin. An alternative approach is the use of a catalyst system to destroy dioxin. These systems have been successfully demonstrated to meet 0.1 $ngITEQ.Nm^{-3}$ concentration limit for dioxins and, when operated in excess of 120^oC, with negligible absorption/contamination of the catalyst with dioxin (CRI Catalysts, 2001).

Abatement of nitrogen oxides

The design of the furnace, incinerator grate and combustion control systems all influence NOx formation. Fluidised bed incinerators, by virtue of their lower operating temperatures, produce less NOx than mass burn incinerators. However, these devices cannot be used to incinerate wastes containing high proportions of metals or glass or bulky wastes as this would lead to slag formation and impede combustion. Accordingly, fluidised bed incinerators require a materials recovery facility and pre-treatment, usually, shredding of waste prior to incineration. In addition, for some hazardous wastes, fluidised bed incinerators may not obtain the high temperatures required for destruction of some hazardous wastes. However, fluidised bed incinerators have been successfully deployed across Europe for the incineration of MSW and sewage sludge. In the UK, sewage sludge incinerators are of the fluidised bed type whereas for MSW incineration there is only one fluidised bed plant, the DERL plant located in Dundee.

Where it is necessary to employ mass burn technology, flue gas recirculation (FGR) can be employed. Whilst FGR alone will not enable MSW mass burn facilities to meet WID limits, it can reduce the overall requirement for NOx abatement and is best considered at the design stage as retrofitting will be a relatively expensive and potentially impractical option. The key barrier to the adoption of FGR by the incineration sector is suspected enhanced boiler corrosion through localised increased carbon monoxide and chloride caused through recirculation of flue gases.

Selective non-catalytic reduction techniques (SNCR), using ammonia or urea injection, are widely deployed within the MSW incineration sector. It is also possible that hazardous waste incinerators will require SNCR systems in order to manage occasional NOx emission spikes.Similarly, sewage sludge incinerators are also likely to require SNCR systems to regulate their NOx emissions. Where these systems are deployed, they should be linked via NOx monitors to a feedback mechanism to regulate and optimise the amounts of reagent injected. The draw backs of SNCR systems are the of reagents (ammonia or urea) and ammonia slippage. For plant equipped with fabric filters, most of the ammonia slip will be collected in the APC residues resulting in a noticeable odour of ammonia in these residues. Leach test studies on APC residues (Energy from Waste Association) have demonstrated ammonia concentrations of between 3.3 $mg.kg^{-1}$ and 10 $mg.kg^{-1}$ which are approximately equivalent to 150 to 500 mg of ammonia per tonne of waste incinerated (based on around 40kg of APC residues produced per tonne of waste incinerated).

Selective catalytic reduction (SCR) techniques also require the addition of a reagent, usually ammonia. However, the reaction between oxides of nitrogen and the ammonia is greatly enhanced by the presence of a catalyst. Only 20% to 30% of the reagent is required when compared to SNCR techniques, and ammonia slippage is much reduced. The principal objection to the use of SCR in the UK incineration sector is its high capital cost. However, from a review of available data, it is not clear what Operator's assumptions are on catalyst lifetimes, a key cost element. Many catalyst manufacturers provide guaranteed lifetimes of 3 or 5 years, but some systems have been demonstrated to operate effectively in excess of 10 years before catalyst replacement is required.

SCR technology is widely deployed across Europe for clinical, MSW and hazardous waste incineration facilities, and has been demonstrated to being capable of reducing NOx emissions to well below 50 mg/m^3. However, in order to operate safely and efficiently these systems require an operating temperature of around 180^oC; thus requiring energy input for re-heating of flue gases. In addition, the presence of a catalyst substrate in an exhaust duct will in itself produce a pressure drop, increasing the fan power required to achieve authorised stack exit velocities. However, evidence from MSW plant fitted with the latest catalyst technologies indicates that pressure drops are in the region of 3 to 7 mbar.

