Introduction

The aim of treating health care risk waste is to minimise the hazards associated with the waste before final disposal to landfill is considered. Hazards may be due to the infectious potential, or from the hazardous nature of the waste such as toxicity, radioactivity, etc. Some countries require waste to be treated to ensure it is not able to recognised or reused. Developing countries face an urgent need for affordable, safe, and appropriate solutions for treating infectious waste as an alternative to burning health care waste in open pits next to health care facilities as is the case in many areas.

A WHO study (2002) in 22 countries found that the proportion of health-care facilities not using proper waste disposal methods was between 18% and 64%. This puts staff, patients and communities at risk from infectious waste and other hazards relating to health care risk waste. In 2004, the WHO drafted Guiding policy principles, which included proper management of waste to prevent health risks to health workers and public in line with the Stockholm and Basel Conventions (WHO 2004). The strategies emanating from this work proposed to develop and implement plans, policies, legislation and manuals on safe medical waste management, as well as to scale up the promotion of non-incineration treatment alternatives.

Subsequently developed WHO core principles (2007) require that all associated with financing and supporting health care activities should provide for the costs of managing health care waste. This is the duty of care and manufactures also share a responsibility to take waste management into account in the development and sale of their products and services. Governments should allocate a budget to cover the costs of sound health care waste management systems and should implement and monitor them. Donors and partners should include a provision in their health programme assistance to cover the costs of responsible waste management. All concerned institutions and organizations should:

- promote sound health care waste management;
- develop innovative solutions to reduce the volume and toxicity of the waste they produce and associated with their products;
- ensure that global health strategies and programs take into account health care waste management.

This document evaluates two waste treatment technologies-incineration and autoclaving-and compares their performance, ease of operation, maintenance, utility requirements, waste stream capability and volume, and capital and operation costs.

General description of the technologies

Incineration

Incineration of healthcare risk waste is defined in the SA Policy on Waste Incineration and the Co-processing of Waste as Alternative Fuels or Raw Materials in Cement Production as “any dedicated method, technique or process to convert waste to flue gases and residues by means of thermal oxidation”. This includes pyrolysis, gasification or plasma processes, which differ to incineration in terms of temperatures achieved and gases used.

There are three main types of incinerators used to burn healthcare waste, namely:
• Controlled air (also known as starved air);
• Excess air;
• Rotary kiln.

Controlled air systems are by far the most common. More than 95% of hazardous waste incinerators are controlled air models (Wahid 2013).

Excess air will dilute the gases and reduce their temperature, so controlling the ingress of air improves combustion efficiency and also reduces the amount of particulate material emitted to atmosphere.

These incinerators have two chambers. Waste is fed into the primary combustion chamber, which is operated with less than the required amount of air. Air enters the primary chamber from below the burning bed of waste and fuel burners keep the temperature at the required level (at least 650°C, but as high as 1000°C).

In the primary chamber, the low air-to-fuel ratio dries and facilitates volatilization of the waste. Most of the carbon in the non-volatile solids will burn but the volatile portion will pass to the second chamber. Here, excess air is added to the volatile gases to complete combustion. Temperatures are higher than those in the primary chamber at around 950°C to 1100°C (recommended minimum 850°C). Again, depending on the moisture content and calorific or heating value of the waste, additional energy may be needed to maintain temperatures. This can be provided by auxiliary burners located at the entrance to the secondary chamber.

The grate can be a fixed system or a moving grate, which is usual in more modern incinerators. Both bottom- and fly-ash is produced during incineration. Bottom ash is what remains in the primary combustion chamber whereas fly ash consists of light particles which float though the incinerator and are captured by the air pollution control devices or emitted to the atmosphere. Fly ash contains high concentrations of heavy metals and small amounts of dioxins and furans and thus requires landfilling at a suitably designed, lined and authorised landfill able to accept hazardous waste.

Both the primary and the secondary temperatures should be maintained until all the waste has been completely combusted. The temperatures achieved should be determined against the inside walls of the chambers and not that of the flame.

After the combustion section, air pollution control devices are necessary. These are commonly called scrubbers and may be “wet”, using liquid to wash gases and particles out of the combustion products, or “dry”, using filtration, centrifugal action or electrical charges to remove particles. Wet scrubbers are more common in low to middle income countries as they are simpler to design and operate. More than one stage will be required to meet internationally acceptable limits. The Stockholm Convention (SSC 2008) lists several types of dry scrubbers as appropriate “secondary measures”. These are listed in the section on emissions and legislation.
The chimney should have a minimum height of nine metres above ground level and clear the highest point of the building by at least 6 metres for flat or 3 metres for pitched roofs. The topography and height of adjacent buildings should be taken into account when determining the optimum height of the chimney. If possible it should be visible to the operator from the stoking floor. The stack must be insulated to maintain the maximum outlet temperature.

