Identification and Screening of Infectious Carcass Pretreatment Alternatives

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Acronyms and Abbreviations

˚C	degree(s) Celsius
°F	degree(s) Fahrenheit
ABP	animal by-product
ABPR	Animal By-products Regulations
APHIS	Animal and Plant Health Inspection Service
BSE	bovine spongiform encephalopathy
CAST	Council for Agricultural Science and Technology
CDC	Centers for Disease Control and Prevention
CFR	Code of Federal Regulations
CFU	colony forming unit(s)
CWD	chronic wasting disease
DEFRA	Department for Environment, Food and Rural Affair
DHS	Department of Homeland Security
EC	European Commission [regulation]
EMPRES	Food and Agriculture Organization of the United Nations
EPA	U.S. Environmental Protection Agency
EU	European Union
FMD	foot-and-mouth disease
GHG	greenhouse gas
h	hour(s)
H_2S	hydrogen sulfide
HEPA	high efficiency particulate air
kg	kilogram(s)
kPa	kilopascal(s)
kW	kilowatt(s)
lb	pound(s)
m3	cubic meter(s)
MDI	methylene diphenyl diisocyanate
MWh	Megawatt-hour(s)
NABC	National Agricultural Biosecurity Council
NHSRC	National Homeland Security Research Center
NRCS	Natural Resources Conservation Service
O_2	oxygen
O&M	Operation and Maintenance
ORD	Office of Research and Development
PAH	polycyclic aromatic hydrocarbon
PAP	processed animal proteins
PFU	plaque-forming unit(s)
pMDI	polymeric methylene diphenyl diisocyanate
PPC	Pollution Prevention and Control
PPE	personal protective equipment
S.E.P.	Scandinavian Energy Project
SPFA	Spray Polyurethane Foam Alliance
TSE	transmissible spongiform encephalopathy
UNEP	United Nations Environment Programme
USDA	United States Department of Agriculture
UV	ultraviolet
WID	Waste Incineration Directive

Executive Summary

The purpose of this report is to identify and screen pretreatment methods for emergency disposal of infectious animal carcasses. This report identifies eleven pretreatment methods and describes how each method can be used prior to, and in conjunction with, the six large-scale carcass disposal options (Figure E-1). The six disposal options considered are: (1) rendering, (2) burial, (3) landfill, (4) composting, (5) incineration, and (6) burning. Nontraditional disposal methods including waste-to-energy (WTE), ocean disposal and the feeding of carcasses to exotic animals (alligators) are not considered in this report. The eleven pretreatment methods for carcasses are: (a) on-site size reduction, (b) digestion, (c) bioreduction, (d) alkaline hydrolysis, (e) sterilization, (f) freezing, (g) physical inactivation, (h) chemical inactivation, (i) additives/sorbents, (j) encapsulation, and (k) packaging. Animal carcasses considered in this report include whole bodies or body parts of dead animals that might be mixed with manure and bedding or other organic materials that cannot be separated from the animal carcasses. Regulatory issues concerning carcass management vary from state to state and the treatment and disposal may require special permit(s) approved by one or more state agencies, the United States Department of Agriculture (USDA), and the local health department.