The Netherlands and Switzerland have already introduced legislation requiring new municipal incineration facilities to comply with NOx emission limits of 70 mg/m^3 and 80 mg/m^3 respectively. Abatement of NOx to these levels in the UK would need to be justified on case-by-case basis in order to demonstrate that the costs of achieving this level of abatement are not disproportionate to the benefits.

Table 10 provides comparative costs for FGR, SNCR and SCR techniques.

Table 10 Estimated capital costs (in Euros) for NOx abatement options for incineration plant

Technology	Installed plant capacity (kilo tonnes per annum)						
	25	50	100	150	200	400	600
FGR	90,000	110,000	160,000	200,000	230,000	350,000	470,000
SNCR	390,000	460,000	660,000	810,000	950,000	1,440,000	1,950,000
SCR	930,000	1,110,000	1,590,000	1,940,000	2,280,000	3,450,000	4,690,000

(Source: European Commission 1997)

7.2 Re-use, recycling and recovery of waste

The Agency has produced a draft protocol for ash recycling. However, this was not available for review. This protocol, when finalised could usefully provide clear guidance on the use and treatment of ash residues and, accordingly, facilitate best practice in their handling and treatment.

Municipal solid waste incinerators

The bottom ash from municipal waste incinerators is either landfilled or recycled to provide aggregate. The re-use of this ash as aggregate is likely to increase as Operators are showing increasing interest in reducing their disposal costs. The benefits of this approach are threefold; avoidance of landfill costs, reduction in landfill capacity required and displacement of virgin aggregate. With the exception of the DERL fluidised bed plant, all the currently operating plant separate out ferrous metals from the bottom ash residues. Typically about 20 kg of ferrous scrap are recovered for every tonne of waste incinerated. More metals, including non-ferrous metals, could be recovered through the use of materials recovery facility prior to incineration. Although, the incineration process effectively decontaminates these materials, the non-ferrous metals are lost in the residues.

The barriers to using processed bottom ash in aggregate centre on finding a suitable end use for the aggregate. The long term environmental impact of leaching metals and salts from the ash is relatively unknown and make end-users wary of the product (CRE 2000). The sensitive nature of incinerator ash use also means the end-users will not divulge their identity (Ballast Phoenix, 2001) thus hindering their involvement in promoting the use of ash. CRE report that the lack of consistent regulation across Europe and within the UK is also a barrier to uptake as it has an adverse effect on the market acceptance. Companies involved in ash recycling argue that there should be a standard risk assessment and specification model for use by the company; they argue that they should not have to require permission from local council officer on a scheme by scheme basis, with decisions that are inconsistent across the country. The potential for a large end-use market in road and car park construction has been indicated by the wide range of companies in the UK that successfully uses recovered ash for these purposes.

APC residues are classified as special wastes. Accordingly, all current APC residues are sent to landfill. In other countries, notably the Netherlands, these residues are recycled, but the residues differ in nature to those from UK plant, as they are first pre-treated. However, as a consequence of the Landfill Directive, the APC residues will require treatment/stabilisation before they can be landfilled. In addition, the effect of the WID 30 minute averaged limit for HCl is likely to result in increased reagent dosage rates for all currently operating plant and consequently increased APC residues.

Hazardous waste incinerators

Only one merchant hazardous waste incinerator (Cleanaway) currently recycles bottom ash, in the form of slag. The Shanks plant in South Wales has made submissions for permission to recycle slag which are awaiting Agency assessment, currently the bottom ash residues are disposed to landfill as non-special waste. APC equipment residues are relatively small (filter cakes) and are also non-hazardous, as they are treated on site prior to disposal. Similarly, it is our understanding that residues from in-house hazardous waste incinerators are also landfilled, particularly as many of these plants are operated as batch processes.

Clinical waste and animal remains incinerators

Ash residues from clinical waste and animal remains incinerators are predominantly disposed to landfill as special waste. There are no known re-uses of these residues.

Drum incinerators

There is little information available on the small drum incinerators. However, as with the MSW incinerators each will recover metals from the bottom ash (as this is their purpose) and will have potentially hazardous APC residues (where APC equipment is fitted). The Cleanaway hazardous waste incineration facility also undertakes drum incineration to remove hazardous contaminants from the drums. The ferrous metals are subsequently recovered and sold.