**Autoclaving**

Autoclaving utilises high pressure steam to disinfect waste. Autoclaves have the advantage that they do not emit dioxins and leave open the possibility of recycling disinfected materials. Most hospitals already have autoclaves for sterilising surgical instruments and so are familiar with their operation.

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and maintenance. Autoclaves are also far cheaper than incinerators to monitor and if effectively maintained, can easily operate for 10-20 years.

At their simplest, autoclaves consist of a pressure vessel and source of steam. Basic models may have only a pressure gauge as temperature is related directly to the pressure; whereas, the most sophisticated will have full automatic controls and a variety of programs for different types of waste pre-installed.

![Figure 3. Schematic of a pre-vacuum autoclave (Pruß-Ustun, Emmanuel et al. 2013).](image)

The main two types of autoclaves are gravity models and vacuum models. Vacuum autoclaves pump the air out of the chamber at the beginning of the cycle, allowing the steam to get deep into the waste and kill any pathogens.

Gravity autoclaves, which depend on the weight of steam to push the air out of the autoclave chamber, are cheaper to purchase than vacuum autoclaves. They can also operate effectively, but action must be taken to ensure that the steam penetrates properly and/or that extra time is allowed for disinfection to take place. “Pulsing” is an important technique to ensure good steam penetration. The autoclave is brought up to pressure, and the pressure is released, ejecting a mixture of steam and air. This is repeated several times (3 or 4 is common) and each time, more of the air is removed. Pulsing can be incorporated into the run cycle of programmable machines.

The terms horizontal and vertical simply refer to the orientation of the pressure chamber; vertical autoclaves are typically smaller - from desk-top size to around 200 litres (around 50-55 US gallons) and have the lid on the top. In horizontal autoclaves, the pressure vessels allow access from the side.

Some autoclaves are designed with a steam jacket surrounding the vessel with steam injected into both the outside jacket and the inside chamber. Heating the outside jacket reduces condensation on the inside chamber wall and allows the use of steam at lower temperatures. An autoclave without a steam jacket, is also known as a “retort”, is commonly found in large-scale applications and is cheaper to construct.

Standard temperature and pressure parameters commonly used in all types of autoclaves are: 121°C and 15psi, or 135°C and 31 psi. Higher temperatures and pressures are frequently employed in high
tech operations, but these are not common in the models most often employed in low to middle income countries.

The time for which the waste has to be held at that temperature depends on a variety of factors, including the time it takes for heat and steam to properly penetrate the waste. For example, liquid waste can take some time to heat up and so the autoclaving program needs to be extended to compensate for this. Automatic models will usually include a “liquids” program that takes account of this and the need for the pressure to be reduced slowly at the end of the cycle to prevent superheated liquids boiling over.

Performance

Waste stream capability

One of the main reasons incinerators are popular is their perceived ability to dispose of all waste streams. However, especially for smaller incinerators of the scale usually installed at the hospital level, there are significant limits to their application.

Mercury, other toxic metals, and radioisotopes will not be destroyed by incineration and will instead be emitted to the atmosphere or pass into the ash, increasing its toxicity.

Sharps waste will not always be destroyed by incineration; metal items such as lancets and needles will remain and unbroken vials and glass items are liable to shatter in the heat, increasing the chance of their causing injury.

Liquid wastes, including expired blood, cannot be properly treated as they will simply drip through the grate before it is possible to destroy them. Similarly, placentas and other pathological waste can be hard to deal with in smaller models.

The table below summarises the applicability of autoclaves and incinerators to the main waste medical waste streams.

<table>
<thead>
<tr>
<th>Waste stream</th>
<th>Autoclave</th>
<th>Incinerator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infectious waste</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Pathological waste</td>
<td>Some of the bigger autoclave/shredders can deal with pathological waste (UNEP 2012)</td>
<td>Can only be burned with the aid of extra supplementary fuel. Will deal with less than rated quantities.</td>
</tr>
<tr>
<td>Sharps waste</td>
<td>Yes</td>
<td>Yes, but metal and glass will remain in the ash</td>
</tr>
<tr>
<td>Pharmaceutical waste</td>
<td>No, but encapsulation and inertisation can easily be applied instead (WHO 1999)</td>
<td>Yes</td>
</tr>
<tr>
<td>Metals including mercury</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Liquid infectious waste</td>
<td>Yes</td>
<td>Only if incinerator is appropriately designed</td>
</tr>
<tr>
<td>Radioactive waste</td>
<td>No</td>
<td>No; the radioisotopes will be emitted to air or be trapped in the ash</td>
</tr>
<tr>
<td>PVC plastic waste</td>
<td>Yes</td>
<td>Incineration of PVC is linked to dioxin production and WHO recommends that it not be burned (WHO 2004)</td>
</tr>
</tbody>
</table>

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Table 1. Applicability of autoclaving and incineration to various medical waste streams

As important as the range of waste streams that each technology can treat are considerations about how effective the treatment method is in destroying pathogens, the amount of pollution they produce, the opportunities for resource recovery and issues with residual waste disposal, among others.