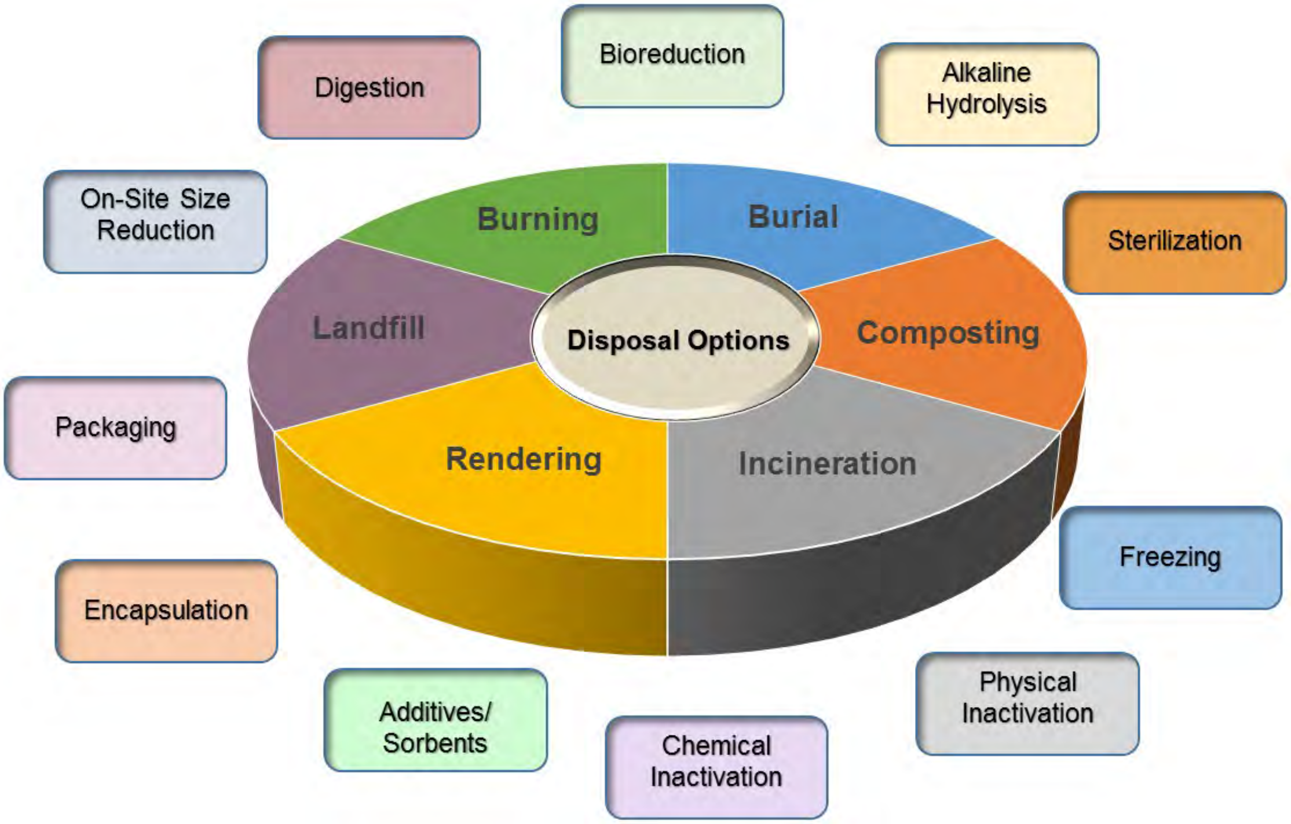


Figure E-1. Domains of Alternate Pretreatments of Infectious Carcasses.

Each of these pretreatment methods was defined and evaluated based on present status and potential applications, advantages and disadvantages, scale of operations, environmental effects, availability from vendors and typical cost range. The evaluation reveals that many pretreatment options are available, and research studies are ongoing to evaluate the effectiveness of these methods and technologies to pretreat carcasses and the impact of these treatments on the air, soil, and water systems. Based on identification and evaluation, Table E-1 provides a qualitative ranking of eleven pretreatment alternatives to foster proactive protection, response, and recovery to dispose animal carcasses in the event of animal disease outbreak. Each of the eleven pretreatment options offers unique advantages and disadvantages. None of these treatments, individually or in combination, should be considered absolute. The pretreatment scheme should be approached on a case by case basis. Two or more pretreatment/disposal methods can be selected so as not to overburden a processing site. Parallel treatment schemes can be considered by using treatment of part of the feed material by selected methods while treating remaining parts of the feed material by other method(s). Example of Color and Qualitative Ranking Codes: The green color cells of the Table indicate the treatment options that are ideal, however, +++ indicates more implementability of the treatment than the ++ or + marked treatments.

Table E-1. Carcass Pretreatment Options Matrix Based on Extensive Evaluation

Disposal Option	On-site Size Reduction	Digestion	Bioreduction	Alkaline Hydrolysis	Sterilization	Freezing	Physical Inactivation	Chemical Inactivation	Additives/ Sorbents	Encapsulation	Packaging
Rendering	🟩 +++	🟧 ++	🟧 ++	🟥 -	🟩 ++	🟩 ++	🟩 ++	🟧 ++	🟧 ++	🟥 -	🟥 -
Incineration	🟩 +++	🟧 +	🟧 +	🟥 -	🟩 +++	🟩 ++	🟩 ++	🟧 ++	🟩 +++	🟧 +	🟧 ++
Composting	🟩 +++	🟧 +++	🟩 +++	🟥 -	🟥 -	🟩 ++	🟩 ++	🟥 -	🟩 +++	🟥 -	🟥 -
Burial	🟩 ++	🟧 +	🟥 -	🟩 +	🟩 +++	🟩 ++	🟩 ++	🟩 ++	🟩 +++	🟩 ++	🟩 ++
Burning	🟩 +++	🟥 -	🟥 -	🟥 -	🟩 +++	🟥 -	🟩 ++	🟧 ++	🟩 +++	🟧 +	🟧 ++
Landfill	🟩 ++	🟧 +	🟥 -	🟩 +	🟩 +++	🟩 ++	🟩 ++	🟩 ++	🟩 +++	🟩 ++	🟩 ++

Notes: Several of the pretreatments may have overlapping processes. Some of the activities can be conducted at centralized or mobile locations. +++, ++ and + denote qualitative importance of the criteria (+++ > ++ > +), and – indicate not applicable.

