Carcass Disposal: A Comprehensive Review

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Chapter

2

Incineration

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Abbreviations Used

AI	avian influenza
APHIS	USDA Animal and Plant Health Inspection Service
BSE	bovine spongiform encephalopathy
CWD	chronic wasting disease
DEFRA	UK Department for Environment, Food and Rural Affairs
EPA	US Environmental Protection Agency
EU	European Union
FAO	Food and Agricultural Organization of the United Nations
FDA	US Food and Drug Administration
FMD	foot and mouth disease
FSIS	USDA Food Safety and Inspection Service
MAFF	UK Ministry of Agriculture, Fisheries and Food
MBM	meat-and-bone meal
NAO	UK National Audit Office
OTMS	UK Over Thirty Months Scheme
PAH	polyaromatic hydrocarbon
PCB	polychlorinated biphenyl
PM	particulate matter
PMF	powder metallic fuel
SEAC	UK Spongiform Encephalopathy Advisory Committee
SSC	European Commission Scientific Steering Committee
TSE	transmissible spongiform encephalopathy
UK	United Kingdom
US	United States
USDA	US Department of Agriculture

Section 1 – Key Content

Incineration has historically played an important role in carcass disposal. Advances in science and technology, increased awareness of public health, growing concerns about the environment, and evolving economic circumstances have all affected the application of incineration to carcass disposal. Today there are three broad categories of incineration techniques: open-air burning, fixed-facility incineration, and air-curtain incineration.

1.1 – Open-Air Burning

Open-air carcass burning—including the burning of carcasses on combustible heaps known as pyres—dates back to biblical times. It is resource intensive, and both historically and recently it has been necessarily supplemented by or substituted with other disposal methods. Nevertheless, open-air burning has persisted throughout history as a utilized method of carcass disposal. For example, open-air burning was used extensively in the 1967 and 2001 foot and mouth disease (FMD) outbreaks in the United Kingdom (UK) (NAO, 2002; Scudamore, Trevelyan, Tas, Varley, & Hickman, 2002), in smaller-scale outbreaks of anthrax in Canada in 1993 (Gates, Elkin, & Dragon, 1995, p.258), and in southeast Missouri in 2001 (Sifford, 2003).

Open-air burning includes burning carcasses (a) in open fields, (b) on combustible heaps called pyres (Dictionary.com, 2003), and (c) with other burning techniques that are unassisted by incineration equipment. Generally, one must have a state permit to open-air burn (APHIS, 2003, p.2707). Open-air burning is not permitted in every state, but it may be possible to waive state regulations in a declared animal carcass disposal emergency (Ellis, 2001, p.27; Henry, Wills, & Bitney, 2001; Morrow, Ferket, & Middleton, 2000, p.106).

Open-air burning should be conducted as far away as possible from the public. For large pyres involving 1,000 or more bovine carcasses, a minimum distance of 3 kilometers (~2 miles) has been suggested in the UK (Scudamore et al., 2002, p.779). Based on the UK experience, an important site-selection rule is to first communicate with local communities about open-air burning intentions (Widdrington FMD Liaison Committee).

Material requirements for open-air burning include straw or hay, untreated timbers, kindling wood, coal, and diesel fuel (see Table 2 in section 3.1) (McDonald, 2001, p.6; Smith, Southall, & Taylor, 2002, pp.24-26). Although diesel fuel is typically used in open-air burning, other fuels (e.g., jet fuel and powder metallic fuels) have also been used or studied (Gates et al., 1995, p.258; Sobolev et al., 1999; Sobolev et al., 1997). Tires, rubber, and plastic should not be burned as they generate dark smoke (MAFF, 2001, p.36). To promote clean combustion, it is advisable to dig a shallow pit with shallow trenches to provide a good supply of air for open-air burning. Kindling wood should be dry, have a low moisture content, and not come from green vegetation (MAFF, 2001, pp.36-37). Open-air burning, particularly in windy areas, can pose a fire hazard.

Open-air burning of carcasses yields a relatively benign waste—ash—that does not attract pests (Damron, 2002). However, the volume of ash generated by open-air burning can be significant (NAO, 2002, p.92). Open-air burning poses additional clean-up challenges vis-à-vis groundwater and soil contamination caused by hydrocarbons used as fuel (Crane, 1997, p.3).

1.2 – Fixed-Facility Incineration

Historically, fixed-facility incineration of carcasses has taken a variety of forms—as crematoria, small carcass incinerators at veterinary colleges, large waste incineration plants, on-farm carcass incinerators, and power plants. During the 1970s, rising fuel prices reduced the popularity of fixed-facility incinerators, but technological improvements in efficiency soon followed (Wineland, Carter, & Anderson, 1997). Small animal carcass incinerators have been used to dispose of on-farm mortalities for years in both North America and Europe, and the pet crematoria industry has grown over time (Hofmann &

Wilson, 2000). Since the advent of bovine spongiform encephalopathy (BSE) in the UK, fixed-facility incineration has been used to dispose of BSE-infected carcasses as well as rendered meat-and-bone meal (MBM) and tallow from cattle carcasses considered to be at-risk of BSE (Herbert, 2001). During the 2001 FMD outbreak in the Netherlands, diseased animals were first rendered and then the resultant MBM and tallow were taken to incineration plants (de Klerk, 2002). In Japan, cattle testing positive for BSE are disposed of by incineration (Anonymous, 2003d).

Fixed-facility incinerators include (a) small on-farm incinerators, (b) small and large incineration facilities, (c) crematoria, and (d) power plant incinerators. Unlike open-air burning and air-curtain incineration, fixed-facility incineration is wholly contained and, usually, highly controlled. Fixed-facility incinerators are typically fueled by diesel, natural gas, or propane. Newer designs of fixed-facility incinerators are fitted with afterburner chambers designed to completely burn hydrocarbon gases and particulate matter (PM) exiting from the main combustion chamber (Rosenhaft, 1974).

One can operate an incinerator if properly licensed, usually by a state government (APHIS, 2003, p.2707). Properly trained operators are critical (Collings, 2002). Small, fixed-facility incinerators may be operated on farms provided one has a permit, although there are increasing regulatory costs associated with maintaining this permit.

In the United States (US), the idea of incinerating carcasses in large hazardous waste, municipal solid waste, and power plants has been suggested. While the acceptance of MBM and tallow from rendered carcasses could be accommodated in the US, large-scale whole-carcass disposal would be problematic given the batch-feed requirements at most biological waste incineration plants (Anonymous, 2003f; Heller, 2003). Many waste incineration facilities refuse to accept whole animals, noting that carcasses are 70 percent water and preferred waste is 25 percent water (Thacker, 2003). The possibilities of combining incineration with rendering (i.e., incinerating MBM and tallow) are more promising and should be explored (see section 7.1).

Many incinerators are fitted with afterburners that further reduce emissions by burning the smoke exiting the primary incineration chamber (Walawender, 2003). Compared to open-air burning, clean-up of ash is less problematic with fixed-facility incineration; ash is typically considered safe and may be disposed of in landfills (Ahlvers, 2003). However, if residual transmissible spongiform encephalopathy (TSE) infectivity is of concern, burial may not be suitable. Although more controlled than open-air burning, fixed-facility incineration also poses a fire hazard.

1.3 – Air-Curtain Incineration

Air-curtain incineration involves a machine that fan-forces a mass of air through a manifold, thereby creating a turbulent environment in which incineration is greatly accelerated—up to six times faster than open-air burning (W.B. Ford, 1994, p.3). Air-curtain incineration technology—which has traditionally been used for eliminating land-clearing debris, reducing clean wood waste for landfill disposal, and eliminating storm debris—is a relatively new technology for carcass disposal (Brglez, 2003, p.18; Ellis, 2001, p.28). Air-curtain incinerators have been used for carcass disposal in the wake of natural disasters in the US (Ellis, 2001, pp.29-30), and imported air-curtain incinerators were used to a small degree during the UK 2001 FMD outbreak (G. Ford, 2003; NAO, 2002, p.74; Scudamore et al., 2002, p.777). Air-curtain incinerators have been used in Colorado and Montana to dispose of animals infected with chronic wasting disease (CWD) (APHIS, 2003, p.2707) and throughout the US in other livestock disasters (G. Ford, 2003).

In air-curtain incineration, large-capacity fans driven by diesel engines deliver high-velocity air down into either a metal refractory box or burn pit (trench). Air-curtain systems vary in size according to the amount of carcasses to be incinerated (Ellis, 2001, p.29). Air-curtain equipment can be made mobile. Companies that manufacture air-curtain incinerators include Air Burners LLC and McPherson Systems (G. Ford, 2003; McPherson Systems Inc., 2003). Secondary contractors, such as Dragon Trenchburning or Phillips and Jordan, are prepared to conduct actual air-curtain operations (Smith et al., 2002, p.28).

Materials needed for air-curtain incineration include wood (preferably pallets in a wood-to-carcass ratio varying between 1:1 and 2:1), fuel (e.g., diesel fuel) for both the fire and the air-curtain fan, and properly trained personnel (G. Ford, 2003; McPherson Systems Inc., 2003). For an incident involving the air-curtain incineration of 500 adult swine, 30 cords of wood and 200 gallons of diesel fuel were used (Ellis, 2001, p.29). Dry wood for fuel is critical to ensuring a proper air/fuel mixture (Ellis, 2001, p.30).

Air-curtain incinerators have met regulatory approval in the US and around the world (G. Ford, 2003). If placed far from residential centers and the general public, they are generally not nuisances (APHIS, 2002, p.11).