Some of these are outlined in the table below; others, such as investment and operating cost, are discussed in more detail later.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Incinerator</th>
<th>Autoclave</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microbial destruction</td>
<td>Assumed to be effective, but almost never tested. Limited data available shows possibility of microbial survival in small scale, low tech incinerators (Blenkharn and Oakland 1989, Wood, Lemieux et al. 2004)</td>
<td>Effective, easily and cheaply tested</td>
</tr>
<tr>
<td>Volume reduction</td>
<td>Good, up to 90%</td>
<td>With shredding and drying, up to 85-90%; little or no reduction with simple autoclaving</td>
</tr>
<tr>
<td>Mass reduction</td>
<td>Good, up to 70%</td>
<td>None</td>
</tr>
<tr>
<td>Dioxin emissions</td>
<td>Often very high, data often missing</td>
<td>None</td>
</tr>
<tr>
<td>Residual waste</td>
<td>Ash is toxic and may still contain sharps; air pollution control devices also produce contaminated residues. These wastes should be disposed of in secure landfill.</td>
<td>Waste is not destroyed; this is a benefit when recycling is possible but may be problematic where recycling and final disposal options are limited</td>
</tr>
<tr>
<td>Nuisance</td>
<td>High, incinerators are often opposed by local people and operated at night to reduce complaints</td>
<td>Little or none; odour may be a problem if extreme amounts of blood, tissue and similar materials are processed.</td>
</tr>
<tr>
<td>Resource recovery</td>
<td>None. Where incinerators are deployed, it is common for all wastes to be burned, reducing recycling across the board</td>
<td>Autoclaved materials- e.g. syringe plastic – can be recovered and sales can subsidise operating costs</td>
</tr>
</tbody>
</table>

Table 2. Performance of incinerators and autoclaves

Waste volume capability

Autoclaves are available from extremely small (tens of litres) benchtop machines which can be deployed in small facilities, clinics and microbiology laboratories, to machines capable of treating tonnes of medical waste per day and used in central treatment facilities. Small machines can be just as effective as the larger scale machines. A small unit placed in a microbiology laboratory can also allow the treatment of cultures and stocks under the supervision of medical microbiologists, reducing the chance of accident and infection from these wastes, which can represent a severe threat to biosafety.

Incinerators, however, are highly dependent on their air pollution devices to operate cleanly and diesel and small scale models typically have either limited or no air pollution control devices as they are too expensive and cumbersome.

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1 Heat can be recovered from large scale incinerators but health care waste incinerators are too small.

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Autoclave-based waste treatment systems are more adaptable to variations in waste quantity than incinerators. They operate on a batch basis, and can be used as frequently or infrequently as necessary, without any loss of performance other than the energy needed to heat the water tank. On the other hand, incinerators produce the most pollution at start-up and shut-down, and as a result are best operated continually.

It can also be advantageous to install two smaller autoclaves rather than one large one so one can be taken out of service as necessary for maintenance without leaving the facility without waste treatment capability.

<table>
<thead>
<tr>
<th>Autoclave</th>
<th>Incinerator</th>
<th>Approx. Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benchtop, suitable for health posts and laboratories. Can be used to treat highly infectious waste e.g., cultures and stocks in the lab</td>
<td>Small scale kerosene fuelled incinerators burn 1 safety box every 8-10 minutes (PATH 2006)</td>
<td>&lt;5kg per hour</td>
</tr>
<tr>
<td>Up to 250 litres. Available in a range of sizes and levels of sophistication. Autoclaves in this range can deal with the waste from most developing world hospitals (up to about 650 beds)</td>
<td>The smallest diesel incinerators burn 10-15 kg/hour. Incinerators in this size range are usually supplied without air pollution control devices.</td>
<td>&lt; 25 kg/h</td>
</tr>
<tr>
<td>250-500 litre. For larger hospitals; can also be used for hub systems where one facility treats waste from neighbouring hospitals and clinics as well as their own</td>
<td>Since incinerators are usually used for all waste from a facility, rather than just the infectious waste, this size will not apply to such large hospitals. Incinerators in this size range are usually supplied without air pollution control devices.</td>
<td>25-50 kg/h</td>
</tr>
<tr>
<td>500 litre and above. This size is most appropriate for central treatment plants</td>
<td>For larger hospitals and central treatment plants</td>
<td>&gt; 50 kg/h</td>
</tr>
</tbody>
</table>

Table 3. Waste stream volume capability

Emissions and legislation

All waste treatment and disposal equipment should be regularly monitored to ensure that it is working properly and not emitting excessive amounts of pollution.

