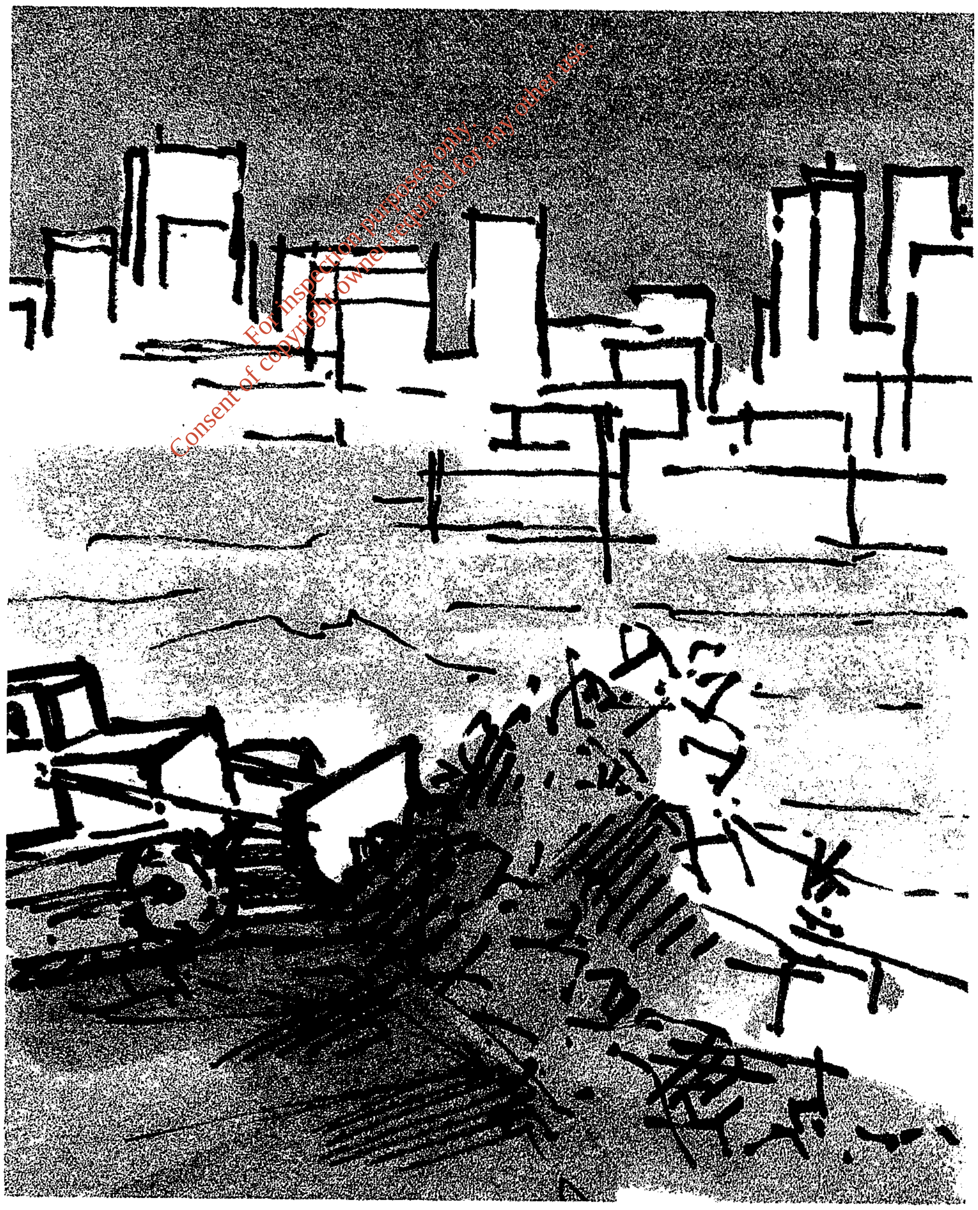
Local authorities, health and environment

World Health Organization
Regional Office for Europe

solid wastes

Waste incineration



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Local authorities, this document is for you

The World Health Organization, Regional Office for Europe regularly receives requests for technical and practical advice on a wide variety of topics linked to the environment and health.

This series of practical pamphlets, written with the help of experts and the support of different partners, aims to help you with your environmental health problems.

Recommendations are prioritised in order to help you to develop a strategy relevant to your local situation.

identifies a recommendation which is basic for a safe and healthy environment. Actions based on these recommendations should be implemented by all local authorities immediately.

identifies a recommendation which should show visible health gains and should be regarded as a priority for action throughout Europe.

identifies a recommendation which is linked to improving the quality of life of your community. These are related to a healthier environment in your community.

Recommendations with no label are made to assist you to implement your own local strategies and are not specifically health-related.

These documents have been written to help decision-makers at local level to make the best informed decisions in the area of environment and health. Technical staff at local level as well as public relations officers will find, in the annexes, practical information which may help them in their daily work.

A list of the pamphlets proposed at the date of publication is to be found inside the back cover.

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solid wastes

Waste incineration

SUMMARY

The incineration of waste is an hygienic method of reducing its volume and weight which also reduces its potential to pollute. Not all wastes are suitable for combustion. Residues from incineration processes must still be landfilled, as must the non-combustible portion of the waste stream, so incineration alone cannot provide a complete waste disposal solution.

Generating electricity or producing hot water or steam as a by-product of the incineration process has the dual advantages of displacing energy generated from finite fossil fuels and improving the economics of waste incineration, which is a very capital-intensive waste treatment option.

Principal advisers :
Mr Jorgen Haukohl and Mr Torben Kristiansen

Modern incinerator

Incineration is one of a number of waste disposal strategies which can be used to ensure that wastes are handled in an environmentally sustainable manner. Most cities or regions will need to employ several strategies for their waste simply because the wastes themselves are diverse. While not all wastes are combustible, the average waste in Europe has an increasing percentage of material which will readily burn.

The average calorific value (potential to give heat) of municipal solid waste is rising in Europe as an increasing proportion of the waste stream is material such as paper and plastic which is readily combustible. Schemes which aim to recycle a high proportion of such combustible wastes will inevitably reduce the total quantity which remains for incineration, and its calorific value.

Typical calorific value of wastes compared by country

Country	Typical calorific value (kilojoules/kilogram)
Denmark	9,000 - 12,000
France	6700 - 8500
Hungary	5,900 - 7,100
Netherlands	7,500 - 9,200
Russian Federation	5,000 - 7,300
Sweden	10,000 - 12,000
United Kingdom	8,000 - 11,000

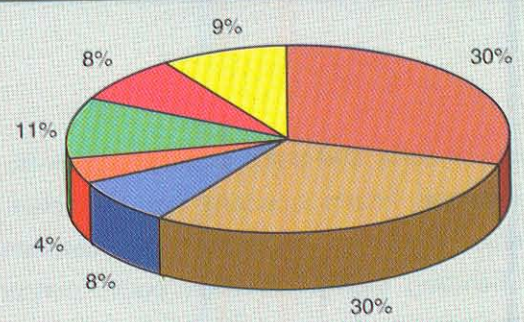
European Union average calorific value of municipal solid waste = 8,000 kJ/kg. For comparison, one tonne of industrial coal has an average calorific value of around 20,000 kJ/kg.
Sources: ISWA, OECD and ADEME (personal communication).

An overview of solid waste management options is given in the pamphlet Solid waste and health in this series.

If incineration forms one part of the disposal plan, a landfill will be needed for the final disposal of non-combustible wastes and the combustion residues. Those residues may constitute 25-30% of the weight of the original waste, but considerably less by volume (10-20% typically). In some countries, such as France and Hungary, the proportion of incinerator residues which come from the flue gas cleaning process are considered to be hazardous, and must be handled and treated separately, which incurs additional cost.