Color Key

🟩 Ideal

🟧 Subject to acceptability of characteristics of feedstock by the processing facility/plant

🟥 Not Suitable

The emerging or evolving technologies for treatment of carcasses are not included within the eleven pretreatment alternatives. Evolving technologies to address disposal include gasification, plasma technology, irradiation, thermal depolymerization, dehydration, and extrusion. These emerging technologies are in research stage and need additional testing and evaluation. Animal carcasses are slowly heated in gasification operations and converted into a producer gas that contains methane, hydrogen, carbon dioxide, and carbon monoxide. Some of the produce gas is burned to supply the heat for the gasification reactions; the rest is combusted. Plasma technology fluidizes the inorganic portion and heat-resistant material of carcasses at very high temperatures (up to 7,000 °C) after its organic portion is converted to vapor at 200 to 600 °C and converted to gas at 600 to 1,000 °C. Thermal depolymerization, is a nontraditional, novel technology where pyrolysis occurs in the absence of air, and the product is a liquid biofuel rather than a gas. Thermal depolymerization can treat ground carcasses under high pressure (600 pounds per square inch) and high temperatures (about 250 °C) in the presence of carbon monoxide to create biofuels. Dehydration and extrusion process uses superheated air to move the particles of ground carcasses into a hot channel to evaporate and reduce their moisture. The materials are conveyed to an extruder barrel, where they are blended, cooked, sheared, kneaded, and formed into a plastic-like material that is converted into dried animal feed.

1 Introduction

1.1 Background

Animal agriculture in the United States of America is an enormous industry. Communicable diseases of poultry and livestock, biological attacks, and natural disasters pose serious risks to animal industry. In the event of a large-scale infection or catastrophe, a large number of animal deaths may occur, either directly as a result of the incident or as a result of steps taken to control the spread of disease. Federal (U.S. Environmental Protection [U.S. EPA]; the Department of Homeland Security [DHS]; the Centers for Disease Control and Prevention [CDC]; and the USDA's Animal and Plant Health Inspection Service [APHIS]) and State agencies have developed strategies for the destruction of animal carcasses. However, with certain pathogens, special pretreatment of the carcasses before disposal may help mitigate risks to the environment, livestock, wildlife, humans, and disposal equipment. Pretreatment using proper processing conditions including mechanical, thermal, or chemical methods and technologies may also aid the disposal options of treated material by reducing the size and physical, chemical and/or biological characteristics of material to be destroyed, or by enabling subsequent disposal processes to occur at a faster rate.

Animal carcasses that die from a zoonotic disease are infectious waste. The key microbial pathogens of concerns of infectious carcasses are: (a) prion/transmissible spongiform encephalopathies (TSEs) (examples: chronic wasting disease [CWD], and bovine spongiform encephalopathy [BSE], and scrapie), (b) spore-forming bacteria (example: anthrax), and (c) virus (examples: avian influenza, foot-and-mouth disease, and rinderpest). Franke-Whittle and Insam (2013) reviewed key pathogens in animal carcasses and they are *Escherichia coli, Salmonella, Clostridium, Brucella abortus, Bacillus anthracis, Mycobacterium bovis*, *Erysipelothrix rhusiopathiae*, BSE prion, aphto virus, rabies virus, African swine fever virus, phlebovirus, and *Cysticercus bovis*. Pauwels et al. (2007) summarized the key viral contaminants of animal cells or tissues that can cause human disease as following categories:

- **Virus in human tissues**: Hepatitisviruses: HBV, HCV, HDV, HEV, HGV; Human Retroviruses: HIV-1, HIV-2, HTLV-1, HTLV-2; Herpesviruses: EBV, CMV, HHV-6, HSV-1, HSV-2
- **Virus in nonhuman tissues**: Flaviviruses: yellow fever virus, Kyasanu Forest Virus; Filoviruses: Marburg, Ebola; Simian hemorrhagic virus; rabies virus; hepatitis A virus; poliovirus; Herpesviruses (Herpes B Virus and others); simian foamy virus
- **Virus in rodent tissues**: lymphocytic choriomeningitis virus (LCMV); Hantaan virus; monkeypox.

Throughout the U.S., the disposal of animal carcasses is regulated by state laws that vary according to animal species. Applicable requirements of federal, state, local, and tribal laws and regulations should be followed. While there are several methods for disposal of animal carcasses, the most common are the following six disposal options:

- **Rendering** – Rendering for disposal of contaminated carcasses involves a series of processes using high temperature and pressure to treat whole animal and poultry carcasses or their by-products. The processes include a combination of blending, cooking, pressurizing, fat melting, water evaporation, and microbial and enzyme inactivation. A pre-rendering process involves size reduction and conveying, and post-rendering process involves screening the protein and fat materials, sequential centrifugations for separation of fat and water, and drying and milling of protein materials.

