2 Situation analysis regarding health-care waste

2.1 Overview

2.1.1 Generation and disposal of health-care waste

Developing countries have had extremely limited options for safe waste disposal, especially for used and/or contaminated sharps (lancets, blades, syringes or hypodermic needles with or without attached tubing; broken glass items such as Pasteur pipettes and blood vials, and other invasive devices) that can cause injury and that are associated with significant risk of infection if indiscriminately disposed. (Infectious waste \(^3\) can also include non-sharps, e.g., materials that have been in contact with blood, its derivatives, or other body fluids, e.g., bandages, swabs or items soaked with blood.) While generally less than 10% of health-care waste is considered infectious, many countries have poorly developed waste segregation practices. This complicates waste management since commingling sharps and other infectious waste with non-infectious waste will increase the amount of waste considered infectious that requires special treatment for safe treatment and disposal.

Resources are extremely limited in many countries, especially in remote areas. Consequently, open pit burning is still widely practiced for health-care waste including sharps, though this practice is objectionable due to emissions, the incomplete disinfection and destruction of the waste, and community complaints.

The volume of health-care waste varies by the size and activity of the clinic/hospital/provider. Small rural clinics may generate relatively small quantities of infectious waste, e.g., 1 to 10 kg of sharps per month. Quantities can be orders of magnitude greater at large urban clinics and hospitals. Quantities can greatly increase during immunization campaigns, e.g., the 2001 measles mass immunization campaign in West Africa (covering all or part of six countries) vaccinated 17 million children and generated nearly 300 tons of injection-related waste (Kezaala 2002). Throughout the developing world, WHO estimates that routine immunizations of children under one year and immunization of women of childbearing age with tetanus toxoid accounted for over one billion injections in 1998, while measles control/elimination activities and disease-outbreak control operations accounted for another 200 million injections in the same year (WHO 1999). These 1.2 billion injections are

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\(^3\) WHO provides the following definition of infectious waste: Infectious waste is suspected to contain pathogens (bacteria, viruses, parasites, or fungi) in sufficient concentration or quantity to cause disease in susceptible hosts. This category includes:

- Cultures and stocks of infectious agents from laboratory work;
- Sharps - items that could cause cuts or puncture wounds, including needles, hypodermic needles, scalpel and other blades, knives, infusion sets, saws, broken glass, and nails. Whether or not they are infected, such items are usually considered as highly hazardous health-care waste.
- Waste from surgery and autopsies on patients with infectious diseases (e.g. tissues, and materials or equipment that have been in contact with blood or other body fluids);
- Pathological waste consists of tissues, organs, body parts, human fetuses and animal carcasses, blood, and body fluids. Within this category, recognizable human or animal body parts are also called anatomical waste. This category should be considered as a subcategory of infectious waste, even though it may also include healthy body parts; • waste from infected patients in isolation wards (e.g. excreta, dressings from infected or surgical wounds, clothes heavily soiled with human blood or other body fluids);
- Waste that has been in contact with infected patients undergoing haemodialysis (e.g. dialysis equipment such as tubing and filters, disposable towels, gowns, aprons, gloves, and laboratory coats);
- Infected animals from laboratories;
- Any other instruments or materials that have been in contact with infected persons or animals.
estimated to produce 12,000 to 20,000 tons of infectious waste. Additional immunizations are anticipated as new vaccines appear and for the poorest countries where vaccines are needed most. Safe waste disposal options are needed to deal with these quantities, as well as the wastes generated by routine health-care provision.

2.1.2 Risks of infection

Improper disposal of health-care wastes, syringes and needles that are scavenged and reused may lead to significant numbers of hepatitis B, hepatitis C, HIV and possibly other infections in the developing world (Simonsen 1999). In some countries (e.g., India and Pakistan), contaminated disposable needles are often scavenged, repackaged, sold and reused without sterilization. Such practices are associated with serious health implications due to the transmission of infectious disease, especially hepatitis and AIDS. Several populations are at risk from poorly managed health-care waste:

- Health workers.
- Waste handlers.
- Scavengers retrieving items from dumpsites.
- People receiving injections with previously used needles/syringes.
- Children who may come into contact with contaminated waste and play with used needles and syringes, e.g., if waste is dumped in areas without restricted access.