Modern incineration equipment fitted with air pollution control technology can make waste incineration an environmentally acceptable form of waste treatment which minimises the potential for harm. It can therefore be possible to locate plants near to densely populated areas. This can lead to reduced transportation costs for the waste input and can also facilitate energy, hot water and steam utilisation. Locating plants within urban areas can create

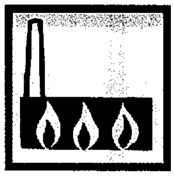
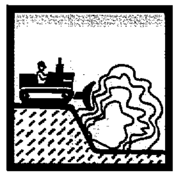
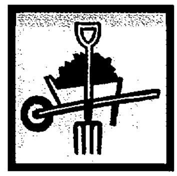
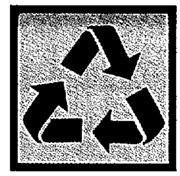
Typical European waste composition



Calorific value	Kilojoules/Kilogram
Paper and board	14,600
Organics	6,000
Metals	nil
Plastic	37,000
Glass	nil
Textiles	16,000
Unclassified (wood, stones, dust)	9,000

Source OECD

Municipal solid waste treatment and disposal routes in selected European countries

Country	Total	Incineration	Landfill	Composting	Recycling
	('000 tonnes/yr)	(expressed as a percentage by weight of total)			
Austria	2,800	11	65	18	6
Belgium	3,500	54	43	0	3
Denmark	2,600	48	29	4	19
Finland	2,500	2	83	0	15
France	22,000	44	45	7	4
Germany	25,000	36	46	2	16
Greece	3,150	0	100	0	0
Hungary	4,900	12	88	0	0
Ireland	1,100	0	97	0	3
Italy	17,500	16	74	7	3
Luxembourg	180	75	22	1	2
Netherlands	7,700	35	45	5	16
Norway	2,000	22	67	5	7
Portugal	2,650	0	85	15	0
Spain	13,300	6	65	17	13
Sweden	3,200	47	34	3	16
Switzerland	3,700	59	12	7	22
United Kingdom	30,000	8	90	0	2

Source: TNO - Survey of Municipal Solid Waste Combustion in Europe, February 1993; Hungarian Institute of Public Health (personal communication).

problems of noise and traffic for local residents, an environmental health concern not restricted to incineration plants but applicable to any centralised waste handling facility. However, public concerns about the possible dangers to health associated with emissions from incinerators can make the siting and construction of such plants difficult. Local authorities should identify land suitable for the construction of waste facilities such as incinerators at the earliest possible stage of town planning, and not wait until planning a specific construction. Conditions which might contribute to making a site suitable include having good transport access (via road, rail or water) for delivery vehicles.

Recovering energy from the waste incineration process can be a valuable option. The production and sale of electricity and/or district heating provides extra income which contributes considerably to the viable economics of the plant.

Although energy recovery is a natural complement to waste incineration, there are circumstances when incineration without energy recovery is a valid disposal option, particularly where the main objective is volume reduction.

Technologies

Several incineration technologies have been developed, with the most widely used being the mass-burning of untreated waste in furnaces fitted with moving grates *(see Technical annex)*.

Other incineration technologies, such those employing fluidised bed technology or the manufacture of refuse-derived fuel in coarse or pelletised form, have also been developed. Burning untreated waste in rotary furnaces is also employed in a few cases, predominantly in the USA. In France, some small-scale plants use oscillating furnaces. Each technology has its own strengths and weaknesses, just as mass-burning technology does.

Incineration is used for the treatment of several types of waste. Normally, municipal waste and hazardous waste are burned in separate plants, but with developments in incineration technology and pollution control equipment, it is technically possible to use co-treatment. Special wastes such as clinical waste can be treated safely in municipal waste incineration plants, although it is not permitted in some countries, for example in Germany.

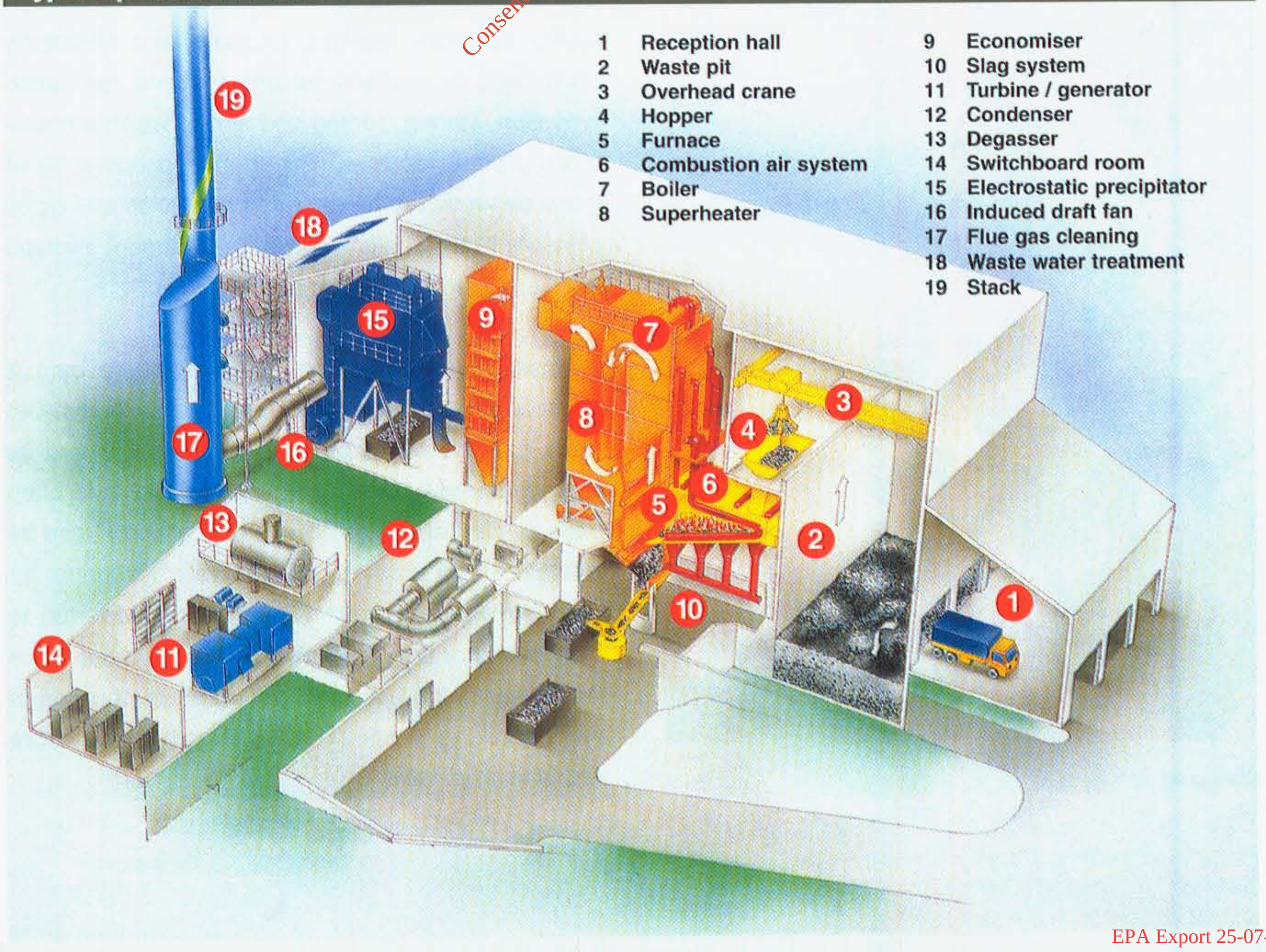
More information on clinical waste management can be found in the Health care waste pamphlet in this series.

Mass burning on a moving grate

In combination with an efficient modern air pollution control system this technology has been developed and tested, and can meet the demands of technical performance and environmental standards which are now required by organizations such as the EU and which are also covered by WHO air quality guidelines *(see references, page 24)*. The moving grate incinerator is a proven technology which is able to accommodate large variations in waste composition.

A typical plant *(see page 5)* consists of a reception area for waste prior to its being deposited in the bunker. From the bunker, overhead cranes mix the

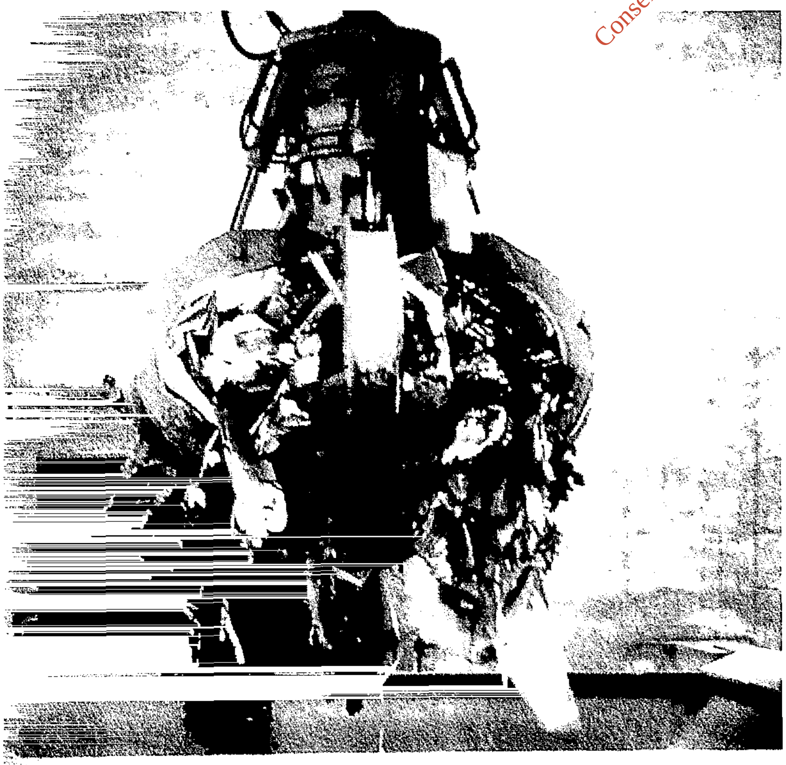
Typical plant schematic



waste and feed it into the hopper which in turn feeds the furnace. On the grate the waste is first heated, then dried and burned. Fans provide a surplus of oxygen during the entire passage of waste through the furnace to ensure complete combustion. The after-burning chamber ensures that the flue gases are further thermally treated before being cleaned and emitted via the stack.