Like open-air burning and fixed-facility incineration, air-curtain incineration poses a fire hazard and the requisite precautions should always be taken. Air-curtain incineration, like other combustion processes, yields ash. From an ash-disposal standpoint, air-curtain incineration in pits is advantageous if the ash may be left and buried in the pits (Smith et al., 2002, p.27). However, in sensitive groundwater areas—or if burning TSE-infected carcasses—ash will most likely be disposed of in licensed landfills.

Unlike fixed-facility incineration, air-curtain incineration is not wholly contained and is at the mercy of many variable factors (e.g., human operation, the weather, local community preferences, etc.). In past disposal incidents involving air-curtain incineration, both ingenuity and trial-and-error have been necessary to deal with problems (Brglez, 2003, pp.34-35).

1.4 – Comparison of Incineration Methods

Capacity

The efficiency and throughput of all three incineration methods—including open-air burning—depend on the type of species burned; the greater the percentage of animal fat, the more efficient a carcass will burn (Brglez, 2003, p.32). Swine have a higher fat content than other species and will burn more quickly than other species (Ellis, 2001, p.28).

For fixed-facility incinerators, throughput will depend on the chamber's size. For small animal carcass incinerators, throughput may reach only 110 lbs (50 kg) per hour (Anonymous, 2003e). Larger facilities dedicated to the incineration of animal remains may be able to accommodate higher numbers. In Australia, for example, one public incinerator is prepared to accept, during times of emergency, 10 tonnes of poultry carcasses per day (Western Australia Department of Agriculture, 2002, p.7). In the US, fixed-facility capacity is generally recognized to not be of an order capable of handling large numbers of whole animal carcasses; however, incineration plants are quite capable of taking pre-processed, relatively homogenous carcass material (Anonymous, 2003f; Ellis, 2001).

Air-curtain incinerator capacity depends on the manufacturer, design, and on-site management. One manufacturer reports that, using its larger refractory box, six tons of carcasses may be burned per hour (G. Ford, 2003). In a burn pit, using a 35-foot-long air-curtain manifold, up to four tons of carcasses may be burned per hour (W.B. Ford, 1994, pp.2, 11). Other studies have shown that air-curtain incinerators have efficiently burned 37.5 tons of carcasses per day (150 elk, weighing an average of 500 pounds each) (APHIS, 2002, p.11).

Cost

Synthesizing information from a variety of sources (see sections 3.1, 3.2, and 3.3), "intervals of approximation" have been used to describe the costs for each incineration technology. These are summarized in Table 1.

TABLE 1. "Intervals of approximation" for carcass disposal costs of open-air burning, fixed-facility incineration, and air-curtain incineration (Ahlvers, 2003; Brglez, 2003, p. 86; Cooper, Hart, Kimball, & Scoby, 2003, pp. 30-31; W.B. Ford, 1994; FT.com, 2004; Heller, 2003; Henry et al., 2001; Jordan, 2003; Morrow et al., 2000, p.106; NAO, 2002, p.92; Sander, Warbington, & Myers, 2002; Sparks Companies, 2002, pp. v, 11; Waste Reduction by Waste Reduction Inc.; Western Australia Department of Agriculture, 2002, p.7).

	Open-air burning	Fixed-facility incineration	Air-curtain incineration
Interval approximating the cost (in US$) per ton of carcass	$196 to $723	$98 to $2000	$143 to $506

Disease agent considerations

Regardless of method used, bacteria, including spore-formers, and viruses should not survive incineration. There has, however, been much speculation that open-air burning can help spread the FMD virus; several studies have examined this question, and while the theoretical possibility cannot be eliminated, there is no such evidence (Champion et al., 2002; J. Gloster et al., 2001).

The disease agents responsible for TSEs (e.g., scrapie, BSE, and CWD) are highly durable (Brown, 1998). This raises important questions about incineration's suitability for disposing of TSE-infected—or potentially TSE-infected—carcasses. The UK Spongiform Encephalopathy Advisory Committee (SEAC) and the European Commission Scientific Steering Committee (SSC) agree that the risk of TSE-infectivity from ash is extremely small if incineration is conducted at 850°C (1562°F) (SEAC, 2003; SSC, 2003a).

TSE experts agree that open-air burning should not be considered a legitimate TSE-related disposal option. Instead, fixed-facility incineration is preferred (SSC, 2003b, p.4; Taylor, 2001). While alkaline-hydrolysis digestion has been widely reported to be the most robust method for dealing with TSEs (Grady, 2004), under controlled conditions fixed-facility incineration is also an effective means by which to dispose of TSE-infected material (Powers, 2003).

Because fixed-facility incineration is highly controlled, it may be validated to reach the requisite (850°C or 1562°F) TSE-destruction temperature.

While air-curtain incinerators reportedly achieve higher temperatures than open-air burning, and may reach 1600°F (~871°C) (G. Ford, 2003; McPherson Systems Inc., 2003), these claims need to be further substantiated (Scudamore et al., 2002, p.779). Noting that "with wet wastes, such as CWD-contaminated carcasses, temperatures...can fluctuate and dip below recommended temperatures," an Environmental Protection Agency (EPA) Region 8 draft document hesitates to endorse air-curtain incineration as a robust method for dealing with CWD (Anonymous, 2003c, p.4). In the UK, the Department for Environment, Food and Rural Affairs (DEFRA) has conducted experiments to elucidate the temperatures reached during air-curtain incineration in fireboxes; but despite efforts that included the placement of temperature probes in the carcass mass, researchers could confirm only a range of attained temperatures (600-1000°C, or 1112-1832°F). This information may be a useful guide, but further studies to confirm the temperatures reached are needed (Hickman, 2003).

Environmental implications

It is generally accepted that open-air burning pollutes (Anonymous, 2003b). The nature of open-air emissions hinges on many factors, including fuel type. Both real and perceived environmental risks of open-air burning were the subjects of studies and complaints during the UK 2001 FMD outbreak. Studies focused on dioxins, furans, polyaromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), metals, nitrogen oxides, sulphur dioxide, carbon monoxide, carbon dioxide, organic gases, and PM—especially PM less than 10 micrometers in diameter that can be drawn into the lungs (McDonald, 2001). The fear of dioxins and smoke inhalation, along with the generally poor public perception of pyres, eventually compelled the discontinuation of the use of mass burn sites in the UK (Scudamore et al., 2002, pp.777-779). However, pollution levels never exceed levels in other (urban) parts of the UK, did not violate air quality regulations, and were deemed to have not unduly affected the public health (Cumbria Foot and Mouth Disease Inquiry Panel, 2002, p.76; Hankin & McRae, 2001, p.5; McDonald, 2001; UK Department of Health, 2001a, 2001b).

In contrast to open-air burning, properly operated fixed-facility and air-curtain incineration pose fewer pollution concerns. During the UK 2001 FMD outbreak, air-curtain incinerators provided by Air Burners LLC offered conspicuous environmental advantages over open-air burning (G. Ford, 2003). Air-curtain technology in general has been shown to cause little pollution, with fireboxes burning cleaner than trench-burners (G. Ford, 2003). When compared to open-burning, air-curtain incineration is superior, with higher combustion efficiencies and less carbon monoxide and PM emissions (G. Ford, 2003). Individuals within the UK government, who have conducted testing on air-curtain fireboxes, are indeed satisfied with this technology's combustion efficiency (Hickman, 2003).

If operated in accordance with best practices and existing environmental regulations, both small and large afterburner-equipped incinerators should not pose serious problems for the environment (Crane, 1997, p.3). However, if not operated properly, small animal carcass incinerators have the potential to pollute. Therefore, it may be environmentally worthwhile to send carcasses to larger, centralized, and better managed incineration facilities (Collings, 2002).

While open-air burning, poorly managed fixed-facility incineration, and poorly managed air-curtain incineration can pose legitimate pollution concerns, they should be considered when other environmental factors (e.g., a high water table, soils of high permeability, etc.) rule out burial (Damron, 2002).

Advantages and disadvantages

Open-air burning can be relatively inexpensive, but it is not suitable for managing TSE-infected carcasses. Significant disadvantages include its labor- and fuel-intensive nature, dependence on favorable weather conditions, environmental problems, and poor public perception (Ellis, 2001, p.76).

Fixed-facility incineration is capable of thoroughly destroying TSE-infected carcasses, and it is highly biosecure. However, fixed-facility incinerators are expensive and difficult to operate and manage from a regulatory perspective. Most on-farm and veterinary-college incinerators are incapable of handling large volumes of carcasses that typify most carcass disposal emergencies. Meanwhile, larger industrial facility incinerators are difficult to access and may not be configured to handle carcasses (Ellis, 2001, p.28).

Air-curtain incineration is mobile, usually environmentally sound, and suitable for combination with debris removal (e.g., in the wake of a hurricane). However, air-curtain incinerators are fuel-intensive and logistically challenging (Ellis, 2001, p.76). Currently, air-curtain incinerators are not validated to safely dispose of TSE-infected carcasses.

1.5 – Lessons Learned

Open-air burning to be avoided

Open-air burning can pose significant public perception, psychological, and economic problems. During the UK 2001 FMD outbreak, carcasses burning on mass pyres "generated negative images in the media" and "had profound effects on the tourist industry" (NAO, 2002, pp.7, 74). In 2001, on-farm pyre burning sent smoke plumes into the air and contributed to an environment of despair for the UK farming community (Battista, Kastner, & Kastner, 2002).