Sewage sludge incinerators

Residues from sewage sludge incineration are currently disposed to landfill. However, the industry is actively seeking to use the furnace residues. The sewage sludge incinerators are fluidised bed systems so the ash contains a high proportion of the bed sand which may make the material suitable for construction purposes. However, depending on the source of the sludge it may also have a high metal content, which would limit its uses. Accordingly, the applicability of the use residue recycling would need to be assessed on a site-by-site basis. There appears to be few published data on the metal content of the residues, however some data have been published from measurements undertaken at a plant combusting sludges from domestic and industrial sources; these data are reproduced in Table 11.

Table 11 Typical Analysis of Esholt Sewage Sludge Incinerator Ash

Constituent	% on dry weight of sample	Constituent	% on dry weight of sample
SiO_2	54.9	SO_4	0.46
Al_2O_3	18.4	Cl	0.30
P_2O_5	6.91	BaO	0.18
Fe_2O_3	5.83	Cr_2O_5	0.11
CaO	5.43	SO_3	0.09
K_2O	1.86	SeO	0.03

MgO	1.27	Trace elements	0.12
TiO_2	1.06	Loss on ignition	1.86 %
Na_2O	0.93		

(Source: Hudson J A and Walker J B)

7.3 Energy Efficiency

There are many general techniques for improving energy efficiency in process plant including incineration. These range from minimisation of heat losses, use of more efficient motors and pumps through to energy recovery techniques. In this section those techniques most applicable to the incineration sector are discussed.

Municipal waste incineration

All currently operating MSW incineration plant utilise energy recovery, principally for electricity production. Few include CHP to provide both heat and power, the most effective method of recovering heat from waste incineration. The principal barrier to the expansion of CHP is economic; the expense of installing infrastructure for exporting heat/high pressure steam, including more efficient heat exchangers and pipelines, needs to be justified against the potential market for this energy. Consequently, unless there is an almost guaranteed market for the energy there will be no incentive for the Operator to invest in CHP.

The usage of energy around the facility will vary slightly between each plant. However, there are few data available for currently operating plant, and those data that are available are mostly estimates. However, it is possible to identify energy uses within a plant through a systematic energy audit process. For a new facility it would also be possible to identify energy consumption for specific items of equipment at the design stage. Currently, it does not appear that this information is collected or collated, although a perspective purchaser of new equipment or facility could place the responsibility for identifying and quantifying energy consumption on the equipment/plant suppliers as a condition of tender.

Hazardous waste incinerators

It is possible to recover energy in the form of heat and electricity from hazardous waste incineration facilities. This has been achieved in some European facilities. However, merchant hazardous waste incinerators operators require flexibility in terms of the waste they can incinerate. Where the waste contains halogens, especially chloride, then rapid quenching or cooling of the combustion gases is required. Consequently, Operators of merchant facilities are unwilling to invest in heat recovery as this would preclude the burning certain types of waste.

In order to reduce consumption of primary fuels, Operator's use high calorific value liquid wastes for partial firing of the incinerator. However, around half of these wastes have been taken up as supplementary fuel by the cement kiln operators, so much of the market left to the merchant hazardous waste operators are wastes that cannot be used in any other process. Gas firing is then preferred to provide steady temperature control.

Clinical waste and animal remains incineration

Clinical waste incineration, and similarly animal remains incineration plant are also capable of providing both heat and power via a heat recovery boiler and a steam turbine. The issues concerning the operation of these facilities are similar to those discussed for MSW incineration above.

Drum Incinerators

Little data is available on these processes. However, the data that are available indicate these are largely batch (i.e. non-continuous) processes and therefore, the savings or income derived from recovery of heat is unlikely to justify the capital investment required.

7.4 Noise and vibration

The issues of noise and vibration are generally horizontal in that they cut across other industry sectors. Accordingly, the actions required to mitigate or avoid noise and vibrational issues are largely covered in existing guidance, including S6.01 (Technical Guidance for Pulp and Paper). Consequently, in this section the discussion will focus upon those issues that are likely to be specific to the incineration sector.