Plants fitted with an energy recovery boiler can produce heat and/or power. Ash and clinker from the furnace bed are extracted via conveyors or pushers and may be recycled (depending on the heavy metal content) after magnetic separation of ferrous material. Residuals from the air pollution control system, which contain the more hazardous materials, are usually landfilled in engineered sanitary landfills with leachate[1] control, but may sometimes be further treated as hazardous waste.

(1) Leachate is the name given to the liquid which percolates through, and can flow out of the landfill site.



Crane grab

Fluidised bed combustion

Fluidised bed incineration is based on replacing the conventional grate with a bed of solid particles in a mixture with a fuel which is fluidised by a flow of air from below. Combustion of the fuel takes place within and above the bed.

The bed material consists of an inert material, most commonly sand but also sometimes including lime or ashes. The fuel, in this case waste, only accounts for a low percentage of the bed material. The technique has been known for a long time and includes several designs: circulating fluidised beds, bubbling fluidised beds and revolving fluidised beds. Only in the last 10 to 15 years has fluidised bed combustion technology been developed for commercial use. Although there is no long-term experience of waste combustion using fluidised bed technology in Europe, there are plants in operation in Sweden, Japan and the USA, and new plants are planned or in construction in France, Spain and the UK.

Pre-treatment in the form of shredding is necessary in order to obtain a waste fuel of uniform fragment size and calorific value. A fluidised bed combustion facility therefore requires crushing and shredding equipment in addition to the facilities for waste reception, storing, sorting and mixing which a mass-burning plant requires. The form and operation of these depends on the delivered quantities and types of waste to be treated. The extra treatment involved may incur additional operating costs.

Fluidised bed combustion is beginning to gain a larger share of the market, particularly for smaller scale projects or for problematic wastes where its improved emissions control is beneficial. It is often used for clinical wastes. With the increasing trend for wastes to be treated as separate streams, for example with wet organic wastes being diverted to composting or dry recyclables being taken out of the mixed waste, the use of fluidised bed combustion of the remaining waste stream may become more economically viable.

Refuse-derived fuel

The concept of producing refuse-derived fuel is based on replacing solid fuels such as coal in a conventional power or district heating plant with a fluff product (coarse or fluff refuse-derived fuel) or densified pellets made from the combustible components of mixed waste.

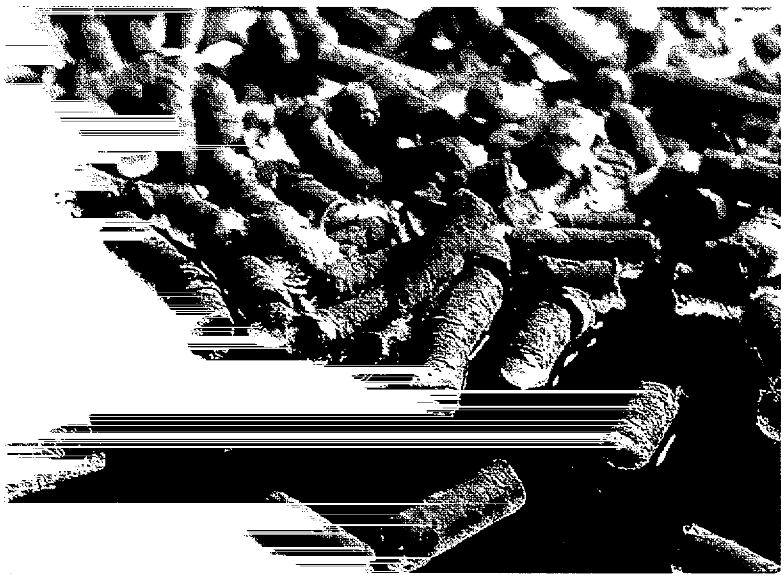
Manufacturing refuse-derived fuel, whether it is undensified or densified into pellets, requires comprehensive pre-treatment of the waste consisting of several sorting and shredding stages.

The technology for both types of fuel product has been exploited in a number of full-scale plants in Europe and the USA. Depending on the waste composition, the fuel product may contain high levels of heavy metals or chlorides, and its combustion in smaller-scale plants with insufficient air pollution control equipment could present health and environmental hazards. As a result, the recent trend has been for on-site burning of refuse-derived fuel at a dedicated power or district heating plant which is properly equipped to handle emissions. This change from selling the fuel to small users to using the fuel on large-scale plant has changed other aspects of the fuel production process. If the fuel product is to be burned on site, the need for densification into pellets is removed, as that process was aimed at facilitating transport.

Refuse-derived fuels have also been used to replace or supplement fuel use in the manufacture of cement. Apart from savings in conventional fuel costs, any acid gases from the fuel are effectively removed by the alkaline cement clinker and, along with the ash residues, incorporated into the product.

Advantages and disadvantages of different technologies

	Advantages	Disadvantages
Incineration in general		
	Reduces volume of waste by up to 90%	High capital outlay
	Reduces weight of waste by up to 80%	High operating costs
	Leaves largely inert residues (except fly ash)	Arouses public opposition Residues need disposal
with energy recovery	Displaces energy production from finite sources	Higher investment costs
	Additional income from sale of heat or power	Moderately high operating costs
Different technologies		
mass burning		
	Processes most of the waste stream untreated	Large-scale plants arouse more opposition
	Large-scale plants have economies of scale	
fluidised bed		
	Smaller-scale plants arouse less public opposition	Requires some preprocessing of waste
	Improved emissions control	Smaller-scale plants have less economies of scale
refuse-derived fuel		
	Less capital intensive than incineration (maybe 10%of costs)	If not burned on-site, the emissions clean up costs are transferred to the point of combustion
	Can be burned with other fuels	Processes only part of the waste stream, balance needs disposal
fluff	Uses less energy in manufacture	Harder to store and transport
		Requires more sophisticated combustor
pelletised	Easier to store and transport	Uses more energy to manufacture
	Burns on conventional grates	



Refuse-derived fuel pellets

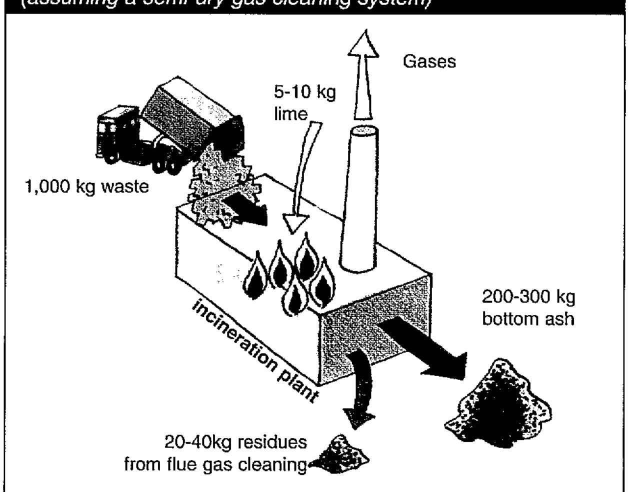
Residues from combustion

Solid incinerator residues consist of two main components: bottom ash from the furnace, which may also have clinker and slag mixed with it, and fly ash from the stack, which contains the more hazardous components. Of the two, the bottom ash is the larger component, while the fly ash makes up the smaller fraction at around 10-20% of the total weight of ash. In some countries, such as France and the Netherlands, the two residue streams must be kept separate, and treated or disposed of separately. In other countries, such as the UK, the less toxic bottom ash is mixed with the fly ash, and the two residues are disposed of together.