Personnel and professional development

Past emergency carcass disposal events have revealed the need for readily available logistical expertise, leadership, and managerial skills (Anderson, 2002, p.82). Indeed, professional development is important. Simulation exercises are key components of preparing for carcass disposal.

US federal, state, and local officials responsible for carcass disposal should seek out opportunities to participate in real-life emergencies that can be anticipated ahead of time (e.g., 2003's Hurricane Isabel). The extra personnel would, of course, offer assistance that is valuable in and of itself; but equally importantly, the extra personnel would learn about carcass disposal in a real-life, pressure-filled context. In addition, and parallel to a recommendation made in the UK (Anderson, 2002, p.82), a bank of volunteers should be available in the event that labor is in short supply to manage mass carcass disposal events, including those involving incineration.

The "digester vs. incinerator" debate

One of the great questions facing US animal disease officials is whether alkaline-hydrolysis digestion or fixed-facility incineration should be preferred for disposal of TSE-infected animals. While high-temperature, fixed-facility incineration may be as effective as alkaline hydrolysis in destroying the prion agent, it is nonetheless laden with unique public-perception problems. This has been evident in recent debates in Larimer County, Colorado, where state wildlife officials have been pushing for the construction of a fixed-facility incinerator to dispose of the heads of CWD-infected deer and elk. While incinerators exist in other parts of the state (e.g., Craig, Colorado), a new incinerator is needed to deal specifically with populations in northeastern Colorado, where there is a high prevalence of CWD among gaming populations.

Despite the need, Larimer County commissioners have heeded local, anti-incinerator sentiments and have, for now, successfully blocked approval of the incinerator. Meanwhile, an alkaline-hydrolysis digester at Colorado State University has generated fewer concerns. Throughout the debate, citizens assembled as the Northern Larimer County Alliance have voiced public health and wildlife concerns about the proposed incinerator—including concerns that the prion agent might actually be spread through the air by the fixed-facility incineration process (de Yoanna, 2003a, 2003b; Olander & Brusca, 2002), a contention that is highly questionable in light of an existing UK risk assessment (Spouge & Comer, 1997b) and preliminary studies in the US demonstrating the low risk of TSE spread via fixed-facility incinerator emissions (Rau, 2003) (see section 7.2).

Based on the UK experience, moves to push for controversial disposal methods (e.g., fixed-facility incineration in Colorado) must include communication with local communities and stakeholders, something that was all too often neglected in the UK (Widdrington FMD Liaison Committee). At the same time, clear regulatory affirmation of technologies (e.g., fixed-facility incineration to manage TSEs) may also hedge against public concerns. In Larimer County, Colorado, officials are most interested in recent deliberations by Region 8 of the EPA; following meetings with laboratory diagnosticians, state veterinarians, and wastewater managers (O'Toole, 2003), EPA Region 8 is close to clearly endorsing fixed-facility incineration as a technology for managing CWD-infected carcasses (Anonymous, 2003c, p.4). According to Dr. Barb Powers of Colorado State University, more clear studies and regulatory rulings like these are needed to respond to attitudes, witnessed in Larimer County, that alkaline hydrolysis is the only way to deal with TSE-infected material (Powers, 2003).

Water-logged materials and carcasses

Carcasses are generally composed of 70 percent water; this places them in the worst combustible classification of waste (Brglez, 2003, p.32). This accentuates the need for fuel and dry burning materials. Experience gained in North Carolina in 1999 (following Hurricane Floyd) and Texas (following flooding in 1998) confirms the importance of having dry wood for incineration. Moist debris was used to burn carcasses in air-curtain incinerators, and the resultant poor air/fuel mixture produced noxious smoke and incomplete combustion (Ellis, 2001, p.30).

Section 2 – Historical Use

Throughout history, incineration has played an important role in carcass disposal. Advances in science and technology, increased awareness of public health, growing concerns about the environment, and evolving economic circumstances have all affected the application of incineration to carcass disposal. This section surveys the historical and current use of three broadly categorized incineration techniques: open-air burning, fixed-facility incineration, and air-curtain incineration.

2.1 – Open-Air Burning

Open-air carcass burning—including the burning of carcasses on combustible heaps known as pyres—dates back to biblical times. The Old Testament is replete with accounts of burning carcasses in the open, often following sacrificial offerings (e.g., Leviticus 4:11-12). Ancient Athens used open-air pyres to incinerate human plague victims (Brown, 1998, p.1146), and by the seventeenth century, European nation-states had begun to officially rely upon burning as a means of disposing of diseased livestock. In the late 1600s, Holland and Prussia blamed improper carcass disposal for the spread of livestock diseases, and soon after it became a crime punishable by death to neglect to burn or bury fallen stock (Committee on Agriculture, 1860, p.4). In Britain and in response to an outbreak of rinderpest there in 1714, Thomas Bates, fellow of the Royal Society and surgeon to King George I, advised the burning of all infected cattle carcasses (MAFF, 1965, pp.3-4). The British government heeded Bates' counsel that all infected cattle should be "bought, killed, and burnt," but casualty numbers soon overwhelmed open-air burning efforts, and burial became the preferred disposal method (Committee on Agriculture, 1860, pp.5-6).

As Britain discovered in 1714, open-air burning is resource intensive and often must be supplemented or substituted with other disposal methods. Three centuries later, little has changed: "burning tends to be difficult and expensive in terms of labor and materials," United States Department of Agriculture (USDA) officials have remarked (Smith et al., 2002, p.22). Nevertheless, open-air burning has persisted throughout history as a utilized method of carcass disposal. Animal health officials have traditionally hesitated to remove carcasses from farms for fear of disease spread; therefore, on-farm open-air burning, along with on-farm burial, has remained a commonly used disposal technique (Hamlen, 2002, p.18). On-farm pyre burning was used extensively in the 1967 and 2001 foot and mouth disease (FMD) outbreaks in the United Kingdom (UK) (NAO, 2002; Scudamore et al., 2002), in smaller-scale outbreaks of anthrax in Canada 1993 (Gates et al., 1995, p.258), and in other recent disposal situations. In southeast Missouri in 2001, extenuating circumstances required the open-air burning of cattle carcasses (Sifford, 2003). During the UK 2001 FMD outbreak, approximately 30 percent of six million carcasses were disposed of by open-air burning; these occurred on 950 sites, some of which featured mass pyres but most of which were smaller, on-farm burns (NAO, 2002, p.74).

2.2 – Fixed-Facility Incineration

In 1882 Francis Vacher, a medical officer of health working near Liverpool, England, complained that burial was an unreliable form of carcass disposal; years before, he had prosecuted a person who had exhumed a buried, diseased carcass to sell as human food. "There is but one efficient way of destroying diseased meat," he concluded, "and that is by cremation" (Vacher, 1882, p.8). The officer explained how he had recently done this with 59,280 pounds of condemned livestock—by cutting the carcasses into pieces and placing them in the retorts used to burn coal for the city's gas-works system (Vacher, 1882).

Vacher's description provides an historical example of fixed-facility incineration. Today, fixed-facility incineration is available in a variety of forms—as crematoria, small carcass incinerators at veterinary colleges, large waste incineration plants, on-farm carcass incinerators, and, not unlike Vacher's example, power plants.

During the 1970s, rising fuel prices reduced the popularity of fixed-facility incinerators, but technological improvements in efficiency soon followed (Wineland et al., 1997). Small animal carcass incinerators have been used to dispose of on-farm mortalities for years in both North America and Europe, and the pet crematoria industry has grown over time (Hofmann & Wilson, 2000).

Since the advent of bovine spongiform encephalopathy (BSE) in the UK, fixed-facility incineration has been used to dispose of BSE-infected carcasses as well as rendered meat-and-bone meal (MBM) and tallow from cattle carcasses considered to be at-risk of BSE (Herbert, 2001). Fixed-facility incineration facilities would have been used during the UK 2001 FMD outbreak, but they were rarely available because of being fully committed to BSE-related disposal efforts (Anderson, 2002, p.112; NAO, 2002, p.74). Fixed-facility incineration is now formally included at the top of the UK FMD contingency plan's disposal hierarchy (DEFRA, 2003c, p.40), and animal carcass incinerator plants are available for the disposal of whole carcasses of livestock for other disease situations—even for diseased seals that are washed up on the shore (DEFRA, 2002).

Outside of the UK, fixed-facility incineration has been combined with other carcass-disposal techniques. During the 2001 FMD outbreak in the Netherlands, diseased animals were first rendered and then the resultant MBM and tallow were taken to incineration plants (de Klerk, 2002). In Japan, cattle testing positive for BSE are disposed of by incineration (Anonymous, 2003d).

2.3 – Air-Curtain Incineration

Air-curtain incineration involves a machine that fan-forces a mass of air through a manifold, creating a turbulent environment in which incineration is greatly accelerated. Air-curtain technology may be used for carcass incineration in either a burn pit or a refractory box. Air-curtain incineration is a relatively new technology (Ellis, 2001, p.28). Its recent appearance on the carcass-disposal stage is evident in Virginia; air-curtain technology was not available to assist with a 1984 avian influenza (AI) outbreak in Virginia, but the technology was readily available to assist in disposing of turkey carcasses after AI returned to the state in 2002 (Brglez, 2003, p.18). Air-curtain incinerators have been used in the wake of natural disasters (e.g., in 1999 in North Carolina following Hurricane Floyd and in 1998 following flooding in Texas) (Ellis, 2001, pp.29-30). Imported air-curtain incinerators were used to a small degree during the UK 2001 FMD outbreak (G. Ford, 2003; NAO, 2002, p.74; Scudamore et al., 2002, p.777). Air-curtain incinerators have been used in Colorado and Montana to dispose of animals infected with chronic wasting disease (CWD) (APHIS, 2003, p.2707) and throughout the United States (US) in other livestock disasters (G. Ford, 2003).