- **Burial -** This disposal option refers to the placing of the infectious carcasses within the ground at the site of the incident. This option should only be used based on site characteristics (such as hydrogeological characteristics will not promote groundwater contamination) and proper environmental controls have been implemented to protect groundwater, surface water, and soil. This option requires an environmental assessment because of the potential contamination of groundwater, or of aquifers if leachate is not controlled.
- **Landfill** – Landfilling is a disposal option involving carefully designed structures built into or on top of the ground in which waste is isolated from the surrounding environment. There are different types of landfills, each designed to handle particular waste streams. For example, hazardous waste must be placed into a RCRA Subtitle C landfill. Municipal solid waste can be placed into a RCRA Subtitle D landfill. In addition, there are construction and demolition landfills and industrial landfills. Generally, each landfill is permitted or licensed for particular kinds of waste. A landfill generally cannot accept waste that falls outside the scope of its permit. Local landfill and the state's solid waste program and division of environmental health should be contacted regarding the specific requirements.
- **Composting** – Composting for disposal of contaminated carcasses is a controlled biological decomposition of biomass to form a humus-like material. Controlled methods of composting include mechanical mixing and aerating, ventilating the materials by dropping them through a vertical series of aerated chambers, or placing the compost in piles out in the open air and mixing it or turning it periodically. This treatment option is distinct from backyard composting that is conducted by individuals on their own property. Instead, composting, as a treatment option, is used to decompose large quantities of waste either on a farm in association with animal disease control activities or off-site composting facilities. Off-site composting will trigger transportation considerations.
- **Incineration** – The incineration disposal option burns the biomass at a high temperature under controlled conditions. Different incinerators are permitted for different kinds of contaminated materials. Hazardous waste must be brought to an incinerator permitted to accept hazardous waste. Municipal solid waste incinerators are permitted to burn municipal solid waste, with some units having the ability to recover energy. Medical waste incinerators are designed to handle pathogenic wastes.
- **Burning** – The deliberate outdoor burning of waste can be done in open drums, in fields, and in large open pits or trenches. The use of this option is highly restricted; many states and local communities have laws regulating or banning open burning. Open burning should be done only when and where it is appropriate and if there are no other alternatives available (U.S. EPA, 2014). Open burning is prohibited for many waste streams and may require special permission for allowable waste streams. Under certain conditions, emergency waivers could be issued.

The implementation of the Animal By-products Regulations (ABPR, EC [Commission Regulation] No. 1774/2002) prohibited the burial and burning of livestock carcasses in the European Union (EU) (DEFRA, 2011). However, due to industry concerns about the costs, practicality and biosecurity of the centralized collection system that was implemented for livestock mortalities, unsanctioned disposal of carcasses is known to occur. Novel carcass treatment technologies may be approved under the ABPR provided that they can be shown to prevent pathogen proliferation. There is concern that disposal methods alone may not render infectious agents into an inactive state. For example, the prions that are believed to be the causative agents of the TSE diseases of scrapie, CWD, and BSE may persist in the soil with burial only. Moreover, rendering plants cannot accept animal materials known to be contaminated with prions. In some cases, it may be advantageous to perform the disposal on the farm, but concerns may be raised about spreading disease to the local animals and wildlife as well as to human populations. Pretreatment options may be available to decontaminate the carcasses before further processing, release onto land, or discharging into water.

A detailed discussion of these key disposal methods is not provided herein, as there are numerous resources available on their use and environmental impact. Instead, this feasibility study focuses on pretreatment methods and technologies to process large numbers of carcasses so they can be managed safely and efficiently. These methods and technologies may act to eliminate infectious agents in or on the carcasses so they are safer to handle, and/or may act to stabilize the carcass biomass to make it easier to transport to the final disposal site or allow it to be disposed on the farm.

The main goal of any pretreatment and disposal process is to prevent the dissemination of infection to other animals and/or humans. Preventing dissemination can involve containment of pathogens or inactivation of pathogens. Secondly, the process must minimize or prevent adverse environmental consequences. The aim is to prevent spread of pathogens while protecting the premises, agricultural operations, and downstream areas. Finally, the process must be feasible in terms of regulatory acceptance (i.e., meets legal issues), timeliness, manpower, available resources, and cost.

The selection of treatment processes also involves consideration of a variety of factors including (a) biosecurity concerns in moving contaminated carcasses, animal products, and other materials off an affected premises, (b) public health or environmental protection laws, (c) number and species of carcasses, and the amount and type of other material in need of disposal, (d) any potential hazard the material may pose to humans or livestock, (e) classification of soil at the potential treatment site, (f) accessibility by large trucks and other vehicles, (g) proximity of water reservoirs and wells, water table and seasonal fluctuations, (h) proximity to high-density housing or other public areas, (i) location of underground and overhead utility structures, (j) climatic and weather factors (e.g., the direction of the prevailing winds) and seasonal conditions (such as wet or frozen ground), (k) intended use of the site after treatment activities are completed, (l) availability of the pretreatment equipment for the type of treatment method to be used, and (m) availability of the necessary supplies and utilities for the type of treatment method to be used. Carcasses can be taken from original generation points to a central collection point prior to off-site transport or on-site treatment and temporary storage. For example, a strategy of off-site treatment may be necessitated by climate (accessibility concerns), high animal population densities, or the presence of wild animals that can spread disease. In other cases, carcasses or materials may need to be stored temporarily until conditions are more amenable to disposal activities (until the threat of a disease agent is reduced or until premises are more accessible). On-site pretreatment may be necessary, for example, if a rendering plant is located far away from the affected farm or immediate disposal is not possible and if the carcasses need to be stored for some time. The advantage of storing carcasses is that one can wait until it is economically viable and the carcasses are convenient to treat. Size reduction or packaging options may help in the transport of the affected carcasses to the central site of disposal.