The majority of ash is landfilled. However, the bottom ash may be re-used in road construction after screening. This possible re-use depends on leaching of heavy metals, the type of construction work and the possible influence on the groundwater. Processes which vitrify the bottom ash from incineration are being successfully used in some countries. Treating the ash at high temperatures so that it turns into a glass-like material reduces its ability to "leach" potentially toxic contents to safe levels. The vitrified ash can then be used in a wider range of beneficial applications, such as in the construction of sea-walls or in road base construction. However, such vitrification is expensive and may not be considered worthwhile in many cases. Any income from the sale of bottom ash should be regarded as a bonus since any saved landfill costs are often offset by the costs of removing ferrous metal and other undesirable material.

Residues from air pollution control systems, together with the fly ash, contain a concentration of heavy metals and other toxic material from the waste that was burned. That concentration may be quite high, but will depend on the wastes themselves. These cannot normally be recycled and require correct handling to ensure that they do not cause environmental harm. Landfilling in a sanitary landfill is the minimum standard of disposal that should be applied.

Inputs and outputs by weight
(assuming a semi-dry gas cleaning system)



Air pollution control

Typically in a modern incineration plant, one of the following air pollution control systems may be used.

The dry system injects lime in dry form directly into the flue gas after the boiler. The lime reacts with acid products. The reaction product and dust are then filtered out in a bag filter or electrostatic precipitator *(see Technical annex)*. The dry system requires only moderate investment, but the running costs are higher than alternative cleaning systems owing to higher consumption of lime, especially if strict emission constraints are to be met. In addition, the higher consumption of lime generates higher amounts of residue.

The semi-dry system injects a slurry of lime and water directly into the flue gas in a reactor. The injection is either done by a spray in the top of the reactor or as a fluid bed injected in the bottom (as shown in the plant schematic on page 5). The major part of the reaction product is precipitated in the following cyclone and recycled for optimal utilisation of the lime. A bag filter or electrostatic precipitator removes dust and reaction products. Initial investments are higher than for the dry system, but the running costs are lower as the lime is utilised more effectively.

The wet system: highly soluble acids are almost completely dissolved, and the flue gases are led through a chamber of acid water. Electrostatic precipitators are inserted in the process prior to the scrubbers to remove dust. The initial investment costs are highest for this option, but running costs low owing to 100% utilisation of lime and to lower costs for disposing of the residues at controlled landfills. Furthermore, this system is capable of meeting stricter emissions limits than either the dry or the semi-dry systems. Waste water is separated into a sludge fraction, which is disposed of to landfill, and a cleaned water fraction containing salts.

Waste characterisation

Not all wastes are suitable for incineration, either because they are too wet or because they have insufficient calorific value to support combustion unaided. Waste for incineration must meet certain basic requirements, the main requirement being a minimum calorific value. The calorific value required varies according to the technology and the operating efficiency, but generally it should not be lower than 6 500kJ/kg. In very specific cases it may be possible to incinerate waste with a lower calorific value, with very skilful management, but normally such waste will not burn without additional fuel.

Another requirement is that the waste is of a size which will fit onto the grate, or in the case of fluidised bed combustion, into the combustor. Some combustible items, such as tyres in some cases, need to be reduced in size by shredding prior to combustion. At some incineration plants shredders are installed in the pit area to handle bulky items.

Incineration with and without energy recovery in Germany, USA, and Japan

Country	No. of plants	% with energy recovery	Form
Germany	53	100%	Heat and electricity
USA	190	85%	Mostly electricity
Japan	1900	75%	Heat

Heat and energy sales

While it is perfectly possible to incinerate waste without energy recovery, where the decision is taken to recover energy in some form, the sale of that energy can be a significant element in the plant economics. It is possible to utilise the energy for several purposes, and the following options are the most popular.

Heat production only. Heat producing incineration plants are less capital-intensive than electrical power producing plants. In areas with an extensive district heating network and a full equivalent price for heat, it is often worthwhile to produce heat only.

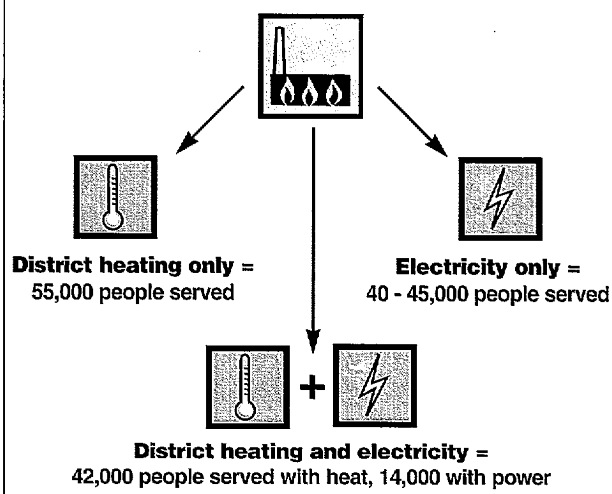
Co-generation or combined heat and power production. With a combination of heat and power production it is possible to utilise a higher percentage of the produced energy. Under optimal boiler conditions (medium pressure and steam temperature) it is possible to produce an output of 24-28% electricity and 72-76% heat from the available energy produced.

Electrical power production only. Producing only electrical power it is possible to convert an output of 30-38% of the available energy to electricity. This option is attractive if the electricity price is very high, and if there is no demand for heat or if the plant is sited far from a district heating network.

The decision as to whether, and in which form, energy production should be included should always be the subject of a feasibility study based on the local conditions. The possibility of generating income from the sale of heat and power depends on the local market for energy and the public policy for secondary heat and power sources.

200,000 tonnes per annum incineration plant to serve a population of around 600,000 people

Alternative forms of energy recovery



It would take 110 plants like this, burning the waste from 66 million people, to produce as much power as one modern pressurised water reactor nuclear plant.

Incineration and public health

In general, properly equipped and operated waste incineration need not pose any threat to human health, and compared to the direct landfilling of untreated wastes, may have a smaller environmental impact.

During the last decade emission regulations have become more rigorous. A major proportion of the existing incineration plants in the EU are being or will be retrofitted with enhanced gas cleaning equipment to meet the new standards. It is predicted that even more rigorous emission control regulations will be imposed within the next 5-10 years for pollutants which still cause concern even in low concentrations.
Because of this, it is technically possible to site incinerators near to densely populated areas. Local planning regulations must be observed. Assuming those are met. In many countries, distance as low as 300-500 metres from residential areas may be permitted, depending on the size of the plant and the local conditions. Good occupational health can be ensured by observing proper operation and maintenance procedures, and ensuring safe working practices and an hygienic environment throughout the plant.

There are no critical occupational health aspects in waste incineration which do not also apply to other waste management functions. When correctly maintained and operated, incineration is not known to pose an increased threat to health for workers. However, personnel should be equipped with the appropriate personal safety equipment during maintenance work: safety shoes, hearing protection, dust masks and clean working clothes. During normal operation, normal clothing can be used. The greatest occupational health risks occur at points where there is direct contact with the waste, for example in the reception hall where the delivery vehicles discharge their loads. Dust and aerosols containing microorganisms in this area can present a health hazard. It is imperative that the plant should be properly lighted and ventilated and that a comprehensive cleaning regime be imposed, both inside and outside the plant. This will protect the health of both workers and nearby residents, as well as making the plant more aesthetically acceptable in its neighbourhood.

A study of the environmental impacts of municipal waste incineration plants in Sweden compared with the environmental impacts of other sources including fossil fuel power plants, traffic pollution, and so on concluded that the contribution from incineration is less than 1% of the total emission of certain pollutants. These were sulphur dioxide, hydrogen chloride, nitrous oxides and heavy metals (excluding mercury).

These are some but not all of the major emissions of concern; emissions of carbon dioxide (which arise from every combustion process not only incineration) are another concern.

Bag filters have proved efficient against the emission of heavy metals excluding mercury, where up to 30% of the total release into the environment comes from incineration plants. The way to reduce mercury is either by source separation to ensure that mercury-contaminated products, such as batteries etc., are not introduced to the plant or by the use of additives in the air pollution control process in order to bond mercury and facilitate its removal.

The emission of dioxins and furans *(see box)* from incineration plants is of great concern in western Europe. The emitted levels have been reduced to about 5% of former emission levels in recent years, owing to improved incineration technology.

Dioxins and furans

Dioxins is a generic name used to describe a family of 75 polychlorinated dibenzo-p-dioxins (PCDDs). There are also 135 structurally similar compounds of polychlorinated dibenzofurans (PCDFs).

Dioxins and furans are physically and biologically stable. None is deliberately manufactured but they occur as trace elements in a number of organic chemicals and in the ash and emissions from most combustion processes. These combustion processes include garden bonfires, steel mills, crematoria and waste incinerators. Traces of dioxins have also been found in paper made from pulp which was bleached by chlorine.

The majority of dioxins are not toxic at the concentrations at which they would normally be found in the environment of waste incinerators.