As autoclaves are generally non-polluting, there is no international legislation on their emissions. The case is different for incinerators because they inevitably produce dioxins and furans, which are toxic, persistent and bioaccumulative. Diesel incinerators require careful operation and multi-stage air pollution control to meet international standards, but this is almost never installed because of the cost implications.

Because of the complexity and cost of collecting and analysing samples for dioxin, this is also almost never done during the routine operation of diesel incinerators.

Conversely, the efficacy of microbial deactivation in autoclaves can be done within 24 hours using inexpensive equipment and requiring no specialist training.

Incineration

For most countries, the largest atmospheric emissions of dioxins and furans are from burning of municipal waste, followed by the burning of medical waste.

*This document was prepared with the support of the US Centers for Disease Control under contract number 200-2010-35770*
The emissions released to air from incinerators are dependent on the quality of the waste fed into the system, the temperatures achieved and the effectiveness of emission control equipment. For example, if the temperature in the primary chamber is too high due to the nature of the waste or poor operating practices, metal emissions may increase. The presence of PVC in the wastes will give rise to high levels of the acidic gas hydrogen chloride (HCl) as well as dioxins and furans (Singh and Prakash 2007). These along with other persistent organic pollutants, such as mercury, although emitted in low concentrations, accumulate in the environment to affect people in and around the facility.

Most low to middle income countries do not have specific legislation on the emissions from incinerators. However, by July 2013, 179 of the world’s countries had ratified the Stockholm Convention on persistent organic pollutants\(^2\). The aim of the convention is to eliminate specific persistent organic pollutants (POPs) including the dioxins and furans which are produced by incineration.

Article 5 of the Stockholm Convention guidelines for Persistent Organic Pollutants (POPs) states that all Parties shall promote “best available techniques and best environmental practices”. In Annex C, Part IV, there is a note on best available techniques which states that “priority consideration should be given to alternative processes, techniques or practices that have similar usefulness but which avoid the formation and release of ... [dioxins and furans].” Single-chamber, drum and brick incinerators do not meet the Best Available Technology (BAT) requirements.

For dioxins, the BAT air emissions performance level equates to 0.1 nanograms I-TEQ/Normal cubic meter at 11% oxygen and for the BAT wastewater performance level for effluents from treatment of gas treatment scrubbers it refers to a concentration of 0.1 nanograms I-TEQ/litre\(^3\). These limits are to be achieved by a suitable combination of “primary measures” which relate to good operating practice and “secondary” pollution control measures. These measures include the following (SSC 2008).

- Primary measures
  - Introduction of waste at 850 °C or higher;
  - Control of oxygen input;
  - Minimum residence time of 2 seconds at 1100 °C in the secondary chamber after last addition of air and 6% O2 by volume (for waste with >1% halogenated substances)
  - On-line monitoring for combustion control (temperature, oxygen, carbon monoxide, dust), and regulation from a central console.

- Secondary measures
  - De-dusting
  - Fabric filter operating below 260°C
  - Ceramic filter used between 800 to 1000°C
  - Cyclones for pre-cleaning
  - Electrostatic precipitators around 450°C
  - High performance adsorption units with activated carbon
  - Disposal of Residues (bottom and fly ash)

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\(^3\) TEQ is the acronym for Toxic Equivalents, which is the unit used to report the toxicity-weighted masses of mixtures of dioxins.
- Ash should be handled, transported (using covered hauling) and disposed of in an environmentally friendly manner
- Disposal in safe dedicated landfills (e.g., landfilling in double-walled containers, solidification, or thermal post-treatment)
- Catalytic treatment or vitrification of filter dusts

Incinerator emissions to air, incinerator ash, and scrubber residues should all be tested. Incinerator ashes are generally treated as hazardous wastes needing to be landfilled securely (Gidarakos, Petrantonaki et al. 2009). Dioxins and furans are the only parameters that are the subject of global regulation, but metals, acid gases and particulates are also of concern and stringent legislation also exists on these parameters in developed countries, e.g. the EU (EC 2000). The pollutants emitted from medical waste incinerators and found in their ash have been reviewed (Singh and Prakash 2007). Many of the incinerators failed to meet the Stockholm Convention guidelines, with emissions orders of magnitude above those deemed acceptable. Lead, cadmium, mercury, chromium, silver and arsenic can all be found at high concentrations in the ash (Singh and Prakash 2007) and can leach out (Sukandar, Yasuda et al. 2006) if it is not properly disposed of. Dioxin levels in chickens’ eggs near low tech medical waste incinerators can be extremely high (IPEN 2005).