Based on data taken from health-care settings, a person receiving one needle stick injury from a contaminated sharp used on an infected patient has a probability of 30%, 1.8% and 0.3% of being infected by Hepatitis B, Hepatitis C and HIV, respectively (Seeff et al. 1978; CDC 1997; Simonson et al. 1999). Globally, Hauri et al. (2004) estimates that the re-use of non-sterile syringes causes 21 million hepatitis B infections (32% of new cases) per year, 2 million hepatitis C infections (40% of new cases) per year, and 260,000 HIV infections (5% of new cases) per year. Other illnesses possibly transmitted by non-sterile syringes include ebola and lassa fevers, malaria, and wound abscesses (Simonsen et al. 1999). Miller and Pisani (1999) estimate 1.3 million deaths per year due to infections transmitted from contaminated injection equipment, while Hauri et al (2004) estimated that there were 501,000 deaths in 2000 due to unsafe injections in health-care settings.

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4 The low estimates is based on a safety box weighing about 1 kg when full of 100 syringes with needles. Associated waste will include gloves, swabs, etc. The high estimate is scaled from Keezala’s (2002) estimate.
Health-care waste treatment options

The many available waste treatment options for health-care waste treatment may be classified into four processes: thermal (including incineration), chemical (using disinfectants), irradiative (using ionizing radiation), and biological (using enzymes). These processes are generally used in conjunction with mechanical shredding, compaction and mixing to render waste unrecognizable, to improve heat or mass transfer, and/or to reduce the volume of treated waste. Reviews of health-care waste treatment options are provided elsewhere (Prüss 1999; HCWH 2001).

The selection of appropriate treatment options depends on many factors including (HCWH 2001):

- throughput capacity
- types of waste treated
- microbial inactivation efficacy
- environmental emissions and waste residues
- regulatory acceptance
- space requirements
- utility and other installation requirements
- waste reduction
- occupational safety and health
- noise
- odor
- automation
- reliability
- level of commercialization
- background of the technology manufacturer or vendor
- costs (both initial and operating)
- community and staff acceptance

HCWH (2001) and others point out that no one technology is a panacea to the problem of health-care waste, and that each technology has its advantages and disadvantages.

2.2 Evaluating technological options

The various technologies should be evaluated using comparable health, environmental and economic criteria. Often, this is difficult given uncertainties but it is possible to describe possible risks, benefits and costs. Importantly, the feasibility and desirability of most waste treatment options will likely depend on waste volumes currently generated and trends for the near-term (say 5 years). In their evaluation, waste generators ideally should undertake a waste audit, formulate appropriate indicators to assess and forecast waste generation trends (e.g., waste generated per type of procedure), and assume moderate-to-intensive efforts to minimize waste (depending on current minimization efforts).

The following criteria are suggested in evaluating small-scale treatment options for health-care waste:

- Effectiveness: Wastes should be completely sterilized and rendered into a form that prevents hazards or reuse.
- Cost-effectiveness: The technology should be economically competitive with other available options. A life-cycle cost basis that accounts for all costs, e.g., capital, operating, training, regulatory, energy, liability, waste disposal, etc.
- Safety: The construction, operation, and closure of the technology/facility should not present unacceptable environmental or human health risks. This includes consideration of occupational, community and environmental risks resulting from any air emissions, water effluents, and solid wastes generated.
- Simple: Small-scale technologies for poor countries should ideally be easy to manufacture, operate and maintain.

- Robust: The technology should consistently meet air emission and other health and safety criteria under a wide variety of operating conditions.

WHO has a larger list of factors to guide the choice of treatment system, noting that many of them depend on local conditions list of criteria (Prüss 1999):

- disinfection efficiency
- health and environmental considerations
- volume and mass reduction
- occupational health and safety considerations
- quantity of wastes for treatment and disposal/capacity of the system
- types of waste for treatment and disposal
- infrastructure requirements
- locally available treatment options and technologies
- options available for final disposal
- training requirements for operation of the method
- operation and maintenance considerations
- available space
- location and surroundings of the treatment site and disposal facility
- investment and operating costs
- public acceptability
- regulatory requirements