The concern about dioxins is mostly around one known as 2,3,7,8 TCDD which in certain animal species has been shown to be fatal at low dosage.

Sweden's Environmental Protection Board has estimated that dioxin levels in the environment are contributed in equal quantities by car exhausts, steel mills and municipal waste incinerators to air, and by sewage sludge and pulp mills to water.

There is no record of human fatality linked to dioxin, and the most severe case of exposure - following an industrial accident at Seveso, Italy - resulted in a skin condition called chloracne, which was not permanent.

In waste incineration, processes to limit the production of dioxins include burning at high temperature, the use of sufficient air, and the rapid cooling of exhaust gases.

See also WHO papers in the Environmental Health series No. 17 - Dioxins and furans from municipal incinerators, No.23 - PCBs PCDDs & PCDFs: prevention and control of accidental and environmental exposures, No. 29 - PCBs, PCDDs and PCDFs in breast milk: assessment of health risks, No. 34 - Levels of PCBs, PCDDs and PCDFs in breast milk, No.37 - Levels of PCBs, PCDDs and PCDFs in human milk and blood: second round of quality control studies.

Local and global environmental impacts

In the process of locating and planning an incineration plant an overall environmental and health impact assessment should be carried out to establish any potential threats to either the local or the global environment(1).

Incineration of wastes enables the environmental impact from landfills to be reduced where direct landfilling of untreated wastes is replaced with the landfilling of inert residues. The production of heat and power from waste burning in modern efficient incinerators has a net reduction in environmental burden where the replaced fuel source was fossil fuel.

Incineration plants can be located close to where the waste is generated, reducing the need for transportation, compared to landfills, which due to public pressure must often be located at a distance from the waste producers.

Noise from the plant and related traffic may be a nuisance to the nearby residents, and while it can be reduced by careful selection of machinery and by enclosing the plant, its impact should not be overlooked. On the other hand, any centrally located waste handling facility, such as a sorting plant for recyclables, will present an equal nuisance.

Waste which is incinerated is rendered inert immediately, compared to waste which is landfilled without prior treatment. Untreated waste generates leachate and gas over several decades. Ash does not create gas but the ingress of water from ground sources or from precipitation can result in pollutants leaching from the ash. Thus similar containment or attenuation measures are needed for ash in landfills as for untreated wastes.

Owing to high operating temperatures and efficient air pollution controls, municipal solid waste incineration plants may also treat waste types that are difficult to landfill or which may present harm to public health. These include infectious hospital waste, syringes and "sharps", and certain types of chemical waste. However, in some countries, such as Germany, the burning of other wastes in municipal waste incineration plants is not permitted.

The main alternative to waste incineration for the bulk handling of waste is direct disposal in sanitary landfills. Both landfilling of waste and incineration of waste have environmental impacts, as organic wastes will create greenhouse gas emissions irrespective of disposal method. However, the actual emissions will vary: the anaerobic decay of waste which takes places in a landfill gives off landfill gas emissions, which are composed of between 50% and 65% methane, the remainder being carbon dioxide with a few trace gases. On the other hand, incineration of the waste will result in the emission of carbon dioxide. Methane is considered to be 7 to 10 times more harmful than carbon dioxide as a greenhouse gas, which could suggest that incineration was preferable to landfill, but since greenhouse gas emissions form only part of the emissions from incineration, it does not offer a straightforward comparison.

(1) See for example: *Introduction of environmental and health impact assessment procedures into planning and decision-making in Poland.* Copenhagen, WHO Regional Office for Europe, 1986.

Economic aspects

Waste incineration plants require large investments during both the construction and operational phases. The economic life of an incineration facility is estimated at 20 years or more, on average. Typically, major refurbishment of plant equipment may be needed after 15 years. The cost of a typical mass burning plant equipped with a wet air pollution control system is shown in the table on page 14.

In Europe much inter-municipal waste co-operation exists. Together municipalities are more able to commit to the large investments required to comply with rigorous environmental demands.

Capitals and large regional centres (more than 250,000 inhabitants) are normally capable of constructing and managing incineration plants independently, whereas smaller cities may choose to join together in inter-municipal waste co-operation, being able to finance, operate and manage one large incineration plant jointly.

When joining in waste co-operation an agreement must be made carefully specifying the ownership, responsibilities, transport management, guaranteed quantities of wastes, and so on. Additionally, a local authority may choose to make service contracts with neighbouring municipalities not participating in the joint operation of the incinerator.

If energy recovery is planned from the waste incineration process, it is important to consider whether a stable market for the sale of energy can be secured. Financing of the services via user charges or a general levy is another consideration, as is ownership and the division of responsibilities for the plant.

The cost of waste incineration, assuming a suitable waste stream, will invariably be higher than the cost of landfilling, irrespective of the landfill standard or the sale of energy from the incineration process. However, that higher cost may be justifiable where volume reduction is a priority, where transport costs to a landfill are high, or where a proportion of the wastes – such as health care wastes – cannot be treated in another way.

Procurement

The following steps should be taken if considering the construction of an incineration plant.

- The siting study should include an environmental impact assessment
- The feasibility study should include:
  - waste quantity,
  - waste composition,
  - calorific value,
  - forecasts for the future,
  - market for energy,
  - disposal of solid and liquid residues,
  - cost estimate of investment and annual operating costs,
- As well as identifying sources and methods of financing, the following stages must be undertaken:
  - preparation and approval of draft project,
  - preparation of tender documents, including design and performance specifications,
  - tendering and selection of contractor(s),
  - supervision during construction,
  - commissioning and control,
  - test runs and start-up.

In order to prepare the necessary feasibility studies and tender documents it may be advantageous to employ a consultant. The selection of a consultant is not in itself a simple task, but with the right choice, the identification of appropriate technology and contractor(s) may be simplified, and could result in an overall reduction of costs, as well as minimising start-up problems and aiding smooth operation.

Approximate costs for investment and operation of incineration plants

The figures in this chart are intended only as guidelines, and will vary considerably according to specific cases and in different countries. For example in Germany investment costs for the larger plant would be between US$330m and US$650m. In France, the typical investment cost for the smaller plant would be US$40m and US$100m for the larger one.

PLANT CAPACITY	90-100,000 tonnes a year	300,000 tonnes a year
Furnaces	2 x 6 tonnes per hour	3 x 12 tph or 2 x 18tph

INVESTMENT COSTS in US$ million:

Civil works	9	20
Furnace and boiler	18	50
Air pollution control and stack	6	15
Equipment for electricity production	7	20
Contingencies, design etc.	10	20
TOTAL	**US$50 million**	**US$125 million**

OPERATING COSTS (ANNUAL) in US$ million:

Staffing	30 employees	50 employees
Salaries	0.8	1.4
Maintenance	0.8	2.3
Chemicals, water etc.	0.5	1
Disposal of residues	0.6	1.8
Capital repayment	5.0	12.4
Contingency	0.3	0.9
Sale of energy	- 3.0	- 8.1
TOTAL OPERATING COSTS	**US$5.0 million**	**US$11.7 million**
Cost per tonne	**US$50**	**US$39**
Cost per person *(assumes 300kg/pp/pa)*	**US$16,8**	**US$11,7**

Notes:

1. The basis for the calculations of capital repayment is a 15 year loan period.
2. Assumes salary plus social costs of US$2,000 per employee. The number of employes required will vary depending on whether some of the services – such as transport of residues, and maintenance – are contracted out. A further factor is plant ownership: a publicly owned and operated plant may employ more people than a private sector facility. Typically the smaller plant would have 30 employees.
3. A US$20 per tonne residue disposal cost is assumed.
4. The cost per person does not include collection and transport costs. More information on waste collection can be obtained from the pamphlet on that subject in this series.
5. The sale of energy will yield very variable revenues based on national circumstances. In countries where the electricity supply industry pays a fuel replacement price only, a lower purchase price which represents only around 25% of the unit price is paid. In free markets where independent producers may sell to the end users direct, they can obtain higher prices. In some countries, such as the UK, electricity generated from non-fossil sources attracts a premium price. For example, in France the sale of energy from the smaller plant would be approximately US$1.6m and US$4.5m from the larger plant.
6. The cost per tonne will also vary considerably, reaching US$80/tonne or higher in many plants.

Conclusions and future trends

In some countries in the European Region the economies are under pressure. In those countries which currently have relatively low net earnings, investment in incineration plants, which are very capital intensive compared to landfills, may only be realistic in capital cities and other larger regional centres. However, use may be made of more innovative approaches to funding for large-scale plants, for example involving private sector investment.