Section 3 – Principles of Operation

Burning is a combustion process to which a range of measures may be applied to control emissions and ensure the completeness of combustion (SSC, 2003b, p.3). This section describes three combustion techniques. The first, open-air burning, is subject to few controls whereas the latter two, fixed-facility incineration and air-curtain incineration, can be generally contained and controlled.

3.1 – Open-Air Burning

How does it work?

Open-air burning includes burning carcasses (a) in open fields, (b) on combustible heaps called pyres (Dictionary.com, 2003), and (c) with other burning techniques that are unassisted by incineration equipment.

Who can do it?

Generally, one must have a state permit to open-air burn (APHIS, 2003, p.2707). From a personnel standpoint, leadership and decision-making skills are important because "the individual in charge of building the fire may have to use ingenuity in acquiring materials and putting them to optimal use" (Smith et al., 2002, p.23). As the UK learned, relevant leadership skills, decision-making ingenuity, and experience may be found in military units and waste-management contractors (NAO, 2002, pp.7, 66).

Where can it be done?

Open-air burning is not permitted in every state. For example, most hog-producing states generally allow for incineration of carcasses but specifically prohibit burning them in the open (Henry et al., 2001; Morrow et al., 2000, p.106). Nevertheless, it may be possible to waive state regulations such as these in a declared animal carcass disposal emergency (Ellis, 2001, p.27).

Open-air burning should be conducted as far away as possible from the public. For large pyres involving 1,000 or more bovine carcasses, a minimum distance of 3 kilometers (~2 miles) has been suggested in the UK (Scudamore et al., 2002, p.779). However, mass pyre burning has since been ruled out as an option in the UK; only small, on-farm open-air burning is allowed, and only as a last resort (DEFRA, 2003c, p.40). Based on the UK experience, an important site-selection rule is to first communicate with local communities about open-air burning intentions (Widdrington FMD Liaison Committee).

What is needed?

The US Animal and Plant Health Inspection Service (APHIS) has provided prescriptive directions for conducting an open-air burn (Smith et al., 2002, pp.22-27). The wide variety of material requirements associated with these directions are summarized in Table 2; all of these material requirements agree with pyre-construction procedures followed in the UK during 2001 (McDonald, 2001, p.6). Although diesel fuel is often used in open-air burning, other fuels have also been used or considered. These include turbo jet-B fuel, which was used in an open-air burn of anthrax-infected bison in northern Canada (Gates et al., 1995, p.258). Jet-B fuel is a mixture of naphtha and kerosene and is more difficult to handle (i.e., more flammable) than other jet fuels; however, jet-B's exceptional cold-weather performance makes it in high demand in very cold areas (CSG Network, 2004; Hildebrand, 2004). Other open-burning energy sources include powder metallic fuels (PMFs), which contain blends of metal powders (aluminum and magnesium) that interact well with water and have shown promise in raising the sustained temperatures in carcass-disposal experiments in the Czech Republic (Sobolev et al., 1999; Sobolev et al., 1997). Tires, rubber, and plastic should not be burned as they generate dark smoke (MAFF, 2001, p.36).

To promote clean combustion, it is advisable to dig a shallow pit with shallow trenches to provide a good supply of air for open-air burning. Kindling wood should be dry, have a low moisture content, and not come from green vegetation (MAFF, 2001, pp.36-37).

TABLE 2. Types and quantities of materials required for an open-air burn (McDonald, 2001; Smith et al., 2002, pp.24-26).

	Straw or hay	Untreated heavy timbers	Kindling wood	Coal	Liquid fuel (e.g., diesel fuel)
Per: 1 bovine carcass, 5 swine carcasses, or 5 sheep carcasses	3 bales	3 timbers, each 8ft (~2.5m) by 1ft sq (~0.3m sq)	50 lbs. (~23 kg)	500 lbs. in large clumps, 6-8 inches (~15-20 cm) in diameter	1 gallon (~4L)

Pre-developed contracts for materials and personnel are also critical to open-air burning. During the UK 2001 FMD outbreak, the organization of contractual agreements, management of contractors, and the urgent need for workers in a high-employment economy greatly complicated and delayed pyre-burning efforts. When poor-quality coal was supplied for the effort, personnel shortages made fire watching and tending inefficient (Scudamore et al., 2002), carcasses awaiting disposal eventually reached more than 200,000, and the military was called in to assist with the disposal effort (NAO, 2002, pp.7, 66).

How long does it take?

Open-air burning is the most lengthy of all incineration processes. The type of species burned influences the length of time; the greater the percentage of animal fat, the more efficient a carcass will burn (Brglez, 2003, p.32). Swine have a higher fat content than other species and will burn most quickly (Ellis, 2001, p.28).

What clean-up is necessary?

Open-air burning of carcasses yields a relatively benign waste—ash—that does not attract pests (Damron, 2002). However, the volume of ash generated by open-air burning can be significant. Depending on groundwater issues and the potential presence of transmissible spongiform encephalopathies (TSEs), ash-disposal options range from the inexpensive burying of ash on-site, as was done during the UK 1967 FMD outbreak, or the comparatively expensive transportation and disposal at landfills, as was done during the UK 2001 FMD outbreak. During the 2001 British experience, about 30 percent of six million animals were disposed of by pyre burning, and concerns about BSE residue in the ash required landfill disposal of ash. 120,000 metric tonnes were disposed of at an expense of £38 million (NAO, 2002, p.92).

Open-air burning poses additional clean-up challenges vis-à-vis groundwater and soil contamination caused by hydrocarbons used as fuel (Crane, 1997, p.3). In this way, clean-up of open-air burning may depend on the type of fuel used.

How much does it cost?

Although open-air burning has in fact been carried out in the past, precise information regarding cost is elusive. Nevertheless, one non-refereed analysis has approximated open-air pyre burning of cattle carcasses to cost $196 per ton of cattle carcasses (Cooper et al., 2003, pp. 30-31). This figure, however, does not take into account regulatory-compliance costs as well as public-perception problems, which in the UK during 2001 were tremendous for the tourism industry (see section 6.2). Ash disposal costs can also escalate out of control, depending on the situation. During the UK 2001 FMD outbreak, there were concerns about the on-farm burial of pyre-ash. Therefore, pyre-ash was disposed of at landfills at a cost of approximately £317 per tonne (NAO, 2002, p.92); converted into US dollars and US tons, this cost amounts to $527 per ton of ash (FT.com, 2004).

Based on the previous information, an "interval of approximation" for the cost of open-air burning is $196 to $723 per ton of carcass material.

Other considerations

All incineration processes, but especially open-air burning in windy areas, pose noteworthy fire hazards; the risk of fire must be addressed. Open-air burning also poses unique environmental and public-perception problems, which are further discussed in sections 5 and 6.2.

3.2 – Fixed-Facility Incineration

How does it work?

Fixed-facility incineration includes (a) small on-farm incinerators, (b) small and large incineration facilities, (c) crematoria, and (d) power plant incinerators. Unlike open-air burning and air-curtain incineration, fixed-facility incineration is wholly contained and, usually, highly controlled.

Typically fueled by diesel, natural gas, or propane, fixed-facility incinerators are, in essence, chambers in which the incineration process is contained. One report has described fixed-facility incineration of carcasses as a convection process in which carcass material is burned to ash in a controlled atmosphere (Sparks Companies, 2002, p.11). Newer designs of fixed-facility incinerators are fitted with afterburner chambers designed to completely burn hydrocarbon gases particulate matter (PM) exiting from the main combustion chamber (Rosenhaft, 1974). Incinerators have been used for years to incinerate both whole carcasses and carcass material.

Who can do it?

One can operate an incinerator if properly licensed, usually by a state government (APHIS, 2003, p.2707). Properly trained operators are absolutely critical. As one environmental scientist has found, afterburner-equipped incinerators that are poorly operated can actually emit more pollutants than non-afterburner-equipped incinerators that are carefully operated (Collings, 2002).

Where can it be done?

Small, fixed-facility incinerators may be operated on farms provided one has a permit, although there are increasing regulatory costs associated with maintaining this permit (see "How much does it cost?" below).

In the US, the idea of incinerating carcasses in large hazardous waste, municipal solid waste, and power plants has been suggested. While the acceptance of MBM and tallow from rendered carcasses could be accommodated in the US, large-scale whole-carcass disposal would be problematic given the batch-feed requirements at most biological waste incineration plants (Anonymous, 2003f; Heller, 2003). Many waste incineration facilities simply refuse to accept dead animals, noting that carcasses are 70 percent water and preferred waste is 25 percent water (Thacker, 2003). The possibilities of combining incineration with rendering products (i.e., MBM and tallow) are more promising and should be explored (see section 7.1).

What is needed?

In addition to the incinerator itself, fuel is more important. Fixed-facility incinerators are often powered by diesel, natural gas, or propane (Sparks Companies, 2002, p.11).

How long does it take?