2.3 Incineration of health-care waste

Incineration has been used for many years (see review by Lee and Huffman, 1996). Incineration can destroy or inactive infectious waste, provide significant (>90%) mass and volume reduction of the waste, and render materials (syringes, etc.) unusable. In developed countries, recent regulatory initiatives have significantly changed the utilization, design and operation of incinerators (see Section 5.8). In developing countries, controlled air incineration using low cost engineered small-scale facilities has been promoted by national governments and UNICEF and is currently used in a number of countries, often with external support. Small-scale incinerators may be built on-site, locally constructed, fixed and/or portable. Units typically operate for 1 to 6 hours per week or month in a batch or intermittent mode to destroy sharps and other health-care waste. For example, the brick incinerators, designed at De Montfort University by JD Pickens, have been introduced into both remote and urban areas in several countries, e.g., West and East Africa, Kosovo, Sri Lanka, etc. When new and appropriately operated and maintained, these high thermal capacity incinerators can achieve relatively high operating temperatures (700 to 800 °C), largely destroying the waste and helping to reduce production and emissions of dioxins and furans in stack gases and ash. These incinerators are far preferable to waste burning in open pits or in steel drums, and user acceptance appears generally high. As discussed below, however, these incinerators are not performing optimally due to significant operation, maintenance and management issues.

There is a need to assess the risks attributable to toxic emissions of small-scale incinerators, to effectively communicate these risks to managers and policy makers involved with health-care waste management, and to document “best practices” to minimize risks should incinerators be used.

2.3.1 Risks from incineration emissions

Incinerator discharges (including disinfectants and pollutants) occur to air, water and soil. These discharges can lead to occupational and environmental exposures to toxic chemicals and subsequent health risks affecting waste workers, the general public, and the environment. With poor management,
infectious risks may also remain, largely in the occupational setting, e.g., waste handlers and incinerator operators.

Health-care waste is a heterogeneous mixture that often contains chlorine (from materials containing polyvinyl chloride and other plastics), heavy metals (from broken thermometers), cytotoxins, radioactive diagnostic materials, infectious materials, pathogens, etc.\(^5\) In consequence, incinerator emissions include both “conventional” pollutants, e.g., particulate matter, sulfur oxides, nitrogen oxides, volatile organic compounds and carbon monoxide, as well as dioxins, furans, arsenic, lead, cadmium, chromium, mercury, and hydrochloric acid. In the aggregate, incinerators can emit significant quantities of gaseous and particulate pollutants to the atmosphere (EPA 1996), and incineration of health-care waste in small and poorly controlled incinerators is a major source of dioxins and furans (UNEP 1999). Small-scale incinerators generally operate without pollutant controls. Additionally, other design, operation and maintenance issues produce much higher concentrations in stack gases than acceptable in modern and well-controlled incinerators.

Much of the concern regarding incinerator emissions concerns dioxins and furans.\(^6\) General conditions necessary for dioxin formation include the presence of fly ash, organic or inorganic chlorine, metal ions and, ideally, a temperature range of 250 - 450 °C (Huang 1996). Combustion of sharps alone in small-scale incinerators does not remove all chlorine from the waste stream and prevent dioxin formation since the polyvinylchloride (PVC) seal between the metal needle and the polyethylene body chlorine and the rubber plunger (piston) head of the syringe may contain chlorine (Oka 2002). (The syringe barrel and most of the piston are polyethylene, which does not contain chlorine, and which can be recycled.)

To date, most concern has focused on air emissions. Locally, incinerator workers and individuals living or working nearby can be exposed directly through inhalation, the so-called ‘direct’ exposure pathway. Additionally, air pollutants deposited in soil, vegetation and water can lead to so-called ‘indirect’ exposures through ingestion of locally-produced foods or water, and dermal absorption due to contact with contaminated dusts, soil, water, etc. For many contaminants, indirect exposures can far exceed direct (inhalation) exposures. Regionally (at some distance from incinerators), individuals are exposed through a different mix of pathways for persistent and/or bioaccumulative pollutants, e.g., polycyclic aromatic hydrocarbons (PAHs), dioxins, furans, polychlorinated biphenyls, mercury, chromium, cadmium, etc., that undergo chemical and physical transformations, cycling in and out of soil, vegetation, and surface water. At regional scales, most exposure is believed to occur through ingestion of food and water, and incidental soil and house dust).

The waste stream from incinerators also includes solid and liquid wastes, namely, bottom ash and residues from pollution control equipment (if any). Typically, solid wastes are disposed in soils (typically landfills or pits). Liquid wastes (e.g., wet scrubber effluent, boiler blow-down, etc.) from some incinerators may be further treated and discharged to a sanitary sewer. (No specific information on liquid waste releases for small-scale incinerators was found, though these processes are rarely employed.) Disposal of waste, ash, liquid or other residues in unlined pits or other improperly managed facilities may contaminate groundwater, which may be used for drinking water.