Noise issues are usually considered first at the formal planning stage for a new incineration facility or where modifications requiring planning permission are requested. In these circumstances, the local authority will typically set within a planning permit a noise limit for a development with compliance to be demonstrated at a specific location or locations. The level at which the limit is set is highly dependent upon the existing background noise and other local considerations, such as the nature of the environment. For example, a residential area will attract a more stringent noise limit than an industrialised area.

The best available techniques for dealing with noise and vibration issues will largely be site specific but would generally include:

1. Prevention of noise at source through the specification of "low noise" equipment (e.g. fans) at the design stage, for new or replacement plant;
2. For existing plant, identification of key noise sources through a "noise audit" and identification of control measures;
3. Enclosure of the facility, as much as practicable, including anacoustic enclosures for especially noisy equipment. This approach can could also reduce the visual impact of the facility and other nuisances such as odour and fugitive dusts;
4. Consideration of the mounting of vibrating machinery (e.g. turbines or magnetic separators) on to separate foundations or damped mountings;
5. Careful consideration of the siting of inherently noisy equipment such as air condensers (also see point 1) in order to prevent transmission of significant noise off-site;
6. Consideration of vehicle movements on site - the design of the facility should include measures to eliminate or minimise vehicle manoeuvring on site (planning consents usually also contain restrictions on the numbers of vehicles and times of entry and exit from the site); and
7. Consideration of end-of-pipe noise abatement such as silencers fitted to emergency release valves.

Whilst the emphasis should be placed on avoidance of noise reduction at source, e.g. through the use of fully enclosed plant, the considerations that may be considered as best available techniques will vary between sites. In particular, the cost of implementation of noise avoidance or reduction measures must be commensurate with the expected benefits. However, working practices on site should also always be carefully considered. For example, for enclosed facilities, much of the benefit of noise suppression can be lost through simple actions such as employees leaving access doors open. Accordingly, in addition to the technical approaches outlined above, systematic management practices should be carefully considered.

7.5 Accidents and their consequences

All the large incinerator Operators are implementing or considering the implementation of an ISO14001 Environmental Management system. Accreditation to this standard is increasingly a requirement of organisations wishing assurance that their suppliers or service providers (the incinerator Operators) do not represent a liability in terms of public relations or Duty of Care Regulations. The strength of these systems is the inherent requirement within the ISO14001 standard for an organisation to identify all its activities (designated as environment "aspects") that interact with the environment. Once the aspects have been identified they are evaluated, essentially through a risk assessment process, in order to identify those that are the most significant. For these significant aspects, the organisation is then required to identify and put in place controls to manage these in a systematic manner. In addition, the organisation must also have developed formal plans for dealing with accidents and abnormal occurrences and these must be practised at regular intervals.

A significant weakness of these systems is that it is largely left to the Operator to decide what constitutes a significant environmental aspect and that stakeholders do not have to be consulted. In addition, the precise methodology by which the organisation uses to determine significance is not specified in the Standard and again is left to the Operator to determine. Consequently, the Operator may undervalue some important aspects. However, the formalised EMS does provide a good framework for the systematic prevention and control of environmental hazards. Accordingly, the value of an EMS in terms of accident prevention and mitigation could be greatly enhanced through consultation with key stakeholders, especially with the Environment Agency.

In summary, regardless of whether an Operator wishes to pursue accreditation to a formalised management system, best practice, with respect to reducing the risk of accidents and their environmental impacts, may be considered as being:

1. Formalised identification of all activities/processes on the site that could give rise to a pollutant release off-site, possibly utilising tools such as fault trees or root cause analysis;
2. Formal mechanism using a risk based methodology (potential consequences evaluated together with the likelihood of occurrence), agreed with the Regulator, for evaluating significance of these activities/processes in relation to the environment;
3. Identification and implementation of controls, both physical (e.g. substitution of reagents with more environmentally benign substances or building of bunds) and systematic (e.g. inspections and/or procedures) to manage these activities/processes;
4. Preparation of emergency response plans and procedures, to be communicated to all staff, together with regular testing of emergency procedures for effectiveness; and
5. Formal reporting and investigation of accidents and near misses in order to identify causes and preventative actions.