Another concern in animal carcass pretreatment is that large animals (such as cattle and horses) pose a unique challenge due to their size and weight. Heavy equipment may be needed to lift and transport the carcasses; likewise, the volume of material to be treated may require a large area of land and can pose significant environmental risk. A single on- or off-site treatment location may be preferable to multiple on- or off-site disposal locations due to disease containment (to minimize the chances of multiple-site and/or groundwater contamination and potential disease spread) and reduction in time and effort needed to secure required permissions and approvals for multiple sites.

This study explores options for on-site pretreatment to better prepare the material for disposal. In the event of a large-scale die-off, such as thousands or tens of thousands of cows, the critical challenge to carcass management is the volume of carcass material to be processed per shift (or day) by a treatment unit (or a series of units). Multiple mobile disposal systems might be able to handle a small- or moderate-scale animal emergency. However, in case large-scale event, it may not be feasible to transport whole carcasses by truck from the farm to the treatment site as the carcasses may begin to decompose before they are transported, which presents environmental risks and odor problems. Decomposing carcasses could transport infectious agents into the surrounding land and water, threatening the health of humans and animals. Furthermore, if appropriate regulations are not followed, decomposing carcasses could allow infectious agents to leak and permeate into the transport truck or vessel, increasing the likelihood of spreading disease along the transport route and to the final destination site. Appropriate design (such as double-lined or sealed trailer) can inhibit the leakage. Wildlife would be attracted to decomposing material and could become infected or could disperse the causative agents by scavenging the carcasses. A carcass must be disposed within 24 hours (as in California) to 72 hours (as in Washington) of the time of death or discovery to avoid nuisance odors or spread of disease (WSDA, 2009; Humane Society, 2014). Rendering plants cannot accept badly decomposed carcasses. Rendering should be performed within 24 to 48 hours of an animal's death. It is easier to remove hides, hair, and paunch from fresher carcasses than from those that are highly decomposed, which have reduced quality of fat and protein (Mukhtar et al., 2008). Finally, the overall cost and labor efforts needed to transport tens of thousands of large whole carcasses make it less desirable. Therefore, pretreatment methods and technologies can help reduce the size of the material to be transported as well as slow the decomposition process. Moreover, on-site pretreatment may allow carcasses to be safely disposed at the site instead of transporting them elsewhere.

However, not all pretreatment options are suitable for all disposal options. Certain treatment options presented in this report can effectively reduce the infectious hazards of the carcass and prevent scavenging but, at the same time, give rise to other health and environmental hazards. For example, incineration may under certain conditions (such as insufficiently high incineration temperatures, inadequate control of emissions) release toxic material into the atmosphere. Leaching and percolation in a subsurface system may result in groundwater pollution if the treatment facility is inadequately designed and/or operated. In choosing a specific pretreatment or a combination of pretreatments of carcasses, the relative risks as well as the integration into the overall framework of comprehensive waste strategy should be evaluated carefully in the light of local circumstances. Based on the preliminary literature search, Table 1 identifies eleven pretreatment alternatives, individually or in combination, to foster proactive protection, response, and recovery to dispose animal carcasses in the event of an animal disease outbreak. These treatments can be sequential and/or combination of technologies, requiring that two or three technologies should be used in sequence to reduce the overload of a large animal disposal event. After the identification, evaluations of these eleven infectious carcass pretreatment methods are discussed in Section 2 and summarized in Section 3.

Table 1. Carcass Pretreatment Options Matrix Based on a Preliminary Literature Search

Pretreatment Option	Disposal Option					
	Rendering[1]	Incineration[2]	Composting[3]	Burial[4]	Burning[5]	Landfill[4]
On-site Size Reduction	●	◕	◕	◐	◕	◐
Digestion[6] (liquefaction/ fermentation)	●	◕	◕	◐	○	◐
Bioreduction[7] (aerobic/anaerobic)	◕	◐	●	◔	○	○
Alkaline Hydrolysis	○	○	○	◐	○	◐
Steam Sterilization	◐	◐	◔	◐	◐	◐
Freezing	◕	◐	◕	◐	◐	◐
Physical Inactivation[8]	◕	◕	◕	◕	◕	◕
Chemical Inactivation[9]	○	◐	◔	◕	◐	◕
Additive/ Adsorbent[10]	◔	●	●	●	●	●
Encapsulation	○	◕	○	◕	◕	◕
Packaging[11]	○	◕	◔	●	◕	●

Legend:

○ Not Acceptable ◔ Poor ◐ Marginal ◕ Good ● Excellent

Notes: Several of the pretreatments may have overlapping processes. Some of the activities can be conducted at a centralized or mobile location. The process and treatment conditions and their performance may vary due to the acceptability of characteristics of feedstock by the downstream processing facility/plant.