### 2.3.2 Incinerator performance

The more recent designs for low-cost small-scale incinerators promise effective sterilization of health-care waste, and these units have been constructed in a variety of settings. However, several studies using “rapid assessment techniques” indicate a variety of problems including operator training, management and supervisor support, operation and maintenance, and siting (see Figures 1 - 3):

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\(^5\) Cytotoxic, radioactive, and mercury-containing wastes should not be incinerated.

\(^6\) In this report, dioxins and furans refers to all polychlorinated dibenzo-p-dioxins and dibenzofurans considered toxic, namely, the 17 congeners chlorinated in the 2,3,7 and 8 positions.
Figure 1  Photos indicating operational/training problems with De Montfort type incinerators.
Left: Incinerator operator wearing motorcycle helmet instead of respiratory protective gear (Mac Robert Hospital, Gurdaspur, Punjab, October 2002, taken from HCWH, 2002). Center: General waste to be burned (Kulathummel Salvation Army Hospital, Thiruva Nanthapuram, Kerala, Sept. 2002, taken from HCWH, 2002). Right: Black smoke indicating high pollutant emissions (WHO presentation, Bradley Hersh, location and date unknown, taken from HCWH, 2002)

Figure 2  Photos indicating construction problems for De Montfort Incinerators in Kenya.
All from Taylor (2003). Left: Front door frame damaged and also off-set inside making cleaning difficult. Right: Loading door frame rusted and hinge broken.

Figure 3  Photos indicating maintenance problems for De Montfort Incinerators in Kenya.
All from Taylor (2003). Left: Front door hinges damaged and frame dislodged from mortar. Right: Damaged masonry and loose fire-bricks
• Kenya: Some 44 De Montfort type incinerators were constructed in 2002, of which 55% are in intermittent or regular use. Tests and interviews were conducted at 14 sites (Adama 2003). Only 1 of 14 sites had an operator with ‘near to adequate’ skills, fewer than 40% of health facility managers demonstrated any level of commitment, many technical defects were observed in the equipment, and most incinerators were operated improperly (Taylor 2003).

• Tanzania: A total of 13 De Montfort incinerators were constructed in 2001 and 2003, and all were in use. Of these, <40% had trained operators, 70% had low smoke disturbance, and 60% have safe ash disposal (Adama 2003).

• Burkina Faso. Where utilized, equipment was poorly operated and under-utilized, i.e., the expected number of syringes incinerated fell short by about two-thirds (Adama 2003).

• India. Eight 1 to 2 year-old De Montfort incinerators at hospitals in India were surveyed by HCWH (2002). This survey indicated visible smoke from the stack; smoke emission from the chamber door and air inlets; commingling of sharps and non-infectious waste, despite some source segregation; large quantities of unburned materials (sometimes plastics, syringes, glass, paper and gauze) in the ash; deficient ash disposal practices; siting in all cases near populated areas (e.g., playground, orphanage, hospital staff quarters, a primary school, town center), and a lack of operator training.

Due to modest sample sizes and unknown inclusion criteria, these surveys may not provide the true frequency of these problems. However, the results of the surveys in the four countries are remarkably consistent and indicate significant technical, operational, maintenance and management shortcomings. Adama (2003) and Taylor (2003) state several key problems:

• No formal health-care waste infrastructure, e.g., lack of clear directives, inadequate definition of responsibilities, no waste management budget, sporadic controls, inadequate maintenance, dispersed training.

• Unclear ownership of incinerator, e.g., whose property and whose responsibility.

• Low skills and motivation of personnel, e.g., assignments to incineration tasks are casual, personnel are unskilled laborers, and assignments are short term (no more than 3 to 6 months).

2.3.3 Control of incinerator emissions

Incinerator emissions and associated risks may be reduced using by implementing emission standards, operational controls, and enhanced management practices. (These ‘best practices’ are discussed later in this report.) Emission rates (and exposures) from current small-scale incinerators are highly variable (see Figure 4) and may be high for a number of reasons:

• Incorrect construction of the incinerator.

• Incorrect operation, in part associated with operator’s lack of training.