All the activities and process identified in (1) should also be reviewed, particularly in the light of new knowledge, at regular intervals, as previously assigned non-significant impacts may become significant e.g. through a change in legislation. In addition, all planned new activities and process for the site should similarly be evaluated.

8. CONCLUSIONS

8.1 Selection of raw materials

The key material inputs into the majority of waste incineration processes (excluding feed stocks) relate to the air pollution control (APC) equipment employed. For dry and semi-dry processes, these inputs of reagents are set to increase in order for most processes to comply with the Waste Incineration Directive's 60 mg/m^3 limit for hydrogen chloride, expressed as a half hourly average. In addition, the Landfill Directive will have important consequences for the treatment of these residues in order to prevent mobilisation of heavy metals and other pollutants.

Wet scrubbing systems are a potential option for all incinerators, and are generally two to four times as efficient as dry or semi-dry systems. For municipal waste incinerators it is possible to use crushed limestone as the reagent, thus avoiding the energy inputs and carbon dioxide outputs from lime kilns. However, the wet scrubbing systems currently employed, predominantly with hazardous waste incinerators, have significant water consumption. Accordingly, when assessing best available techniques for acid gas removal, a life cycle analysis approach should be taken which should include consideration of the use of wet APC systems featuring closed loops or integral treatment plant.

Notwithstanding the choice of abatement technique adopted, reagent usage should be minimised and continually controlled through linking of reagent dosage rates with appropriate process parameters.

Most incineration installations utilise, or intend to utilise, ammonia or urea injection within nitrogen oxide abatement techniques. Of these, urea is the least environmentally harmful and is the easiest to handle and contain should a spillage occur. However, injection of ammonia solution is simpler than injection of crystalline urea. Accordingly, both techniques may currently be considered as being BAT provided adequate control procedures are implemented for ammonia storage and handling.

The Agency should consider the use of selective catalytic reduction (SCR) of nitrogen oxides as BAT. The technique can enable emissions of nitrogen oxide to be kept below 50 mg/m^3, which is not obtainable by other techniques. The technique is proven but relatively expensive. However, further tightening of limits on incinerator emissions are likely to focus on nitrogen oxides. Indeed, Switzerland and the Netherlands already effectively require this technology to be employed to waste incineration.

8.2 Materials recycling and reuse

Currently published studies indicate that the impact of anticipated increases in recycling of wastes on MSW incinerator performance will be minimal. However, removal of chlorinated wastes such as PVC from the input stream to an incinerator would reduce the amount of APC reagent through avoided acid gas emissions. Accordingly, the use of a materials recovery facility prior to incineration would lead to reduced APC residues and bottom ash.

The majority of municipal waste incinerator operators either currently recycle the bottom ash as aggregate or are seeking to do so. Economics are the key driver for this as operators seek to avoid landfill costs and, in at least one case, create an additional income stream. The barriers to re-using these residues are the acceptability of the residues in terms of quality and their perceived impact on human health and the wider environment.

The bottom ash from hazardous waste incineration facilities can be recycled into building blocks when these facilities are operated in "slagging mode" to produce a vitrified ash. However, at least one facility is restricted by the Agency from recycling its ashes in this fashion whilst another operator is permitted. Accordingly, the Agency should consider the revision and release of its Ash Protocol in order to formulate and clearly communicate the Agency's policy on the issue of the recycling of ash residues.

Sewage sludge operators are also considering the use of bottom ash in building blocks. However, we are not currently aware of this happening in practice.

The bottom ash arisings from other types of waste incineration (i.e. clinical waste) are not thought to be reusable and, in certain circumstances, may be considered hazardous.

APC residues from all forms of incineration plant are currently disposed in landfill, principally as special wastes. In the near future, the Landfill Directive is likely to require pre-treatment of these wastes in order to prevent mobilisation of pollutants including metal elements and chlorides.