Another major constraint may be the waste composition in such regions, where, although the combustible proportion is likely to rise gradually, it may not currently be at a viable level. Where the calorific value of the waste is too low, additional fuel must be used, the purchase of which will further distort the plant economics. Careful evaluation of current and predicted waste composition will be crucial for future planning.

In countries which currently have low standards of landfill design and management, the costs of waste incineration will be comparatively very expensive relative to those of simple uncontrolled dumping. In such cases, WHO would recommend the upgrading of landfills before consideration of other technologies such as incineration. Large communities could consider the construction of an incineration plant when the following criteria are met:

- an appropriate waste stream with sufficient calorific value
- sufficient waste volumes
- adequate financial resources
- availability of an environmentally sound final disposal site for non-combustibles and for residues
- management capacity and technical expertise.

Unless all these conditions are met, well-designed and properly managed sanitary landfill will be better suited to the economy and the sustainability of the city.

The future trends in waste incineration may be for large-scale centralised plants serving a group of towns or cities, where the delivered waste has already been reduced by waste minimisation measures, and by recycling and composting schemes.

Increasing attention to product design will make products more recyclable, minimise production waste and reduce its toxic components. All of these changes will render the waste for final disposal more homogeneous and, where that waste is to be incinerated, make its combustion simpler. Incineration technologies have already developed considerably in the past 20 years, and continuing concerns about the local and global environment are likely to maintain the pressure for it to improve still further.

Recommendation 1

No sound decision about waste strategies can be taken in the absence of detailed data.

Evaluate the quantity and composition of waste, and trends in waste generation.

A minimum level of combustible waste must be available to make waste incineration viable.

Set any plan to incinerate waste in context with an overall waste management strategy, taking into account any plans or opportunities for recycling, separate collection, promotion of home composting or any other activity which might impact on the waste quantities or composition.

Conduct a feasibility study using an expert independent consultant. This must include very detailed costings for plant construction and operation.

A detailed scientific understanding of the different substances in the waste, and their fate during and after incineration, is vital for environmental protection and as a basis for any source segregation measures under consideration.

Recommendation 2

If the decision is taken to incinerate waste, public support is vital.

Conduct a public information campaign to inform the population of the options, the choices made, and the measures which will be taken to protect the local environment including their quality of life.

Publicise the overall waste management strategy, with attention given to waste minimisation and recycling and demonstrate how the different strands will contribute.

If energy recovery is planned, explain the local and global benefits this offers.

Waste incineration

TECHNICAL ANNEX

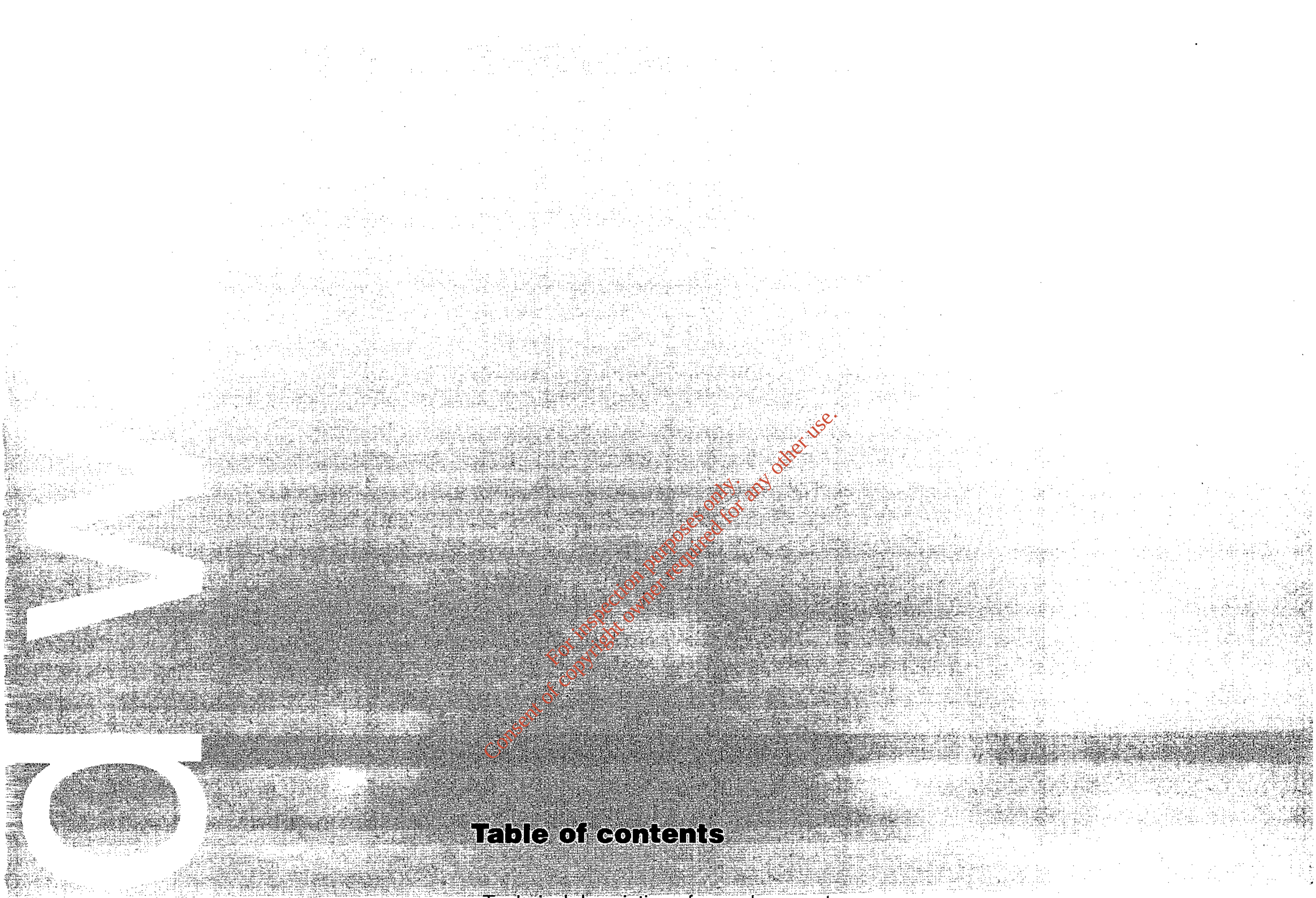


Table of contents

Technical description of a modern waste incineration plant

A mass burning incineration plant with power production includes the following basic sections:

- waste registration
- waste reception area and storage pit
- overhead waste crane
- furnace
- boiler and economiser
- air pollution control system
- turbine section for utilisation of the steam for production of power
- cooling section for excess heat
- control and monitoring equipment.

A schematic view of a waste incineration plant equipped with a wet air pollution control system is to be found on page 5.

Waste registration

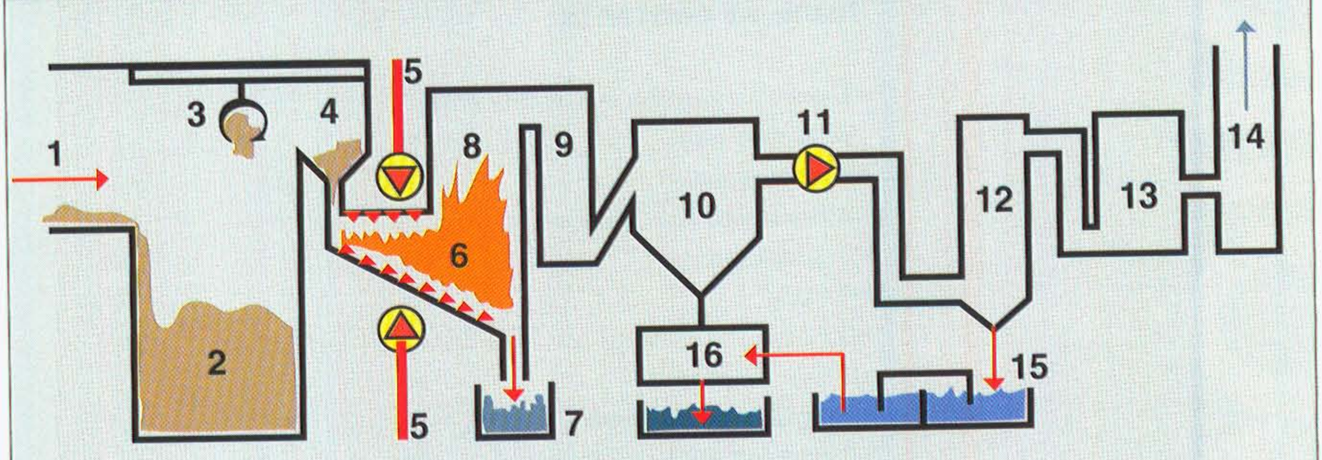
An incineration plant must be furnished with a weighbridge where all arriving trucks are weighed and their loads registered with details of source and waste type as well as weight. During registration, the waste should be checked for conformity with the permitted waste supplies.