The type of species greatly influences the speed at which carcasses are incinerated; the greater the percentage of animal fat, the more efficient the carcass will burn (Brglez, 2003, p.32). Swine, which have a comparatively high fat content, burn more quickly (as short as two hours for a hog) than do other species (Ellis, 2001, p.28; Walawender, 2003). The throughput of fixed-facility incinerators depends on the chamber's size. For small animal carcass incinerators, the kinds of which may be used on farms for fallen stock, the throughput may reach only 110 lbs (50 kg) per hour (Anonymous, 2003e). Conversely, larger facilities dedicated to the incineration of animal remains may be able to accommodate larger numbers. In Australia, for example, one public incinerator is prepared to accept, during times of emergency, 10 tonnes of poultry carcasses per day (Western Australia Department of Agriculture, 2002, p.7). In the US, fixed-facility capacity is generally recognized to not be of an order capable of handling large numbers of whole carcasses (Ellis, 2001).

What clean-up is necessary?

Most incinerators are fitted with afterburners that further reduce emissions by burning the smoke exiting the primary incineration chamber (Walawender, 2003). Compared to open-air burning, clean-up of ash is less problematic with fixed-facility incineration; ash is typically considered safe and may be disposed of in landfills (Ahlvers, 2003). However, if residual TSE infectivity is of concern, burial may not be suitable (see sections 4.2 and 7.2).

How much does it cost?

Fixed-facility incinerators offer a tremendously biosecure disposal option, but they are expensive. A 500-pound incinerator costs $3000 and will last for approximately four years (Sander et al., 2002). However, fixed-facility incinerators of all sizes are being closed down on account of increasing regulatory-compliance and inspection costs. In

Missouri, for example, the annual cost of maintaining a permit for a small, on-farm incinerator has reached $2000, a cost which has resulted in a "rapid phase-out of farm incinerators" (Morrow et al., 2000, p.106). For larger facility incinerators, the experience is the same. At colleges of veterinary medicine, new inspection requirements anticipated to cost $20,000 per year have led to the phasing out of incinerators (Ahlvers, 2003). Increasing regulatory cost requirements have also led to a significant reduction in the number of US plants capable of incinerating medical and hazardous waste (Heller, 2003).

Larger, fixed-facility incineration has been approximated at $460-$2000 per ton of carcass material in the US (Waste Reduction by Waste Reduction Inc.). This interval captures a forecasted during-emergency price at an Australian fixed-facility incinerator; converted into US dollars and US tons, emergency disposal of poultry carcasses would cost $1531 per ton (FT.com, 2004; Western Australia Department of Agriculture, 2002, p.7). For smaller (e.g., 500-pound-capacity) incinerators processing swine, costs are lower but depend on whether or not an afterburner is attached; costs range from $98 per ton of carcasses (incinerator without afterburner) to $146 (incinerator with afterburner) (Henry et al., 2001). For these smaller fixed-facility incinerators, costs for cattle would be slightly higher due to the need for pre-incineration processing (i.e., cutting into smaller pieces) of carcasses larger than 500 pounds (Sparks Companies, 2002, pp. v, 11).

Fixed-facility incineration costs are quite variable and may significantly vary as (a) incineration is combined with other disposal technologies and (b) governmental intervention is taken to manage waste (see section 7.1).

Based on the previous information, an "interval of approximation" for the cost of fixed-facility incineration is $98 to $2000 per ton of carcass material.

Other considerations

Fixed-facility incineration has been validated for the destruction of TSE disease agents (see section 4.2), poses environmental issues that may be best addressed by large incineration plants (see section 5.1), and has been the subject of public-perception concerns (see section 6.2). Although more controlled than open-air burning, fixed-facility incineration poses a fire hazard.

Several countries have combined rendering with fixed-facility incineration. In the Netherlands, this combination was used as incinerators were employed to dispose of MBM and tallow from rendered carcasses associated with the 2001 FMD outbreak (de Klerk, 2002, p.793). Rendering-incineration combinations have also been used to help manage the TSE situation in the UK and continental Europe (see section 7.1).

3.3 – Air-Curtain Incineration

How does it work?

Air-curtain incineration involves a machine that fan-forces a mass of air through a manifold, thereby creating a turbulent environment in which incineration is greatly accelerated—up to six times faster than open-air burning (W.B. Ford, 1994, p.3). Air-curtain incineration is suitable for not only carcasses but also other waste material (McPherson Systems Inc., 2003; Scudamore et al., 2002, p.779; Smith et al., 2002, p.27). Large-capacity fans driven by diesel engines deliver the high-velocity air down into either a metal refractory box or burn pit (trench). Air-curtain systems vary in size according to the amount of carcasses to be incinerated (Ellis, 2001, p.29). Air-curtain equipment can be made mobile.

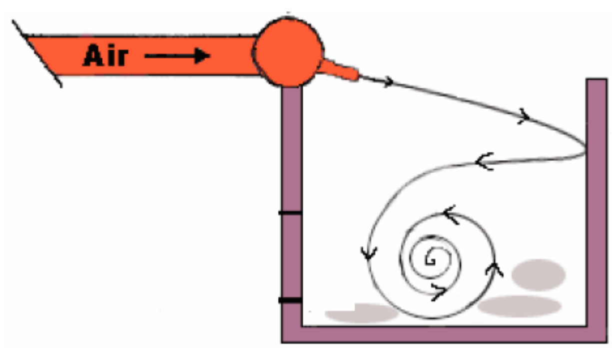

FIGURE 1. Depiction of air-curtain incineration technology, adapted from slide no. 9, entitled "Air Burners LLC: Principles of Operation," in Ford (2003).

Who can do it?

There are several companies that manufacture air-curtain incinerators. One of these, Air Burners LLC, manufactures equipment in Florida and has been involved in several emergency carcass disposals—from swine disposal in Texas to CWD-infected elk disposal in Colorado to disposal work for the Florida Department of Agriculture (G. Ford, 2003). Air-curtain equipment—whether manufactured by Air Burners or other firms such as McPherson Systems (McPherson Systems Inc., 2003)—is often operated by secondary contractors, such as Dragon Trenchburning or Phillips and Jordan (Smith et al., 2002, p.28).

Where can it be done?

Air-curtain incinerators have been used all over the US and around the world and met regulatory approval (G. Ford, 2003). According to an APHIS environmental assessment, air-curtain incinerators do produce a fair amount of noise, but if placed away from residential centers and the general public they are generally not nuisances (APHIS, 2002, p.11).

What is needed?

Materials needed for air-curtain incineration include wood (preferably pallets in a wood-to-carcass ratio varying between 1:1 and 2:1), fuel (e.g., diesel fuel) for both the fire and the air-curtain fan, and properly trained personnel (G. Ford, 2003; McPherson Systems Inc., 2003). For an incident involving the air-curtain incineration of 500 adult swine, 30 cords of wood and 200 gallons of diesel fuel were used (Ellis, 2001, p.29). Dry wood for fuel is critical to ensuring a proper air/fuel mixture (Ellis, 2001, p.30).

How long does it take?

Speed of throughput depends on the manufacturer, design, and management of the air-curtain system. The type of species also influences the throughput; the greater the percentage of animal fat, the more efficient a carcass will burn (Brglez, 2003, p.32). Swine carcasses, for example, have a higher fat content and burn more quickly than other species (Ellis, 2001, p.28).

One manufacturer of air-curtain technology reports that, using its larger refractory box, six tons of carcasses may be burned per hour (G. Ford, 2003). Using a burn pit, and a 35-foot-long air-curtain manifold, up to four tons of carcasses may be burned per hour (W.B. Ford, 1994, pp.2, 11). Air-curtain incinerators have been shown to efficiently burn 37.5 tons of carcasses per day (150 elk, weighing an average of 500 pounds each) (APHIS, 2002, p.11).

What clean-up is necessary?

Air-curtain incineration, like other combustion processes, yields ash. From an ash-disposal standpoint, air-curtain incineration in pits is advantageous if the ash may be left and buried in the pits (Smith et al., 2002, p.27). However, in sensitive groundwater areas—or if burning TSE-infected carcasses—ash will most likely be disposed of in licensed landfills.

How much does it cost?

Cost information for air-curtain incineration varies and depends on variables such as species type, fuel costs, and ash disposal. Cost reports (the first of which excludes "cross-cutting" costs related to decontamination and transportation) range from $143 to $471 to $506 per ton of carcass material (Brglez, 2003, p. 86; W.B. Ford, 1994; Jordan, 2003).

Based on the previous information, an "interval of approximation" for the cost of air-curtain incineration is $143 to $506 per ton of carcass material.

Other considerations

Unlike fixed-facility incineration, air-curtain incineration is not wholly contained and is at the mercy of many variable factors (e.g., human operation, the weather, local community preferences, etc.). In past disposal incidents involving air-curtain incineration, a process of trial-and-error has been necessary to deal with problems. An excellent example of trial-and-error occurred during the 2002 AI-related disposal effort in Virginia:

> After burning several tons of [poultry] carcasses at an extremely slow rate, it was quickly determined that wood from the

> landfill was not a good fuel source due to its high moisture content. The boxes are specially designed with electric fans to blow air onto wood to make the wood burn faster and also smokeless...However, due to the high content of moisture, the birds created a terrible stench that could be smelled miles away. People living nearby had to be moved into hotels. It was determined by trial and error that the best method of burning the carcasses was by layering the birds on top of wood pallets. This allowed sufficient air circulation to burn the birds efficiently. Thus, a combination of forest wood and pallets were used. The only drawback in using pallets was the nails that remained in the ash. The nails were required to be removed...when the ash was to be re-applied to land as a rich source of nutrients.
>
> (Brglez, 2003, pp.34-35)

Indeed, trial-and-error (and on-the-spot ingenuity!) is often necessary when using air-curtain incinerators in the field.