• Poor combustion, e.g., low temperatures (<800 C) and short residence times (well below 1 second).^7

• Lack of process monitoring. Visual cues are sometimes used, but temperatures and other parameters are not directly monitored.

• Inadequate maintenance.

• Absence of pollution controls. Existing units generally have no pollution controls.

^7 Small-scale incinerators are manually charged with fuel and waste at the operator’s discretion. Charging practices greatly affect temperatures, residence times, entrainment of ash, etc. For example, the De Montfort design appears to operate optimally at a charging rate of one safety box every 10 min (about 6 kg waste/hour) [personal communication, DJ Pickens, Dec. 15 2003]. Higher charging rates may overheat the system, causing the stack to glow red, increasing draft, decreasing residence, and increasing emissions.
Figure 4  Photographic examples of smoke emissions. All taken from Taylor (2003).
Left: Dark and dense smoke with excessive particulate matter emissions. Right: Low or almost no smoke emissions.

- Insufficient waste segregation and waste minimization. Waste segregation practices are generally deficient.
- Lack of emission limits, process and emission monitoring, inspection, etc.
Correcting these deficiencies can reduce emissions, with a commensurate reduction in risks.
As mentioned earlier, exposure to incinerator emissions has the potential to cause various health effects, both chronic (e.g., cancer) and acute (e.g., systemic toxicity) risks. In general, most health concerns are raised by emissions of particulate matter, heavy metals, dioxins, furans, and sometimes hydrogen chloride (Chen et al. 2001; Ficarella and Laforgia 2000; Cudhay and Helsel 2000).

2.3.4 Incinerator costs
Locally built small-scale incinerators like the De Montfort design cost about $1,500 to $2,000 USD to construct, plus costs of shelter, ash pit, etc. Construction costs depend on a number of factors, especially the availability and cost of refractory bricks, metal and metal-working facilities. Operational costs depend on utilization, but costs have been estimated to range from $1.8 to $8.8 USD per kg of waste for units handling 250 and 15 safety boxes per month, respectively (Taylor 2003). This cost analysis is presented, with minor modifications, in the left-most columns in Table 1. The right-hand side of the table provides cost estimates with enhanced training, management, oversight and maintenance, and several additional and required costs are incorporated. These enhancements increase costs in the low use scenario by 37% to about $12 USD per kg waste, and in the high use scenario by 13% to $2.7 USD per kg waste.

The cost estimates in Table 1 are preliminary and based on incomplete information. It should be noted that replacement metal parts constitute ~60% of initial construction costs, of which the chimney represents 30 – 50%. 160 bricks required are estimated to cost $208 USD (Taylor 2003).
Appendix B describes several small-scale incinerators, including costs.
Table 1  Costs of De Montfort type incinerators under two usage scenarios with and without enhanced operation.
Low use based on 15 safety boxes burned per month. High use based on 250 safety boxes burned per month, and weekly burnings. Current conditions based in part on Taylor (2003) and HCWH (2002). Initial construction costs estimated to range from $1 530 to $2 000 USD (higher value selected below). Changes in enhanced analysis are shown in bold.