1. Rendering 1 ton of carcasses generates approximately 3000 lbs to 4000 lbs of wastewater. No storage is necessary for carcasses ≤ 400,000lbs (400 cattle carcasses); otherwise, there might be need to store the extra carcasses. The throughput of a typical rendering plant is approximately 8333 lbs per hour.
2. High temperature (≥850 degree Celsius, ˚C) anaerobic combustion via Fixed Facility Incineration or Animal by-products Pollution Prevention and Control (PPC) Directive /Waste Incineration Directive (WID) (Directive 2000/76/EC of the European Parliament and of the Council, of 4 December 2000 on the incineration of waste) approved incinerators generate greenhouse gases (GHGs) and other emissions (polycyclic aromatic hydrocarbons [PAHs]; dioxins, furans, and other chemicals), particulates, smoke, and odor. These releases may require additional treatments. Approximately 600 lbs (or 1-5% of initial carcass volume) of ash is generated per ton of carcass.
3. Soil and water contamination can occur due to release of leachate. Additional treatments are required to address odor control, GHGs and other gas emissions.
4. Soil and water contamination can be avoided by appropriate design to contain release of decayed material.
5. Air emission issues (smoke, odor, particulate materials, and dioxins) may require additional treatments.
6. Digestion includes key processes including liquefaction, fermentation (lactic acid/yeast), and preservation (heat/acid-base/chemicals).
7. Bioreduction includes both aerobic and anaerobic subcategories.
8. Physical inactivation includes application of water, ultra-high pressure steam, energy (thermal, plasma arc irradiation, pulsed-field electricity, ultrasonic energy, ultraviolet (UV) light).
9. Chemical inactivation includes but is not limited to oxidizers (chlorine, hypochlorite, ozone, and peroxide), organic acids (lactic acid, acetic acid, and gluconic acid), organics (benzoates, propionates), bacteriocins (nisin, magainin [antimicrobial peptides]). Biological treatments (such as use of bacteriophage/bacteriocins) are also included under this category.
10. Corn silage, straw/manure, ground cornstalks, saw dust, wood chips, rice hulks, and other sorbent materials with appropriate water holding capacity, porosity, gas permeability, compaction, and ability to maintain desired O_2 concentrations.
11. Packaging mainly involves during transport and storage of untreated or treated carcasses.

1.2 Purpose and Scope

The purpose of this study is to identify and evaluate pretreatment methods for emergency disposal of affected animal carcasses. This report defines eleven pretreatment methods and describes how each method can be used prior to, and in conjunction with, the six disposal options. Each section below examines the advantages and disadvantages, scale of operations, environmental effects, sample vendors and typical cost ranges. The scope of this study focuses on the identification and screening of pretreatment alternatives prior to large-scale carcass disposal operations, with an emphasis on the pretreatment of livestock carcasses. Animal carcasses considered in this report include bodies or body parts of dead animals that may be mixed with manure and bedding or other organic materials that cannot be separated from the animal carcasses. This report does not discuss decontamination of the animal facilities; however, this action must be incorporated into all comprehensive carcass management plans. Such actions may include disinfection of fomites such as farm equipment, water and food troughs, and pens and stables, and may vary depending on the pathogen and mode of transmission. Lastly, regulatory issues concerning carcass management are not discussed in this report, as they vary by state. Catastrophic carcass treatment and disposal usually requires a special permit approved by one or more state agencies, depending on the state of origin of the material (Council for Agricultural Science and Technology [CAST], 2009). These permits may require the participation of the local landfill management, as well as external coordination and approval with the state office of solid waste. In many instances, the USDA and the local health department may also be involved. In most instances, permits should include both approval for acceptance of carcasses and bedding and acceptance of free-flowing liquids as part of the waste stream.

1.3 Analysis of Existing Data

An extensive review of existing literature is an important component of this study. Literature review was conducted to identify and collect the available peer-review journal articles, trade factsheets, reports and guidance reports, and other pertinent information related to pre-treatment for transport of infectious carcasses for disposal. Various sources of information were identified on carcass management of large-scale animals, where mortality is due to infectious agents. The peer-reviewed articles were downloaded after libraries searches across seven key databases (Academic OneFile, Academic Search Complete, MasterFILE Complete, Newspaper Source Plus, OAIster, and WorldCat.org) and other web science searches. Technical reports released by various federal agencies (e.g., U.S. EPA, DHS, USDA, CDC, and others) and international organizations were identified and collected. Additional vendor-supplied data, newsletters, and fact-sheets were obtained. Information included in the report was drawn primarily from peer-reviewed publications. Peer-reviewed publications contain the most reliable information, although some portions of the report may contain compilations of data from a variety of sources and non-peer-reviewed literatures (workshop proceedings; graduate degree theses/dissertation; non-peer-reviewed reports and white papers from industry, associations, and non-governmental organizations) and unpublished data (online databases, personal communications, unpublished manuscripts, unpublished government data). Non-peer-reviewed and unpublished sources did not form the sole basis of any conclusions presented in the report of results. Generally, these sources were used to support results presented from peer-reviewed work, enhanced understanding based on peer-reviewed sources, identified promising ideas of innovative pre-treatment technologies, and discussion on challenges. The qualitative ranking has been performed based on the review of the literature search. The justifications of the qualitative ranking have been discussed for each treatment technologies under various sub-sections application, operational capacity, environmental issues associated with the specific treatment option, how treatment tracks to each of the six disposal options, and vendors and cost information. Secondary data were used as per the U.S. EPA approved Quality Assurance Project Plan (Tetra Tech, 2014) and review of published or unpublished data for identifying relevant information and assessment in treatment of infectious carcasses. These secondary data included original research papers published in peer-reviewed journals and pertinent review articles that summarize original research, obtained from hard copies and computerized databases. The sources of the data including costs have been cited. However, no quality assurance (accuracy, precision, representativeness, completeness, and comparability) of secondary data has been conducted. The costs obtained from the literature were cited indicating the date of publication. The cost information obtained from vendor website or via communications were collected during 2014. Unless otherwise mentioned as equipment rental, the cost numbers are equipment costs. A disclaimer has been included at the beginning of this report. The data cited in this report were collected from published literature/fact-sheets/web, and no attempt has been made to verify the quality or veracity of data collected from various sources.