Like open-air burning and fixed-facility incineration, air-curtain incineration poses a fire hazard and the requisite precautions should always be taken. There are environmental and disease-agent considerations regarding air-curtain incineration; these are elaborated in sections 4.2, 5.1, and 7.2.

Section 4 – Disease Agent Considerations

This section considers separately conventional pathogens (bacteria, viruses, and spores) and TSE disease agents.

4.1 – Conventional Pathogens

Viruses and non-spore-forming bacteria

Bacteria and viruses are both generally temperature susceptible and cannot survive normal burning temperatures. However, FMD, a highly contagious viral disease, may be spread via airborne pathways. The virus is generally resistant to background environmental factors (e.g., air and sunlight) and can spread through the air (Donaldson & Ferris, 1975), as it did within the UK during the 2001 FMD outbreak (J. Gloster et al., 2003) and between Brittany, France, and the Isle of Wight, UK, in 1981 (Anderson, 2002, p.40). Other aspects of FMD spread, including dust- and bird-mediated transport of the virus from continental Europe to the UK on various occasions between 1965 and 1967, have been reported as well (Hurst, 1968). Curiosity about FMD's contagiousness continues to spread, and some have argued that pyre (open-air) burning efforts during the UK 2001 FMD outbreak actually helped spread the virus. This question has been examined thoroughly; and while the theoretical possibility cannot be eliminated, there is no evidence that open-air burning or air-curtain incineration contributed to virus spread (Champion et al., 2002; J. Gloster et al., 2001).

Spore-forming bacteria

Carcasses infected with spore-forming bacteria, such as *Bacillus anthracis* (the causative organism of anthrax), should be thoroughly incinerated (Everett, 2003). If not properly incinerated, the spores can persist in the environment for months, even years, and communicate disease to other animals, even humans (Anonymous, 2003a). If burning anthrax-infected carcasses is not immediately possible, a substitutional measure of protection may be taken by not cutting open the carcasses; normal, anaerobic decomposition processes prevent sporulation of this oxygen-requiring bacteria (Everett, 2003), and bacteria in their vegetative form are very unlikely to survive (Turnbull, 2001, p.29).

4.2 – TSE Disease Agents

Durability of TSE disease agents

The disease agents responsible for TSEs (e.g., scrapie, BSE, and CWD) are highly durable (Brown, 1998). For example, scientists have demonstrated the persistent infectivity of the scrapie agent in soil, and healthy sheep have contracted scrapie after grazing on land that had served, three years earlier, as pasture for scrapie-infected sheep (Brown & Gajdusek, 1991). While incineration is used to dispose of TSE-infected animals, including scrapie-infected sheep and goats, (EU, 2003, p.7) the disease agents responsible for TSEs (i.e., prions) are extremely heat resistant. This raises important questions about incineration's suitability for disposing of TSE-infected—or potentially TSE-infected—carcasses.

One study subjected the scrapie agent to varying time and temperature combinations—5 to 15 minutes at 150 to 1000°C (302 to 1832°F). Temperatures of 600°C (1112°F) completely ashed the samples, but some infectivity remained (Brown et al., 2000). The UK Spongiform Encephalopathy Advisory Committee (SEAC) has recently affirmed its belief that the risk of infectivity from ash would be extremely small if incineration was conducted at 850°C (1562°F) (SEAC, 2003), and the European Commission Scientific Steering Committee (SSC) recognizes the same temperature as a standard for disposing of TSE-infected material (SSC, 2003a).

Open-air burning

World-renowned TSE expert Dr. David Taylor explains that open-air burning is imprecise and not normally a legitimate TSE-related disposal option because of doubts it can completely destroy TSE infectivity (Taylor, 2001). For similar reasons, the European Commission SSC argues that fixed-facility incineration is preferred to open-air burning:

> There is no reliable data to indicate the extent of risk reduction that could be achieved by open burning. It is reasonable however to assume that overall it will be rather less effective in reducing the infectivity of BSE/TSE than well-conducted incineration. Moreover the reproducibility of the risk reduction is likely to be very variable even at a single location.
>
> (SSC, 2003b, p.4)

For now, open-air burning of TSE-infected carcasses should be prohibited. For exceptional cases in which open-air burning might include TSE-incubating carcasses (e.g., in the UK during 2001, when open-air burning of FMD-infected carcasses likely included some sheep and cattle incubating scrapie and BSE), studies conclude that the risk of TSE spread is acceptably low ($7x10^{-7}$) (Taylor, 2001, citing a risk assessment report by DNV Technica). It should also be noted that open-air burning temperatures have been greatly enhanced through the use of PMFs (see section 3.1). In the Czech Republic, for example, PMFs have been used to reach temperatures (1200-1400°C, or 2192-2552°F) capable of destroying TSE agents (Sobolev et al., 1999; Sobolev et al., 1997). While promising, environmental questions remain, and studies clearly validating PMF-assisted destruction of the TSE agent are needed (see section 7.3).

Fixed-facility incineration

Unlike open-air burning, fixed-facility incineration is highly controlled, lends itself to validation for reaching the requisite (850°C or 1562°F) TSE-destruction temperature, and is a reliable method for dealing with TSE-infected carcasses. While alkaline-hydrolysis digestion has been widely reported to be the most robust method for dealing with TSEs (Grady, 2004), this is not entirely accurate. Both fixed-facility incineration and alkaline hydrolysis may be used to dispose of TSE-infected material (Powers, 2003).

As discussed further in section 7.1, combinations of fixed-facility incineration and rendering have been used to manage risk in European countries that have been home to BSE. Although all animals confirmed to be TSE-infected are disposed of in fixed-facility incinerators, other "at-risk" animals and material have been disposed of by using a combination of rendering and incineration. These include carcasses or parts of carcasses suspected of TSE infection, animals that have died on the farm (fallen stock), and, in the UK, animals older than 30 months (DEFRA, 2003b; Herbert, 2001). The UK's Over Thirty Months Scheme (OTMS) is a precautionary policy requiring the removal from the food chain and destruction of cattle aged over 30 months, an age above which it is thought animals are at greater risk of developing BSE (MAFF, 1996). Under the OTMS, carcasses are rendered and, at a great cost to the UK government, the resultant MBM and tallow is stored and then disposed of in fixed-facility incinerators. At several of the incineration plants, including one waste-management incinerator that was the subject of an interview, energy is recovered from the MBM and tallow and an EU subsidy is received (Anonymous, 2003g; Hilliard, 2003; Scottish Parliament, 2002; Shanks, 2001).

Air-curtain incineration

Air-curtain incinerators reportedly achieve higher temperatures than open-air burning, and may reach 1600°F (~871°C) (G. Ford, 2003; McPherson Systems Inc., 2003). Such claims, particularly as they relate to reaching the requisite (850°C or 1562°F) TSE-destruction temperature, need to be further substantiated (Scudamore et al., 2002, p.779). Noting that "with wet wastes, such as CWD-contaminated carcasses, temperatures...can fluctuate and dip below recommended temperatures," an Environmental Protection Agency (EPA) Region 8 draft document hesitates to endorse air-curtain incineration as a robust method for dealing with CWD (Anonymous, 2003c, p.4). In the UK, the Department for Environment, Food and Rural Affairs (DEFRA) has conducted experiments to elucidate the temperatures reached during air-curtain incineration in fireboxes; but despite efforts that included the placement of temperature probes in the carcass mass, researchers could confirm only a range of attained temperatures (600-1000°C, or 1112-1832°F). This information may be a useful guide, but further studies to confirm the temperatures reached are needed (Hickman, 2003).

Section 5 – Environmental Implications

5.1 – Air Pollution

Open-air burning, poorly managed fixed-facility incineration, and poorly managed air-curtain incineration all pose legitimate pollution concerns.

It is generally accepted that open-air burning poses pollution problems (Anonymous, 2003b). The nature of open-air emissions hinges on many factors, including fuel type. Both real and perceived environmental risks of open-air burning were the subjects of studies and complaints during the UK 2001 FMD outbreak. In the Dumfries and Galloway region of Scotland, environmental monitoring of open-air pyre burning focused on dioxins, furans, polyaromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), metals, nitrogen oxides, sulphur dioxide, carbon monoxide, carbon dioxide, organic gases, and PM—especially PM less than 10 micrometers in diameter that can be drawn into the lungs (McDonald, 2001). Elsewhere in the UK, in Cumbria, 130 pyres were used to dispose of carcasses, and officials there noted that open-air burning—particularly with slowly burning pyres—emanated an offensive, "acrid smoke" (Cumbria Foot and Mouth Disease Inquiry Panel, 2002, p.75). According to the Food and Agricultural Organization (FAO) of the United Nations, the first six weeks of the UK pyre-burning campaign involved the release of dioxins in an amount equal to 18 percent of the UK's annual emissions (Brough, 2002). The fear of dioxins and smoke inhalation, along with the generally poor public perception of pyres, eventually compelled the discontinuation of the use of mass burn sites at Arscott Farm in Devon, three sites in Scotland, Eppynt in Wales, Catterick in Yorkshire, and Hemscott Hill in County Durham (Scudamore et al., 2002, p.777-779). As it turned out, pollution levels associated with pyre-burning never exceed levels in other (urban) parts of the UK, did not violate air quality regulations, and were deemed to have not unduly affected the public health (Cumbria Foot and Mouth Disease Inquiry Panel, 2002, p.76; Hankin &

McRae, 2001, p.5; McDonald, 2001; UK Department of Health, 2001a, 2001b).