Analysing atmospheric emissions of dioxins from incinerators is beyond the capability of laboratories in most low to middle income countries. USEPA Method 23\(^4\), originally designed for municipal incinerators but applicable to other stationary sources, requires a multi-stage sampling train and analysis with high resolution gas chromatography and high resolution mass spectrometry. The laboratory analysis alone costs in the region of US$800 per sample.

The cost means that these measures are almost never followed and so diesel incinerators will not meet international legislation. The Stockholm Convention comments:

“Due to the high investment, operational, maintenance and monitoring costs of waste incinerators using best available techniques, economical and effective plant operation is seldom achieved, especially for small hospital incinerators. This is also indicated by the fact that many small plants have been shut down instead of being retrofitted”.


In 2004, WHO commissioned a screening-level health risk assessment for exposure to dioxins and furans from small-scale, kerosene fired incinerators. The study found that the expected practice with small-scale incinerators resulted in unacceptable cancer risks under medium usage (two hours per week) or higher (Batterman 2004). The report concluded that small-scale incineration should be viewed as a transitional means of disposal for health-care waste.

**Autoclaving**

Autoclaving experts agree that medical waste should be disinfected to STAATT level III, which is defined as:


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“Inactivation of vegetative bacteria, fungi, lipophilic/hydrophilic viruses, parasites, and mycobacteria at a 6 Log10 reduction or greater; and inactivation of G. stearothermophilus spores and B. atrophaeus spores at a 4 Log10 reduction or greater.”

This can easily be tested using self-contained biological indicators (SCBIs) which contain spores of heat-resistant bacteria (UNDP and GEF 2010). Chemical integrator strips can also be used to make a quick assessment but should not be used to replace SCBIs. SCBIs cost approximately US$2-3 each and need to be incubated for 24 hours. This makes monitoring autoclaves cheap and easy, in contrast to incinerators which require complex analyses beyond the capability of the laboratories in most low to middle income countries.

There is a distinctive odour associated with autoclaving of waste with a high biological content, which can become a nuisance if the facility is located too close to incompatible activities. However, well segregated infectious waste is mostly plastic and high cellulose materials, so odour is not always an issue. If volatile chemicals are autoclaved, these will be released to air, so it is essential that wastes are segregated at source and only suitable wastes are presented for autoclaving. High efficiency particulate air (HEPA) filters can be used on steam vents to contain any untreated microorganisms.

Ease of operation

Autoclaves

Many autoclaves are automatically operated with a number of pre-installed disinfection programs so operation can be extremely easy.

The Indian government, in their Bio-Medical waste rules, give standard times for different types of machines (GoI 2010) (http://dpcc.delhigovt.nic.in/pdf/Pollution_Control_Law.pdf#PAGE=1034). These are conservative and it may be possible to safely disinfect waste with shorter cycles.

Whatever type of autoclave is chosen, it is always recommended that the disinfection cycle is validated to prove that it is effective with the waste stream that is being used on, and routine monitoring is carried out (Emmanuel, Kiama et al. 2008, Stolze and Kühling 2009, Stringer, Kiama et al. 2010, UNDP and GEF 2010).

Standard temperature and pressure parameters commonly used are: 121°C, and 15psi, or 135°C and 31 psi. Higher temperatures and pressures are frequently employed in high tech operations, but these are not common in the models most often employed in low to middle income countries. In fact, in low resource environments, operating at 121°C may be best as it does not require the expensive and hard to source polypropylene bin bags to contain the waste.

The time for which the waste has to be held at that temperature depends on a variety of factors, including the time it takes for heat and steam to properly penetrate the waste. For example, liquid waste can take some time to heat up and so the autoclaving program needs to be extended to compensate for this. Automatic models will usually include a “liquids” program that takes account of this and the need for the pressure to be reduced slowly at the end of the cycle to prevent superheated liquids boiling over.

Incinerators

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Diesel incinerators of the scale used in low to middle income countries will require manual operation. The operator must start the incinerator with supplementary fuel and wait until it has reached the correct operating temperatures (at least 650°C in the primary chamber and 800°C in the secondary chamber) before adding waste. The waste must then be fed at the correct rate to ensure effective combustion and supplemental fuel used whenever necessary to maintain temperature. The operator must understand the thermal values of the different types of waste and feed each one in at the right rate to maintain a good operating temperature.

If too much waste with high liquid content or low thermal value is fed in at one time, the combustion temperature will drop unless the burners are activated. Conversely, if too much waste of a high calorific value (e.g., large amounts of plastic) is fed at once, the machine can overheat, shortening the lifetime of components, especially in the flue and any air pollution control devices. When all the waste has been burned, supplemental fuel must again be fed to hold the temperature at the correct temperature until all of the waste has been burned.