1.4 Overview of Animal and Carcass Handling Biosecurity Factors

The handling of animals and carcasses presents multiple on-site issues. The primary concerns are the safety of personnel, protection of the environment, and prevention of disease spread in the case of infectious agents. All three focus areas fall under the umbrella of on-site biosecurity.

Personnel safety includes physical safety, disease agent protection, and process safety. Physical injury can occur when handling animals and working with or near operating machinery. Training and protective devices need to be used, including personal protective equipment (PPE) (gloves, eye protection, respirator, hearing protection, steel toed shoes/boots, and body suits, as necessary), and external protective equipment such as squeeze chutes and fencing. Machinery needs to have safety devices in place, such as belt guards, screens, and similar protective elements. Personnel needs to be trained on protection against infective agents with a focus on biosecurity and use of PPE.

Protecting the environment includes training and processes to eliminate or minimize environmental impacts of the processes and materials utilized in the various pretreatment and disposal processes. The Food and Agriculture Organization of the United Nations (EMPRES) provided recommendations on biosecurity that the carcasses and other items awaiting disposal should be guarded to prevent unauthorized access and to prevent domestic pets, wild animals, and birds from removing potentially infectious material. Control of insects should be considered if there is a risk of passive transmission by insects to nearby susceptible species (Geering et al. 2001).

Prevention of the spread of disease is critically important especially when dealing with highly infectious transboundary diseases such as avian influenza, exotic Newcastle disease, foot-and-mouth disease (FMD), and swine vesicular disease. Special consideration is given when working with prions and anthrax. Live animals may have to be moved to a central collection point for euthanasia or transport. Animal carcasses *in situ* would have to be moved to a central point for carcass processing. In either case, there is the potential to contaminate soil, infrastructure (fences, building, roadways, etc.), water, and air with the animal or carcass movement.

At the central processing point, the potential for spread of disease continues. One area of special concern is the production of infectious aerosols (Miller, 2013). Studies have shown infectious viruses such as FMD have the potential to move miles in the air (Gloster et al., 2004). Processes and procedures must be in place to manage environment contamination and subsequent disease spread. These safeguards include processing in enclosed, fixed facilities or within tented areas; blowers providing negative pressure, enclosures, ducting, high efficiency particulate air (HEPA) filters to contain aerosols; and use of physical or chemical decontaminants to minimize disease spread. Excellent biosecurity measures should be established and enforced, and all personnel working within the infected zone must be trained in biosecurity and provided the proper equipment and materials for infectious agent control.

These issues are common across all methods of animal and carcass pretreatment/disposal. These issues should be evaluated and considered before selecting the appropriate pretreatment option and subsequent disposal option.

1.5 Infrastructural Requirements

On-site pretreatment operations may require special equipment that needs to be taken to the site to reduce impacts to surface and groundwater resources, to reduce the impact of odors, and to decrease the spread of pathogens. Thus, the treatment team must consider the need for utilities, wastewater treatment, and air emission monitoring. Structures may need to be erected to protect the equipment from inclement weather and/or to contain aerosols. Large pretreatment equipment may require fuel or a power source (generator), water, and/or heavy vehicles for lifting and moving. Fencing may be necessary to exclude animals until the site is safe for use. The planning and design of the facilities or processes must conform to all federal, State and local laws, rules and regulations, including provisions for closing and/or removing the facility where required. Design of all structural components integral to the animal mortality facility shall meet the structural loads and design criteria as described in the Natural Resources Conservation Service's (NRCS) National Handbook of Conservation Practice standard for Animal Mortality Facility (code 316), Waste Storage Facility (code 313), and conservation practice standard Roofs and Covers (code 367), unless otherwise designated. In addition to the NRCS practice standard for an animal mortality facility, directives by the appropriate state or federal authorities (typically the state veterinarian or USDA APHIS) should be followed.

Major considerations in planning animal carcass pretreatment facilities are: a) available equipment and land application area at the operation, b) management capabilities of the operator, c) degree of pollution control required by state and local agencies, d) effect on wildlife and domestic animals, e) economics of the available alternatives, and f) effect on neighbors.