In contrast to open-air burning, properly operated fixed-facility and air-curtain incineration significantly reduce pollution concerns. During the UK 2001 FMD outbreak, air-curtain incinerators provided by Air Burners LLC offered environmental advantages over open-air burning. In Devon, where the sky had previously been clouded with smoke from mass pyres, air-curtain incinerators were praised for providing complete combustion and reduced air emissions (G. Ford, 2003). Nevertheless, it should be noted that air-curtain incinerators can pose a pollution threat if the air curtain is broken (Anonymous, 2003c, p.4). Air-curtain technology in general has been shown to cause little pollution, but fireboxes burn cleaner than do trench-burners (G. Ford, 2003). When compared to open-burning, air-curtain incineration is superior, with higher combustion efficiencies, less carbon monoxide emissions and PM (G. Ford, 2003). Individuals within the UK government, who have conducted testing on air-curtain fireboxes, are indeed satisfied with this technology's combustion efficiency (Hickman, 2003).

If operated in accordance with best practices and existing environmental regulations, both small and large afterburner-equipped incinerators should not pose serious problems for the environment (Crane, 1997, p.3). However, if not operated properly, small animal carcass incinerators have the potential to pollute. Therefore, it may be environmentally worthwhile to send carcasses to larger, centralized, and better managed incineration facilities (Collings, 2002).

5.2 – Groundwater and Soil Pollution

During the UK 2001 FMD outbreak, Scotland was unique in that it burned, mostly through open-air burning on farms, over 98 percent of its carcasses. This was done primarily because burial was more environmentally problematic given the thin soils and vulnerable aquifers in the Dumfries and Galloway region primarily affected by the outbreak (NAO, 2002, p.124). Researchers in the US agree that incineration is a legitimate alternative when factors related to hydrology (e.g., a high water table) or geology (e.g., soils of high permeability) rule out burial (Damron, 2002).

Unfortunately, however, open-air burning itself poses problems for groundwater contamination, primarily in the form of the hydrocarbons used as fuel (Crane, 1997, p.3). Dioxins and PCBs, both of which are known to emanate from pyres, are also of soil- and food-pollution concern; but the UK Food Standards Agency confirmed that levels of these two pollutants, with a few exceptions, were within normal range throughout the 2001 pyre-burning campaign and "that no significant harm was expected from food produced near pyres" (Cumbria Foot and Mouth Disease Inquiry Panel, 2002, p.76). Nevertheless, the general risks that incineration, particularly open-air burning, pose to groundwater and the soil are real and should always be minimized.

Section 6 – Advantages, Disadvantages, & Lessons Learned

It is important to take stock of past experiences, but it is more important to actually learn from that stock-taking. One of the observations made in the wake of the UK 2001 FMD outbreak was the failure to have learned from the past; for example, a 1968 conclusion that burial was preferable to on-farm burning was not immediately heeded in 2001 (Anderson, 2002, pp.23-24). As the US joins Canada, Australia, New Zealand, and other nations in revising its animal disease management contingency plans (NAO, 2002, p.27), hopefully it can genuinely learn from the past and the comparative advantages and disadvantages of the various disposal methods.

6.1 – Advantages and Disadvantages

Dr. Dee Ellis of the Texas Animal Health Commission has conducted an in-depth review of the advantages and disadvantages, based on recent US and international experience, of carcass disposal methods. Some of Ellis' comments regarding incineration are summarized below.

Open-air burning

Open-air burning can be relatively inexpensive, but it is not suitable for managing TSE-infected carcasses. Significant disadvantages include its labor- and fuel-intensive nature, dependence on favorable weather conditions, environmental problems, and poor public perception (Ellis, 2001, p.76).

Fixed-facility incineration

Fixed-facility incineration is capable of thoroughly destroying TSE-infected carcasses, and it is highly biosecure. However, fixed-facility incinerators are expensive and difficult to operate and manage from a regulatory perspective. Most on-farm and veterinary-college incinerators are incapable of handling large volumes of carcasses that typify most carcass disposal emergencies. Meanwhile, larger industrial facility incinerators are difficult to access and may not be configured to handle carcasses (Ellis, 2001, p.28).

Air-curtain incineration

Air-curtain incineration is mobile, usually environmentally sound, and suitable for combination with debris removal (e.g., in the wake of a hurricane). However, air-curtain incinerators are fuel-intensive and logistically challenging (Ellis, 2001, p.76). Currently, air-curtain incinerators are not validated to safely dispose of TSE-infected carcasses.

6.2 – Lessons Learned

Open-air burning to be avoided

Open-air burning can pose significant public perception, psychological, and economic problems. During the UK 2001 FMD outbreak, carcasses burning on mass pyres "generated negative images in the media" and "had profound effects on the tourist industry" (NAO, 2002, pp.7, 74). In 2001, on-farm pyre burning sent smoke flumes into the air and contributed to an environment of despair for the UK farming community (Battista et al., 2002). The following statement illustrates the problematic nature of one mass pyre site:

> The greatest palpable impact came from the mass pyre at Hemscott Hill. This produced thick smoke, much of which blew inland over the houses nearby and the settlements up to several miles away, carrying with it a foul stench. This forced people to shut their windows and stay indoors. For some households, this became so unbearable that they moved away from the area for some weeks, assisted in some cases by MAFF.
>
> (Northumberland FMD Inquiry Panel, 2002, p.104)

Largely because of problems of public perception, open-air burning was stopped on 7 May 2001 (NAO, 2002, p.74) and quickly followed by the recommendation that mass pyres not be used again for carcass disposal (Anderson, 2002, pp.17, 108). Although small, on-farm open-air burning has not entirely been ruled out in the UK, open-air burning on a mass scale has in fact been ruled out in future FMD contingency planning (DEFRA, 2003c, p.40). Conversely, fixed-facility incineration remains a viable option. While fixed-facility incineration was not used during the UK 2001 FMD outbreak, revised contingency plans now prefer the use of such incineration during the early stages of such an outbreak (DEFRA, 2003c, p.40; NAO, 2002, p.74). Contracts between the UK government and nine animal carcass incinerators are currently being negotiated (DEFRA, 2003c, pp.40-41). If open-air burning must be conducted, it is important to select sites out of the public view, taking into account the prevailing winds (Ellis, 2001, p.28).

Personnel and professional development

Past emergency carcass disposal events have revealed the need for readily available logistical expertise, leadership, and managerial skills (Anderson, 2002, p.82). Indeed, professional development is important. Simulation exercises are key components of preparing for carcass disposal. However, training itself is not enough, as the UK National Audit Office (NAO) has reported regarding training efforts conducted within the UK State Veterinary Service:

> Generally, however, the exercises were seen as helpful in reinforcing theoretical training, though they could not simulate fully the pressures that would exist in a real situation or the long-term commitment that would be needed.
>
> (NAO, 2002, p.41)

From this observation, US federal, state, and local officials responsible for carcass disposal should seek out opportunities to participate in real-life emergencies that can be anticipated ahead of time (e.g., 2003's Hurricane Isabel). The extra personnel would, of course, offer assistance that is valuable in and of itself; but equally importantly, the extra personnel would learn about carcass disposal in a real-life, pressure-filled context.

In addition, and parallel to a recommendation made in the UK (Anderson, 2002, p.82), a bank of volunteers should be available in the event that labor is in short supply to manage mass carcass disposal events, including those involving incineration.

The "digester vs. incinerator" debate

One of the great questions facing US animal disease officials is whether to use alkaline-hydrolysis digestion or fixed-facility incineration to dispose of TSE-infected animals. While high-temperature, fixed-facility incineration may be as effective as alkaline hydrolysis in destroying the prion agent, it is nonetheless laden with unique public-perception problems. This has been evident in recent debates in Larimer County, Colorado, where state wildlife officials have been pushing for the construction of a fixed-facility incinerator to dispose of the heads of CWD-infected deer and elk. While incinerators exist in other parts of the state (e.g., Craig, Colorado), a new incinerator is needed to deal specifically with populations in northeastern Colorado, where there is a high prevalence of CWD among gaming populations.

Despite the need, Larimer County commissioners have heeded local, anti-incinerator sentiments and have, for now, successfully blocked approval of the incinerator. Meanwhile, an alkaline-hydrolysis digester at Colorado State University has generated fewer concerns. Throughout the debate, citizens assembled as the Northern Larimer County Alliance have voiced public health and wildlife concerns about the proposed incinerator—including concerns that the prion agent might actually be spread through the air by the fixed-facility incineration process (de Yoanna, 2003a, 2003b; Olander & Brusca, 2002), a contention that is highly questionable in light of an existing UK risk assessment (Spouge & Comer, 1997b) and preliminary studies in the US demonstrating the low risk of TSE spread via fixed-facility incinerator emissions (Rau, 2003) (see section 7.2).

Based on the UK experience, moves to push for controversial disposal methods (e.g., fixed-facility incineration in Colorado) must include communication with local communities and stakeholders, something that was all too often neglected in the UK (Widdrington FMD Liaison Committee). At the same time, clear regulatory affirmation of technologies (e.g., fixed-facility incineration to manage TSEs) may also hedge against public concerns. In Larimer County, Colorado, officials are most interested in recent deliberations by Region 8 of the EPA; following meetings with laboratory diagnosticians, state veterinarians, and wastewater managers (O'Toole, 2003), EPA Region 8 is close to clearly endorsing fixed-facility incineration as a technology for managing CWD-infected carcasses (Anonymous, 2003c, p.4). According to Dr. Barb Powers of Colorado State University, more clear studies and regulatory rulings like these are needed to respond to attitudes, witnessed in Larimer County, that alkaline hydrolysis is the only way to deal with TSE-infected material (Powers, 2003).