8.3 Energy efficiency

The recovery of heat to generate electricity is integral to the operating economics of a municipal waste incineration facility. However, few MSW incinerators provide both heat and power, the most effective method of recovering heat from waste incineration. The principal barrier to overcome is economic; the expense of installing infrastructure for exporting heat/high pressure steam including more efficient heat exchangers and pipelines needs to be justified against the potential market for this energy.

Operators should give consideration to long term planning and feasibility of combined heat and power schemes. Accordingly, for facilities currently with or planned electricity production only, the choice of not providing combined heat and power (CHP) should be justified.

It is possible to recover energy in the form of heat and electricity from hazardous waste incineration facilities. Operators of current merchant facilities are reluctant to invest in combined heat and/or power as this would preclude them from burning certain types of waste. As currently around 50% of the hazardous waste market (typically the relatively "clean" high calorific value wastes such as solvents) is captured by the cement kiln operators, the hazardous waste incinerator operators cannot be too choosy over the wastes they incinerate. However, the potential for energy recovery should be explored, especially for new plant and a decision not to implement energy recovery techniques should be justified

Clinical waste incineration plant has the potential for both heat and power. Many incinerators situated within hospitals already recover energy in the form of heat but not for electricity production. The issues concerning the operation of facilities remote from hospital sites are similar to those discussed for MSW incineration above. However, unlike the large MSW incinerators many of these facilities do not operate continuously and therefore the potential revenues from exporting energy off-site will not be as favourable.

Very little data is available on the usage of energy around incineration facilities, and data that are available are best estimates only. Accordingly, for existing plant we recommend the use of energy auditing as a tool for identification of key energy uses and losses from a plant and identification of savings. For proposed new plant, the energy consumption for both specific items of equipment and the whole incineration process should be identified and evaluated in terms of cost and benefit at the design stage. This responsibility for identifying and quantifying energy consumption could be placed on equipment suppliers as a condition of tender.

8.4 Noise and vibration

Noise issues are well covered by local authorities, typically at the formal planning stage for a new incineration facility or where modifications requiring planning permission are requested. The noise limits set for individual installations vary with their specific locations since they are set in the context of their locations i.e an installation situated on an industrial site is likely to have a less stringent limit than a similar installation situated adjacent to housing.

For all facilities consideration should be given to noise prevention at source through the specification of "low noise" equipment (i.e. fans) at the design stage, for new or replacement plant. However, the considerations that may be considered as best available techniques will vary between sites. In addition to technical measures, systematic management practices should also be carefully considered.

8.5 Accidents and their consequences

All the large incinerator operators are implementing or considering the implementation of an ISO14001 Environmental Management system. The strength of these systems is the inherent requirement within the ISO14001 standard for an organisation to identify all its activities (designated as environment "aspects") that interact with the environment. Once the aspects have been identified they are evaluated to identify those that are the most significant. For these significant aspects, the organisation is then required to identify and put in place controls to manage these in a systematic manner. In addition, the organisation must also have developed formal plans for dealing with accidents and abnormal occurrences and these must be practised at regular intervals.

A significant weakness of these systems is that it is largely left to the operator to decide what constitutes a significant environmental aspect and that stakeholders do not have to be consulted. In addition, the precise methodology by which the organisation uses to determine significance is not specified in the standard and again is left to the operator to determine. Consequently, the operator may undervalue some important aspects.

Accordingly, best practice, may be considered as being:

- Formalised identification of all activities/processes on the site that could give rise to a pollutant release off-site, possibly utilising tools such as fault trees or root cause analysis;
- Formal mechanism using a risk based methodology (potential consequences evaluated together with the likelihood of occurrence), agreed with the regulator, for evaluating significance of these activities/processes in relation to the environment;

- Identification and implementation of controls, both physical (i.e. substitution of reagents with more environmentally benign substances or building of bunds) and systematic (i.e. inspections and/or procedures) to manage these activities/processes; and
- Formal reporting and investigation of accidents and near misses in order to identify causes and preventative actions.

In addition, all activities and processes should also be reviewed, particularly in the light of new knowledge, at regular intervals and all planned new activities and processes for a site should similarly be evaluated.

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