Waste reception area and storage pit

The waste is delivered at the waste reception, where it enters the refuse storage pit. The waste reception area should be covered or semi-covered both to prevent windblown waste and to keep the working area dry. A strict regime for cleaning the area should be maintained.

A modern incineration plant is designed to draw waste odours into

Schematic view of incineration plant equipped with wet air pollution control system and bag filter



1 Reception
2 Refuse storage pit
3 Crane
4 Furnace hopper and chute
5 Combustion air system
6 Furnace
7 Slag extractor
8 Boiler
9 Economiser
10 Dust filter, electrostatic precipitator
11 Induced draft fan
12 Scrubber
13 Bag filter with injection of activated carbon (optional)
14 Chimney
15 Water treatment
16 Residues

the combustion zone. This is achieved by drawing the primary and secondary air needed for combustion from the refuse storage pit. Unpleasant odours from the plant are thereby reduced to an absolute minimum.

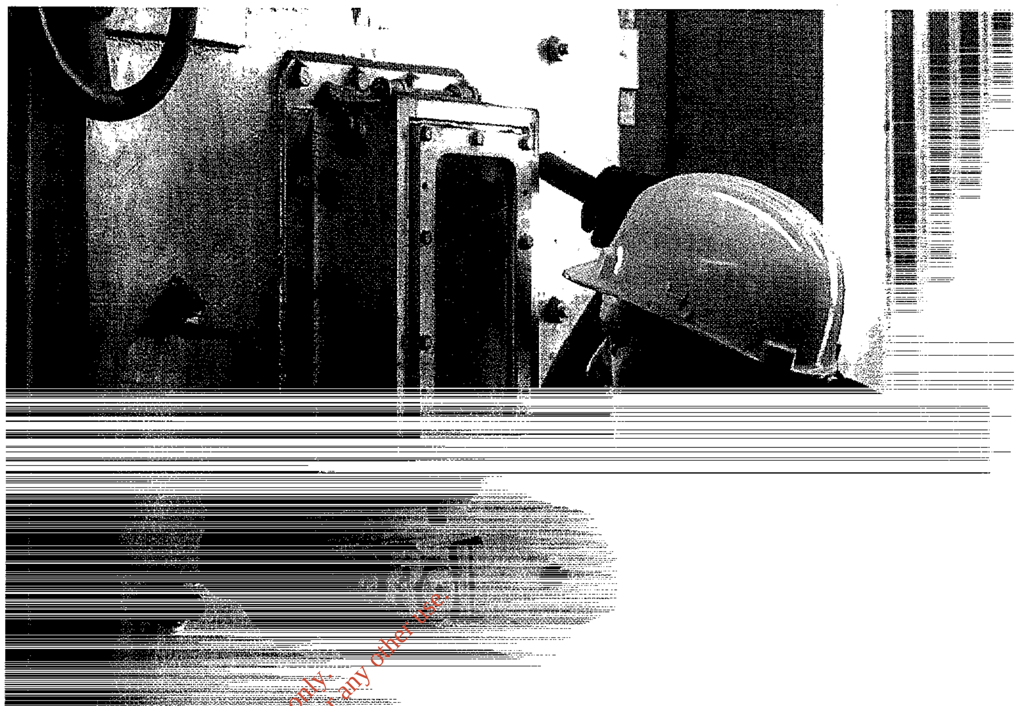
A waste pit is designed according to waste generation rates and the operating conditions of the plant. By experience, the following requirements determine the volume.

- The incineration plant is normally operated 24 hours a day, but waste is delivered to the plant only during certain times and on certain days. The waste pit must therefore be designed to receive at least the amount of waste needed for continuous operation over a defined period of time which will be at least 3 days to allow for weekends and public holidays such as Christmas, as well as for industrial disputes. An alternative disposal site for waste must be arranged for emergency situations such as an unscheduled shut-down of the plant or protracted industrial dispute, when the plant may not be operating for a long period.

- There must be sufficient capacity to enable the agreed quantity of waste to be received even with one processing/combustion line out of operation for a week.

- The width (minimum 8 to 12 metres) must ensure that the waste can be mixed adequately.

Man looking into furnace



Overhead crane

The overhead waste crane has multiple functions:

- to carry waste from the pit to the hopper where it is transported via the chute to the furnace;
- to remove bulky or inappropriate waste items from the pit;
- to mix waste in the pit to ensure optimum combustion and energy output.

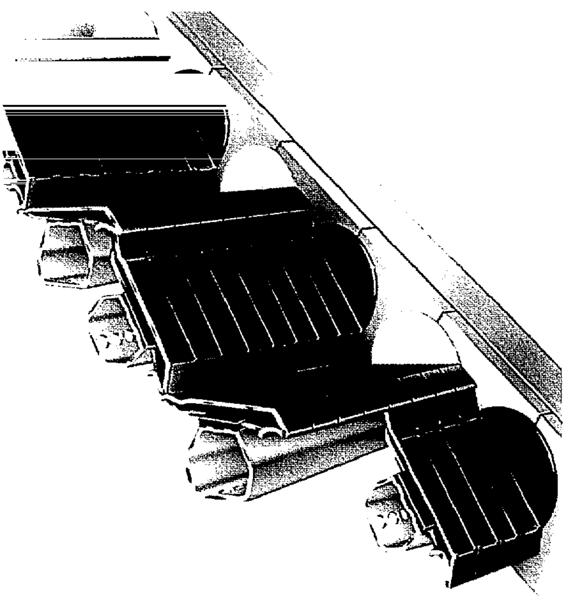
To ensure high availability, multiple cranes are often installed, for instance two waste cranes each with the capacity of the total plant, to make certain that the plant will not be stopped if one crane is out of order.

Furnace

Conventional mass burn incineration of waste without prior sorting or shredding and with a movable grate incinerator is the most widely used and the most thoroughly tested technology for thermal treatment of solid waste. In combination with an advanced air pollution control system, this technology can meet technical specifications on performance and rigorous environmental standards. The moving grate incinerator can accommodate large variations in waste composition and calorific values.

Modern mass-burn incinerators have been developed to ensure a very high combustion efficiency, a minimum content of unburned residues in the ash, optimum excess air, low carbon monoxide values and stable, high furnace temperatures. The risk of organic gaseous emissions is consequently reduced to a minimum.

The development of incineration technology to the present high standard has been driven by the demand for low environmental impact and maximum exploitation of energy.



Sectional moving grate

Grates

Several grates based on different principles are available on the market today, most of them based on European technology. As the grate is a vital part of the furnace design, the type should in each case be very carefully selected and be in accordance with the waste treated at the plant.

On the grate, the waste is dried and then burned at high temperature (1,000-1,200°C). Primary and secondary air is supplied to the combustion process to maintain the correct temperature and amount of oxygen in the furnace.

The grate design must ensure efficient transportation and agitation of the waste and an even distribution of the primary air. This requires the grate to be sectioned in individually adjustable zones. Usually the combustion air can be pre-heated to accommodate variations in the lower calorific value of the waste. Pre-heating improves the thermal efficiency of the plant.

To remove chemicals such as dioxins and unwanted volatile hydrocarbons, a secondary or after-burning chamber further thermally treats the flue gases before they are cleaned and emitted via the stack.

When the waste is transformed into bottom ash (slag) it falls via the ash chute into the bottom ash discharger. From here it is cooled and transported to the ash pit from where it is subsequently landfilled or sieved and recycled.

Energy recovery unit

The main purpose of the steam boiler and the economiser is to exchange heat between the flue gas and the water/steam circuit, thereby producing superheated steam for the power-generating turbine.

The boiler and economiser have a water tube construction with heating surfaces specially designed for waste gas operation. The boiler incorporates superheater and economiser sections. Gas-side cleaning equipment is installed to prevent fouling and ensure continuous operation.

In the boiler, the flue gas passes through different sections. Finally, the flue gas enters the economiser where the gas temperature is reduced to about 160-180°C. In the economiser the feed water is heated to saturation.

As the amount of electricity which can be produced by a certain quantity of steam is very dependent on the output state – temperature and pressure – these are important parameters in the design of a boiler. Increased steam temperatures can create corrosion problems. Corrosion in incineration plant boilers is mainly caused by the presence of chloride in the waste which during combustion is released as HCl. High flue gas temperatures in combination with HCl may result in severe corrosion if adequate protective measures are not taken.