Water-logged materials and carcasses

Carcasses are generally composed of 70 percent water; this places them in the worst combustible classification of waste (Brglez, 2003, p.32). This accentuates the need for fuel and dry burning materials. Experience gained in North Carolina in 1999 (following Hurricane Floyd) and Texas (following flooding in 1998) confirms the importance of having dry wood for incineration. Moist debris was used to burn carcasses in air-curtain incinerators, and the resultant poor air/fuel mixture produced noxious smoke and incomplete combustion (Ellis, 2001, p.30).

Section 7 – Critical Research Needs

7.1 – BSE-Related Disposal Involving Incineration

The December 2003 discovery of BSE in the US has spawned additional questions about carcass disposal and the role incineration might play.

In a January 2004 technical briefing on the BSE situation, USDA officials explained that they do not plan to use alkaline hydrolysis or incineration to dispose of young (less than 30 months) cattle associated with the Washington state BSE case; USDA's decision is being taken in light of science indicating that one cannot generally detect TSE infectivity in cattle less than 30 months of age (USDA, 2004). However, should the BSE situation in North America deteriorate, the US may need to consider precautionary (or public-perception preservation) culls of large numbers of cattle, both young and old. Although BSE-infected animals would have to be directly disposed of (presumably, by alkaline hydrolysis or fixed-facility incineration), "at-risk" animals (e.g., fallen stock, downer cattle, or members of BSE-infected herds) and specified risk materials (i.e., skull, brain, trigeminal ganglia, eyes, vertebral column, spinal cord, and dorsal root ganglia of cattle 30 months of age or older and the small intestine of all cattle) might be disposed of by combinations that include incineration. Such a scenario is not far-fetched or unthinkable; this is precisely what has been done in the UK and continental Europe, where at-risk cattle (e.g., in the UK, cattle over 30 months) have been rendered, with the resultant MBM and tallow incinerated. Significantly, USDA-APHIS publications citing the Harvard Center for Risk Analysis have asked for input on how to best dispose of at-risk animals should the US ever find a domestic case of BSE (APHIS, 2003), which has now occurred and has led to the quick promulgation of regulations prohibiting downer cattle and specified risk materials from the food supply (FSIS, 2004).

Taking a cue from the UK and continental Europe, one approach to disposing of at-risk carcasses and specified risk materials is to combine rendering with incineration. In the US, rendering plants have a capacity to reduce TSE infectivity by as much as 99.9 percent (APHIS, 2003); but, as Europe has learned, storage and incineration of rendered MBM and tallow would be required to ensure complete destruction of any potential TSE infectivity. In Europe, and as section 4.2 alluded, the situation has been managed by the introduction of a subsidy program rewarding incineration plants for recovering energy from the MBM and tallow (Anonymous, 2003g; Hilliard, 2003; Scottish Parliament, 2002; Shanks, 2001). The program has been shown to pose an insignificant risk to the public health (Spouge & Comer, 1997a).

USDA-APHIS should commission research to identify what kinds of government-intervention policy options might be appropriate for sustaining combination strategies, including a rendering-incineration strategy, for dealing with TSE situations (both BSE and CWD). The US EPA already has placed a high priority on waste combustion with energy recovery (EPA Office of Solid Waste and Emergency Response, 2002, p.11), and some private companies (e.g., Smithfield pig farms in North

Carolina) are experimenting with the use of biomaterial waste for electricity production (Anonymous, 2001). Animal fats have an energy value of 17,000 British Thermal Units per pound; rendering plants can re-sell them as fuel (Brglez, 2003, p.32). In the UK, EU subsidies have been central to the success of disposing of cattle deemed to be "at-risk" of TSEs (DEFRA, 2003a; Hilliard, 2003), and research should be conducted to ascertain if a similar program might ever be workable, or even necessary, in the US. Leaders of the rendering industry have signaled an interest in helping manage TSE-related disposal; however, there are significant policy hurdles (e.g., no clear, validated, government-endorsed "clean-out" procedures) and economic barriers (e.g., customers refusing to accept rendered products from plants that participate in TSE-related disposal) (Hamilton, 2003). If these hurdles were overcome, perhaps by government intervention, rendering plants could contribute the first phase of a robust rendering-incineration TSE management plan. Fixed-facility waste-incineration plants in the US are generally not well suited to take whole carcasses, but they are quite capable of taking homogenous material, such as MBM and tallow yielded from rendering plants (Anonymous, 2003f).

This is a critical research area for USDA as it contemplates how to deal with the reality of disposing of at-risk-of-TSE animals and specified risk materials. Already, USDA has suggested combining air-curtain incineration with alkaline-hydrolysis digestion. The suggestion includes separately disposing of the carcasses (in air-curtain incinerators) and the high-risk head tissues (in alkaline hydrolysis) (APHIS, 2002, pp.11-12). As USDA continues to evaluate how to combine disposal technologies, rendering-incineration combinations should be considered.

7.2 – Other TSE-Related Issues

For both the US and Europe, it would be helpful to have information on the potential for post-incineration airborne dispersal of heat stable disease agents, namely those responsible for TSEs. Although highly questionable in light of existing risk assessments (Spouge & Comer, 1997b), the TSE risks posed by incinerator emissions have nonetheless been raised in recent debates regarding CWD (in Larimer County, Colorado; see section 6.2). Recently, the Food and Drug Administration (FDA) Transmissible Spongiform Encephalopathies Advisory Committee (TSEAC) met to discuss the TSE risks posed by air emissions arising from the incineration of scrapie tissue. During this meeting, preliminary research conducted by TSE experts Paul Brown and Edward Rau were presented; although preliminary and not yet published, their research found no TSE infectivity in air emission samples arising from incinerated scrapie-infected brain tissue (Rau, 2003).

Research is also needed to ascertain how to improve the efficacy of the combustion process to ensure the inactivation of heat-resistant disease agents in carcass waste (SSC, 2003b, p.4). Research cited in this report has begun to look at PMFs as a way to enhance the temperatures reached in open-air burning and air-curtain incineration. As already mentioned (see section 4.2), testing has begun in the UK (at DEFRA) to discern whether or not air-curtain incinerators can in fact attain temperatures capable of inactivating TSE agents. Future research in this area might be coordinated transatlantically, with the research staff at DEFRA.

With respect to TSE risks posed by ash, the European Commission SSC urges research "to identify the residual risks…from the burial of ash…in uncontained sites" (SSC, 2003c, p.8).

7.3 – Validation Studies on Open-Air Burning

Even in the UK and continental Europe, it is recognized that open-air burning may need to be used, albeit as a last resort. For example, the revised UK FMD contingency plans rules out mass pyres but stops short of banning smaller, on-farm pyres, which might become necessary in future emergencies (DEFRA, 2003c, p.40). Validated protocols for safe burning in emergency situations need to be established (SSC, 2003b, p.2). Such protocols would, presumably, take into account much of the best-practices described in section 3.1. Researchers have looked at PMFs as a way to enhance the temperatures reached in open-air burning; perhaps these fuels could be included in the validation studies. Similarly, researchers should investigate broadening the use of highly flammable fuels (e.g., jet-B fuel) hitherto used only in cold climates. Research in this area would be of value to regulatory bodies and local government officials on both sides of the Atlantic and around the world.

7.4 – Efficiency, Cost, and Environmental Aspects of Incineration

Researchers should consider how to reduce the need for supplemental fuels in incineration, reduce the time for incineration, improve the throughput, and minimize the release of gaseous pollutants. Drying and pyrolysis are important parts of the overall incineration process. The material being incinerated must first be dried and then heated until it reaches temperatures suitable for pyrolysis or thermal degradation which converts the material into combustible volatile substances and a residual carbonaceous solid (char). The pyrolysis temperature influences the yield of volatiles and char. The rates of time for drying and pyrolysis depend on both the temperature of the surrounding environment and the size of the material. Considerable knowledge of these and other issues with respect to wood and other biomass is available. This knowledge base should be exploited and expanded for application to carcass incineration.

7.5 – Exploitation of the Calorific Value of Carcasses

Researchers should investigate how to exploit the calorific value of carcasses during incineration. There is some calorific value in the protein, fat and bone of animal carcasses. Although it is not as high as wood, this value should be exploited to reduce the fuel requirements for incineration. Experimental data on the effects of temperature and size on the times for drying and pyrolysis of meat and bone pieces is needed along with complementary data on the composition of the volatiles. Experimental data on the calorific value as well as heat capacity of meat and bone is also needed. This knowledge can be used to design rapid and energy-efficient incinerators capable of high throughput.

7.6 – Energy-Recovery Incineration Options

Investigate energy-recovery incineration options, including self-perpetuating systems. A variety of industrial equipment, including multiple hearth furnaces, rotary kilns, fluidized beds and stoker grates, has been adapted to municipal solid waste gasification for the purposes of energy recovery. This equipment should be explored for carcass disposal applications. Energy-recovery research would be a part of studies proposed in section 7.1.

7.7 – Education

In one of the UK FMD inquiry reports, an official concluded that biosecurity and related issues should be incorporated into agricultural education curricula (Anderson, 2002, p.14). Taking this cue, it is suggested that research be undertaken within the US land grant system to discern how best to educate an agricultural work force that is prepared to deal with a range of biosecurity issues, including carcass disposal techniques featuring incineration technologies.

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