In practice, the proper procedures for start-up and shut-down are often ignored, especially when fuel is in short supply. It is not uncommon for operators to fill the chamber with waste before operating or start charging with waste immediately on start-up, and to shut down once the last waste has been added. These practises will result in vastly increased dioxin emissions. One study of municipal incinerators found that the dioxin emissions from a few (1-4) badly controlled start-ups created dioxin emissions of the same order as an entire year’s worth of emissions from normal operations (Wang, Hsi et al. 2007).

**Maintenance**

All waste management equipment needs regular preventive maintenance and repair. In theory, most of the routine repairs can be conducted by the operator or a local engineer. In practice local support from the manufacturer is very important. As much as half of all donated medical equipment is not in use and the inability to maintain it or source spare parts is a large contributor to this waste.

**Autoclaves**

As stated before, ordinary autoclaves are primarily pressure vessels combined with steam generators.

The most common causes of breakdown/malfunction include:

- failure of the sealing gasket on the door;
- Leaks from pipework etc;
- heating element burnout, (especially in low tech vertical ones which can boil dry);
- blockages and corrosion due to poor water supply
- Failure of controllers and other electronics.

More complex hybrid machines may have moving parts such as rotating chambers and internal shredders. These bring extra maintenance issues and costs.

Even when the autoclave itself is in good repair, inadequate disinfection can result from:

- overloading of autoclave so steam cannot penetrate;
- improper packing of waste, also a cause of poor steam penetration;
- use of an inappropriate program from the selection available,

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use of a program which is not suitable for its intended purpose. This last result from poor or no validation at installation time, or if the waste stream and its packaging changes from that used during the validation.

Almost all hospitals have experience with autoclaves as most will have them in the sterile stores department. Hence, employing them also in the waste treatment section should create less extra work than installing an entirely separate technology. Note that of course, waste treatment and equipment preparation must be carried out in different locations and using separate machines to prevent cross-contamination.

Gaskets can almost always be changed by the operator. Leaks in pipework can often be fixed by the operator, hospital maintenance engineer or local plumber/engineer. Heating elements in the simplest models can be changed by an electrical engineer. However, controllers and electronics can usually only be repaired or replaced by the manufacturer or their agents.

Spare gaskets and the tools and materials for fixing leaks should always be kept in stock. Heating elements and other spares may be advisable, depending on the model.

With reasonable maintenance, it is possible for autoclaves to remain operational for 10-20 years, as evidenced by the many older machines operating in sterile stores departments around the world.

The more complex hybrid autoclaves, with, for example, rotating chambers and internal shredders pose far more potential maintenance problems and are only advisable where the manufacturers are able to provide technical support.

**Incinerators**

Incinerators are often more complex than autoclaves, with two or more burners, and the need to control large amounts of fuel and process air. Whilst not exhaustive, the list of spare parts below, provided by a manufacturer, is indicative of the scope of maintenance needs that can be anticipated.

Photocell, spark electrode, oil filter element of primary thermocouple and heated refractory screens may need replacement once in two years; Fire bars approximately once every 5 years; pumps and burner motors may only need replacing once in 10 years.

The amount of maintenance that can be carried out by healthcare facility staff and local engineers will vary from place to place, but controllers and electronics can usually only be repaired or replaced by the manufacturer or their agents.

Manufacturers give the lifetime of their machines as in excess of 10 years, but in practice it is likely to be closer to 5 years.

**Utility requirements**

The vast majority of autoclaves are electrical and this is often cited as a problem in places where the electrical supply is limited or unreliable. However, all but the most primitive incinerators will require electricity for fuel pumps, fans, temperature and other gauges, and so are not immune to power outages and shortages. Moreover, the amount of electricity used by a waste autoclave is trivial compared to that consumed by the other operations in any healthcare facility.

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Whatever technology is used will require resources and this must be factored into investment, operating and maintenance budgets. It is not uncommon to encounter incinerators standing idle because the equipment and the fuel had been paid for by external donors and the hospital did not factor it into its budget once the grant expired.

Very few data are available on the utility requirements for specific appliances and this should be checked thoroughly during any procurement process.