<table>
<thead>
<tr>
<th>Category</th>
<th>Unit rate</th>
<th>Current Conditions</th>
<th></th>
<th>Enhanced Operation, Training, Maintenance</th>
<th></th>
</tr>
</thead>
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<tr>
<td></td>
<td></td>
<td>Low Use Scenario</td>
<td>High Use Scenario</td>
<td>Low Use Scenario</td>
<td>High Use Scenario</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cost or quantity</td>
<td>Cost</td>
<td>Cost or quantity</td>
<td>Cost</td>
</tr>
<tr>
<td>Waste</td>
<td>Weight waste per box (kg)</td>
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<td>0.75</td>
<td>0.75</td>
<td>0.75</td>
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<tr>
<td>Burned</td>
<td>No. safety boxes per burn</td>
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<td>50</td>
<td>15</td>
<td>50</td>
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<tr>
<td></td>
<td>Burns per year</td>
<td>12</td>
<td>52</td>
<td>12</td>
<td>52</td>
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<tr>
<td></td>
<td>Total weight burned (kg/yr)</td>
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<td>1950.00</td>
<td>135.00</td>
<td>1950.00</td>
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<tr>
<td>Initial Costs</td>
<td>Shelter, Pit, etc. cost ($)</td>
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<td>500.00</td>
<td>300.00</td>
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<td></td>
<td>Lifetime (year)</td>
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<tr>
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<td>Costs</td>
<td>Annualized cost ($/yr)</td>
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<td>727.55</td>
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<td></td>
<td>Person hours (hr/burn)</td>
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<td>6.50</td>
<td>3.00</td>
<td>7.50</td>
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<tr>
<td></td>
<td>Labor cost ($/hr)</td>
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<td>Operating</td>
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<td>225.33</td>
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<td>Costs</td>
<td>Fuel cost /burn (1L kerosene, $)</td>
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<td>0.47</td>
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<tr>
<td></td>
<td>Solid fuel (3.5 kg/kg waste, $/kg)</td>
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<td>Total fuel costs ($/yr)</td>
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<td></td>
<td>Total safety box cost ($)</td>
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<td>3466.67</td>
<td>240.00</td>
<td>3466.67</td>
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<td>Maintenance</td>
<td>Percent of Capital costs (%)</td>
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<td>10.00</td>
<td>20.00</td>
<td>20.00</td>
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<tr>
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<td>Maintenance cost ($/yr)</td>
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<td>200.00</td>
<td>460.00</td>
<td>500.00</td>
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<td>Training +</td>
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<td>16.00</td>
<td>16.00</td>
<td>16.00</td>
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<td>Oversight</td>
<td>Inspections (1 hr 12 times/year)</td>
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<td>8.00</td>
<td>8.00</td>
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<td>Management and permitting (4 hr/year)</td>
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<td>Total annual cost ($/yr)</td>
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<td>Cost per kg ($/kg waste)</td>
<td>8.88</td>
<td>2.45</td>
<td>12.14</td>
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</tr>
</tbody>
</table>

2.4 Other options
A variety of non-incineration treatment and disposal technologies for health-care waste, including several low cost options, are available or under development. While the emphasis of this report is small-scale incineration, these other options should be compared to incineration using identical evaluative criteria.

Appropriate low cost treatment options for sharps and other infectious wastes have focused largely on burial, encapsulation and autoclaving (sterilization by steam and pressure). Shredding of waste and landfill disposal is required following autoclaving. In developed countries, many hospitals and other generators have moved away from incineration to autoclaving, responding to increasingly stringent emission controls, cost arguments, and public acceptance. Autoclaving has a number of advantages:

- The technology is simple and effective.
- Costs are low, and the process can be modularized allowing scaling and application to small to large waste generators.
Medical institutions have experience with autoclaves, e.g., many hospitals have similar facilities in laboratory and/or central sterile supply departments.

Health-care waste options are described elsewhere (HCWH 2001; 2002; WHO 1999). HCWH (2003) and others have begun pilot testing several innovative treatment technologies at rural hospitals, including the collection of sharps waste from immunization campaigns using reusable metal containers, which are collected and transported for treatment in a small centralized autoclave-shredder system. Two winners in HCWH’s recent contest included:

- Solar-powered autoclave-style sterilizer (Sydney University) in 1.5 and 14 L/batch versions.
- Boiling chamber with mechanical grinder and compactor (Newcastle upon Tyne Hospitals NHS Trust) in which bags of medical waste are placed into a grinding chamber, reduced to small particles that are then boiled by a firebox.

Other technologies under development include:

- Whole syringe melting/sterilization. Application of sufficient heat (>165°C) will melt syringes into a consolidated mass in which needles are embedded. This material may be recycled or disposed. Solar powered units may be feasible.8
- Enhanced recycling. Polyethylene is easily recycled, but the potential for recycling can be increased by several factors: more effective ways to disable the needle (rather than needle cutters); elimination of all metal from the syringe (including needle remnants and retaining clips); and elimination of non-polyethylene components (e.g., replacing current rubber plunger head with other elastomers).

At a recent WHO workshop (December 15, 2003), it was suggested that tenders for the development and demonstration of safe waste treatment options be solicited as part of – or prior to – major immunization campaigns. New technologies can be expected to undergo several cycles of testing and improvements, requiring a few years. Strong support, including financial, technical, management, outreach, communication and management, will hasten technology innovation, refinement, and adoption.

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8 IT Power India has a prototype solar powered melting system. Development work on another melting system is underway at the Georgia Institute of Technology. (Personal communications, T. Hart, Y. Chartier, Dec. 15, 2003; J. Colton, January 2004).