Generation of electricity in incineration plants can in general be based on conventional industrial power plant technology using steam turbines. Thus, the energy-producing unit consists of three main elements, the waste boiler, a turbine/alternator, and a condenser (excess heat cooler). In the water/steam circuit for a typical power-producing unit, the super-heated steam expands in the turbine, after which it is condensed in the condenser before it re-enters the boiler via the feed water pump. Part of the steam is extracted from the turbine and used for pre-heating the feed water.

Different types of condensers (surplus heat coolers) can be used and three main concepts are available:

- water-cooled condensers which depend on the availability of water from an adjacent river or the sea. If the plant is located close to the water reservoir this type of condenser will be the cheapest and most efficient condenser.
- water-cooled condensers which use evaporative cooling towers. This system requires a source of water to make up for the losses due to evaporation and desalination.
- closed-circuit air-cooled condensers which use forced draught. This solution is chosen if water is not available or too expensive.

Air pollution control system

In general, the following three air pollution control systems are used.

The dry system injects lime in dry form direct into the flue gas after the boiler. The lime reacts with the acid products such as HCl, HF and SO_2. The reaction products and dust are filtered out in a subsequent bag filter or electrostatic precipitator. The system requires moderate investment, but the running costs are high owing to a high consumption of lime, especially if strict emission constraints are to be met. The higher lime consumption results in higher amounts of residue. In addition, production of lime is itself an energy-intensive process.

The semi-dry system injects a slurry of lime and water direct into the flue gas in a reactor. The injection is either effected by a nozzle in the bottom of the reactor or as a fluid bed injected in the bottom. The major part of the reaction product is precipitated in the following cyclone and recycled for optimal utilisation of the lime. A bag filter or electrostatic precipitator removes dust and reaction products. Initial investments are larger than for the dry system, but the running costs are lower as the lime is utilised more effectively.

The wet system ensures that highly soluble acids such as HCl and HF are almost completely dissolved in a scrubber, where the flue gas is led through a chamber of alkaline water. Mercury is to a large extent removed as well. The acid SO_2 can be dissolved in a subsequent scrubber with a neutral pH value. An electrostatic precipitator or a bag house filter is inserted in the process ahead of the scrubbers to remove dust. The flue gas has to be reheated well above the dew point prior to exhaust through the stack. The initial investments for the wet system are larger than those of the two other types of air pollution control system, but the running costs are low owing to 100% utilisation of lime and to the lower costs of disposing of the residues at sanitary landfills. Waste water is separated into a sludge part, which is disposed of by landfilling, and a cleaned water fraction containing salts (NaCl, $CaCl_2$).

If a strong regulatory limit on dioxin is to be met, installation of additional, expensive, equipment is necessary. One possibility is to install a subsequent system based on activated carbon injection followed by a bag filter. In addition to the reduction of dioxin, the bag filter precipitates dust, salts and heavy metals adsorbed on the surface of the carbon.

After the air pollution control system the flue gas is exhausted through the stack.

Control and monitoring equipment

The growing demand for maximum utilisation of energy and the vital influence of the combustion quality on the environment have placed the regulation and control function of the plant in the front line.

In a modern plant, all equipment is typically controlled and monitored from the central control room. The control system may be fully automatic and enable remote control for continuous operation. Equipment which has to be operated during start-up and shut-down may also be controlled remotely.

The system is computer-based and allows the automatic printing of operation and alarm reports, and the performance of analyses and calculations to give the plant management a proper basis for optimising the plant operation, along with an up-to-date picture of the important operational parameters. These include the total amount of waste treated, and the quantity of heat and electricity generated.

Waste characteristics

When using a moving grate incinerator, the waste may be burned without prior sorting, shredding or drying.

A few items in the typical municipal waste stream are unsuitable for combustion on moving grate incinerators. These include bulky waste items such as mattresses and tyres, engine blocks, bicycles etc. These must be visually identified and removed from the refuse storage pit.

The lowest possible calorific value for trouble-free operation depends on the design of the furnace/grate. In general, 6,500 - 7,000 kJ/kg is considered to be the lower limit at which the waste can burn with no or only a limited supply of auxiliary fuel (at start-up and shut-down). Below this value, it is necessary to pre-heat the combustion air and to use auxiliary fuel to obtain a satisfactory process. The implementation of flue gas recirculation can lower the limit of the calorific value at which auxiliary burners are necessary. At higher calorific values, the combustion can take place without auxiliary burners and with a satisfactory combustion process at high temperature. However, there is also an upper limit for calorific value, depending on the furnace design.

Pollution control

The pollutants primarily originate from the waste, but chemical formations are influenced by the combustion process where oxygen is added at high temperature. Consequently, pollutants such as NOx, CO, dioxins etc. are present in the flue gas.

The waste contains various substances: combustible organic elements such as carbon, oxygen, sulphur and nitrogen; metals and heavy metals such as Fe, Zn, Pb, Cu, Hg, Cd, As, Ni ; halogens such as Cl, F. Thus, the waste itself is a source of pollution and must therefore be handled in a proper manner.

The presence of waste in the waste pit is a source of unpleasant odours. By drawing the combustion air from the waste pit, low pressure in the waste pit is maintained, and hence smell from the plant is reduced to an absolute minimum.

After combustion the various elements can be traced in the different streams from the plant: flue gas, grate shiftings, bottom ash, fly ash and residues from the flue gas cleaning system. A fundamental knowledge of the fate of different substances in the waste is not only needed to improve the technical design and operation of the plant, but it may also help to decide on beneficial source separation strategies.

The reduction of environmental impact has become one of the most important issues when an incineration plant is designed. Beside measures to minimise noise and to ensure a proper disposal of the residues, the reduction of pollutants such as dust, heavy metals, halogens (Cl, F), sulphur dioxides and dioxins in the flue gas is the main task.

Residues

Incineration is not a final waste treatment stage. After incineration, the solid waste volume is reduced by approximately 90%, while the weight is reduced by approximately 75%. The residues from incineration (bottom ash, boiler ash, fly ash, and acid gas cleaning residues) must subsequently be dealt with, either by landfilling or by beneficial use. Utilisation is preferred to landfilling, provided this does not give rise to unacceptable environmental impacts or health hazards.

The two major types of residues produced in the process of incineration of municipal solid waste are bottom ash and air pollution control residues. The major environmental concern about the residues from incineration has been the impact of the content and leachability of heavy metals. Salts have so far only been considered a major problem in regard to utilisation.

The increased knowledge of heavy metal reactions in the combustion chamber, of their partitioning into the different mass streams, and of their long-term behaviour in these matrices have triggered technical measures designed to improve the process of waste incineration. Thus, a state-of-the-art municipal solid waste incineration plant should not create any special heavy metal problems in the stack emissions or in the different residue streams.

It is possible to utilise the bottom ash after some type of treatment such as magnetic separation and sieving.

In some countries the fly ash is still allowed to be mixed with the bottom ash/slag, but generally the tendency is towards separate treatment because of the greater leachability of fly ash. Therefore the fly ash is often treated together with the air pollution control system residues.

The specific types of residues from the air pollution control system vary according to the type of system. In general, the quantity of residues is largest from a dry system and smallest from a wet system. Where a wet air pollution control system is installed, the related waste-water must be treated prior to discharge to the sewer system, unless it is evaporated and recycled.

Check-list for local authorities considering waste incineration as part of their waste management strategy

	YES
1. Is your waste collection system comprehensive and efficient ?	☐
2. Is there sufficient volume of waste ? *(Very small plants may be 30-60,000 tonnes per year, medium sized plants around 100-150,000 tonnes per year, while in some countries plants of 200,000 tonnes per year, or larger, are considered.)*	☐
3. Does the waste have a lower calorific value of at least 6,500kJ/kg ?	☐
4. Do you intend to introduce any recycling measures which would affect the waste volumes or composition ?	☐
5. Do you have a suitable site on which the plant could be constructed ?	☐
6. Do you have a source of financing for the plant ?	☐
7. Do you have technically competent staff who can be trained to operate the plant ?	☐
8. Do you have a properly engineered and operated landfill site for the disposal of combustion residues ?	☐

References

The material presented has been derived from many sources and in general has not been referenced in the text. All of these sources are gratefully acknowledged, with particular thanks to The World Resource Foundation, Tonbridge, United Kingdom, for extensive use of their library.

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Keyboards

Waste incineration
(Environmental health planning pamphlet series; 6)
1.Environmental health - refuse disposal - incineration

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Titles available or in preparation as of October 1996

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- Air and health
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- Industrial air pollution
- Traffic and air pollution
- Air pollution from wastes and solvents
- Energy and air pollution
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- Asthma
- Air and global issues
- Smog warning

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- Lead and housing
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