<table>
<thead>
<tr>
<th>Utility</th>
<th>Incinerator</th>
<th>Autoclave</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity</td>
<td>For all but the most primitive models, electricity will be needed for fuel pumps, fans, temperature monitoring etc.</td>
<td>Almost all autoclaves are run on electricity. Some can use steam generated by gas, but will probably still need electricity for control systems.</td>
</tr>
<tr>
<td>Water</td>
<td>For wet scrubbers</td>
<td>Needed to generate the steam. Does not need to be of potable quality, but should be free of salts which can cause corrosion and clog pipes.</td>
</tr>
<tr>
<td>Diesel or kerosene</td>
<td>The smaller incinerators can be fuelled with kerosene, larger ones with diesel</td>
<td>Not required</td>
</tr>
<tr>
<td>Drainage</td>
<td>For washing purposes and disposal of scrubber effluent</td>
<td>For spent water. Steam vents can also be directed to the drains.</td>
</tr>
<tr>
<td>Ventilation</td>
<td>Important to keep working area cool and prevent exposure to toxic gases</td>
<td>Important to keep working area cool</td>
</tr>
<tr>
<td>Lime for dry scrubbers</td>
<td>120kg/tonne of waste burned</td>
<td>Not required</td>
</tr>
</tbody>
</table>

*Table 4: Utility requirements for autoclaves and incinerators*

**Economics**

The World Health Organisation has developed costing tools which can be used to estimate the expenses associated with different waste treatment strategies\(^5\). For many situations, autoclaving will turn out to be the most economical option.

**Capital costs**

Like any type of equipment, the price of incinerators and autoclaves varies significantly. The high end models, particularly those manufactured in the US and Europe, can cost several times more than those made in places like India and China.

*Incinerators*

Any incinerator capable of meeting the Stockholm Convention guidelines will be extremely costly.

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\(^5\) World Health Organisation Costing Estimation/calculation methods.  
[http://www.healthcarewaste.org/resources/costing-calculations/](http://www.healthcarewaste.org/resources/costing-calculations/)  
Accessed 18 July 2013  
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Figure 4: Graph from the 2012 UNEP compendium of healthcare waste treatment technologies (UNEP 2012) showing the capital costs of incinerators capable of meeting international standards on air pollution. Note that these are also large capacity installations, far beyond the needs of most countries for medical waste treatment alone. The dark lines give the average costs calculated by linear regression analyses. The dashed curves are the boundaries of the lowest and highest data points. In general, they do not include construction or renovation of the treatment space and commissioning.

In contrast, diesel incinerators of the type usual in developing countries are generally sold with little or no air pollution. One vendor approached during the research for this document explained that this was because the air pollution control devices needed to meet international standards cost 3-5 times more than the incinerator alone. The only estimate received for a diesel incinerator capable of meeting air pollution standards equivalent to those of the Stockholm Convention was $275,000 for an installation burning 50kg/hour.

Figure 5 below shows data on the capital costs of incinerators capable of burning up to 80kg/hour. Note that none of these are likely to be able to meet international pollution control standards.
Figure 5: Capital costs of diesel incinerators which do not meet international air pollution standards.

**Autoclaves**

The graphs below show the range of costs for autoclaves taken from the 2012 UNEP compendium of healthcare waste treatment technologies (UNEP 2012). These costs include the larger and more sophisticated models.

Figure 6. Variation in capital costs of medical waste autoclaves under 100kg/hour (UNEP 2012). This will include highly sophisticated hybrid machines with internal shredders or mixing paddles to break up the waste and maximise the steam penetration. The dark lines give the average costs calculated by linear regression analyses. The dashed curves are the boundaries of the lowest and highest capital costs.
highest data points. In general, they do not include construction or renovation of the treatment space and commissioning.

Smaller scale autoclaves show a similar distribution as shown in the chart below. Those with the lower cost to capacity ratio tended to be manufactured in India and the more expensive models were US or European-manufactured. Some of these more expensive models included shredders.

Figure 7. Variation in capital costs of medical waste autoclaves over 100kg/hour (UNEP 2012). This will include highly sophisticated hybrid machines with internal shredders or mixing paddles to break up the waste and maximise the steam penetration. The dark lines give the average costs calculated by linear regression analyses. The dashed curves are the boundaries of the lowest and highest data points. In general, they do not include construction or renovation of the treatment space and commissioning.
Figure 8: Capital cost versus operating capacity for autoclaves below 50 kg/hour capacity.

Operation costs

Operating costs are often overlooked when considering the purchase of new equipment but in the long term they can outweigh the investment costs. It is also particularly important to consider them in a donor situation to be sure that donated equipment will continue to provide the intended benefits for the longest possible period.
**Autoclaves**

Figure 9: Operating costs of autoclaves in US dollars per kg/hour of treatment capacity.

In the table above, it can be seen that the majority of autoclaves for which data were available were able to treat waste for less than 1 US$ per kg, including maintenance costs. The outliers were again the high tech European manufactured models, with the most expensive model being one that incorporated an internal shredder. The majority of the data here are in line with the data from the UNEP technology compendium (UNEP 2012), which estimates treatment costs for autoclaves to be 0.14-0.33 US$/kg.

**Incinerators**

The UNEP technology compendium (UNEP 2012) estimates that incineration of waste with air pollution control cost in the region of US$ 0.27-1.66 per kg.

Not enough data were obtained to allow the estimation of total operating costs for diesel incinerators, but combined diesel and electricity costs ranged from 0.15-0.81 US$/kg. Most manufacturers projected fuel use at 0.1-0.3 litres per kg of waste; the maximum was 0.47l/kg waste. One incinerator in Tanzania was reported to be using 20-40 litres of fuel per day to burn 70-120kg of waste over a period of 2-4 hours (Manyele and Kagonji 2012). The authors commented that this was indicative of poor performance, but similar results have been reported elsewhere. In Laos, fuel consumption of around 0.5 litres per kg of waste caused financial problems (Kuhling and Pieper 2012). In Taiwan, two incinerator units were used to dispose of medical waste in a large hospital. One, which burned general medical waste including cultures and stocks, human blood and blood products, isolation wastes, and sharps consumed 0.475 litres of diesel per kg of waste. The other, which burned pathological and animal waste with high moisture content needed 2.09 litres of diesel per kg of waste (Lee and Liow 2002).
According to the WHO guidelines on the safe and sustainable management of waste from healthcare facilities (Prüss-Ustun, Emmanuel et al. 2013), incineration of waste is affordable and feasible only if the calorific (energy) value of the waste reaches at least 2000 kcal/kg (8370 kJ/kg). Some healthcare waste may contain a high proportion of wet waste with much lower values and thus require an additional source of fuel to achieve and maintain temperatures. This adds to the operational costs.

Only one incinerator vendor gave information on spare parts likely to be needed (see also maintenance section above). The costs of these averaged out at approximately $1900 per annum.

**Resource recovery**

According to the Stockholm Convention (SSC 2008), “When considering proposals to construct new waste incinerators, priority consideration should be given to alternatives such as activities to minimize the generation of waste, including resource recovery, reuse, recycling, waste separation and promoting products that generate less waste. Priority consideration should also be given to approaches that prevent the formation and release of persistent organic pollutants.”

In many developing countries, incineration is an accepted waste treatment technology that allows for energy recovery from waste. However, medical waste incinerators are too small for this to be practical.

The co-processing of selected general and hazardous wastes as alternative fuels and/or raw materials for example in cement production is an attractive option in the search for cost effective raw materials for this manufacturing sector. It also presents a significant opportunity to reduce the volume of waste landfilled, particularly for organic wastes. High-temperature incineration of health care risk waste, such as chemical and pharmaceutical waste in industrial cement kilns or steel furnaces is practised in some countries.

In practice, the facilities for collecting and transporting infectious waste safely, and usually on a daily basis as it cannot be safely stored without refrigeration in tropical climates, are rarely available. The Stockholm Convention guidelines further state that infectious medical wastes are not recommended for co-processing (SSC 2008).

Where diesel incinerators are installed, they tend to be used for all of the waste produced by the health care facility, preventing materials recycling. This may be convenient where recycling facilities are lacking and since a large proportion of the recyclables- primarily paper and plastic- have a high heating value, they may be used to reduce the incinerators’ fuel needs.

However, most of the waste from the health care facility is similar to municipal waste and there is significant scope for recycling. Where facilities exist, plastic is usually the largest single waste stream, followed by paper, and these also generate the largest amounts of income.

**Siting constraints**

Siting of treatment centres for any type of hazardous waste treatment needs careful consideration. Autoclaves have few restrictions on their location as they do not emit pollutants and create little nuisance.

On the other hand, siting incinerators is often controversial due to objections from neighbours. Small-scale diesel incinerators usually have a short stack (up to 10m) and so gaseous emissions can

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impact nearby inhabitants. Best practice on siting incinerators includes the following measures (Batterman 2004):

Minimizing ambient air concentrations and deposition of pollutants to soils, foods, and other surfaces, e.g.,
- Open fields or hilltops without trees or tall vegetation are preferable. Siting within forested areas is not advisable as dispersion will be significantly impaired.
- Valleys, areas near ridges, wooded areas should be avoided as these tend to channel winds and/or plumes tend to impinge on elevated surfaces or downwash under some conditions.

Minimizing the number of people potentially exposed, e.g.,
- Areas near the incinerator should not be populated, e.g., containing housing, athletic fields, markets or other areas where people congregate.
- Areas near the incinerators should not be used for agriculture purposes, e.g., leafy crops, grasses or grains for animals.

For small-scale kerosene units, a buffer zone around the incinerator is recommended based on dispersion modelling to achieve 1000-fold dilution of the emissions. During the day and with terrain that allowed good dispersion, this translated to 250m buffer around the unit. Units are often operated at night to reduce inconvenience to neighbours; in this case, a buffer of 500-750m would be more appropriate (Batterman 2004).

References
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