Identification and initial planning of pretreatment facility site suitability should include referring to the USDA's Soil Surveys' soil interpretations for "disaster recovery planning" (http://websoilsurvey.nrcs.usda.gov/). A few of the key criteria of the site include the following:

- Movement of odors toward neighbors should be minimized by appropriate treatment or management.
- Down gradient from springs or wells is preferable to prevent contamination.
- Preferred location of treatment facility is a site that has restricted percolation. Appropriate site selection and/or design measures should be taken to protect the water table from contamination. In general, a minimum of two feet between the bottom of the facility and the seasonal high water table is desirable, unless special design features are incorporated that address seepage. Unless site restrictions require location within the floodplain, site should be above the 100-year floodplain elevation. If located in the floodplain, protect the facility from inundation or damage from a 25 -year flood event.
- Agricultural Waste Management Field Handbook - Part 651: Appendix 10D should be considered for selection of sites using acceptable liner technology where seepage can be restricted with normal construction techniques.
- Structural details of all components including locations of electrical and gas lines, and requirements for the number of pieces of process equipment and accessories, their capacities and loads (weights) to be identified. Design data and building dimensions should be determined where a roof structure is used to protect the facility.
- Traffic patterns should be established to avoid crossing livestock pathways and feed lanes with carcass transport.

- Appropriate measures should be taken to maintain appropriate visual resources, reduce odor, and provide dust control. Vegetative screens and topography should be used to shield the animal mortality facility from public view, to reduce odors, and to minimize visual impact.

Many on-site carcass pretreatment methods require common infrastructural resources and equipment. Not every element may be required in each situation, but using a checklist will assist the disposal team in determining which elements will be required for the chosen pretreatment option.

Infrastructure Requirements (Peters et al., 2003; Chattopadhyay and Lal, 2007; Ohio Department of Health, 2013)

- Power grid (fixed) - electric (110, 220, 440 volts)
- Portable power-fuel generated electricity (110, 220, 440 volts) and heat/steam generation
- Water
    - Potable
    - Non potable
- Working area - (hard stand and supportive ground)
    - Processing area
    - Staging area for equipment
    - Decontamination area
    - Parking area
    - Storage area
    - Loading area
    - Administrative area
- Solid waste (infectious and noninfectious)
    - Collection
    - Storage
    - Loading and movement
- Fluid waste (infectious and noninfectious)
    - Collection
    - Storage
    - Loading and movement
- Carcass material (infectious and noninfectious)
    - Collection
    - Storage
    - Loading and movement
- Communications capability
    - Phone
    - Radio
- Road access (suitable)
- Support facilities/structures
    - PPE donning and doffing area
    - Decontamination area
    - Showers and eyewashes
    - Restrooms

  - Office
  - Meals and rest area
  - Storage areas
    - Hazardous
    - Nonhazardous
  - Material assembly/handling area
- Process facilities/structures
  - Fencing, chutes, gates
  - Buildings/tents
    - Equipment protection
    - Environment protection
      - Solids
      - Fluids
      - Aerosols

Equipment Requirements

- PPE
- Decontamination equipment for all relevant systems (personnel, infrastructure, and infected carcass)
- Euthanasia equipment
- Carcass moving equipment (bucket loader, skid loader, front end loader, claw loader, or other)
- Material handling equipment (fuel, water, other materials)
  - Hazardous
  - Nonhazardous
- Waste handling equipment (infectious and noninfectious)
  - Fluid
  - Solid
  - Air/aerosol.

Based on the infrastructure and available utilities, appropriate plans for operation and maintenance (O&M) of the treatment facility should be developed. In addition to normal and operating parameters of the processes, the O&M plan should include the overall waste management system protocol, safety issues, method and procedures of treatment(s), biosecurity concerns, contact(s) and phone numbers of person(s) to contact in case of catastrophic losses, records of date, average weight, and number of deaths, periodic inspections of facility, repair or replacement schedule of damaged components of equipment and accessories, and information of manufacturer or installer for trouble shooting.

In addition, large generators and other mobile assets may be required for mobile pretreatment facilities. Four diesel generators with standby ratings of 62 kilowatts (kW) and prime ratings of 56kW are capable of supplying 208-240V/416-480V three phase voltage, and 240/12V single phase voltage (Ohio Department of Health, 2013). These mobile assets can be transported via one-ton pickup trucks to haul 12-foot trailers. These trailers are generally equipped with a 2-inch hitch and a gross combined weight rating of 6,000 pounds (lbs). The fuel consumption rate for these units is about 4.31 gallons per hour at full load.

2 Infectious Carcass Pretreatment Options

2.1 On-site Size Reduction

2.1.1 Definition

On-site carcass size reduction is the manual or mechanical cutting, grinding, or crushing of the carcass to decrease the dimensions of the resultant parts for ease of handling, decreasing carcass volume, or to enhance further processing (NABC, 2004; Mukhtar et al., 2008). Key size reduction processors include crushers, shredders, and grinders. Crushers are machines that use impact, shear, compression or abrasion to reduce a variety of solid products to a desired particle size range. The difference between crushing and grinding is that in crushers, the crushing elements are fixed with relation to one another, whereas in grinders the crushing elements are free and are held apart from one another by the biomass that is being ground between them. Shredding is carried out in a machine that is low speed and high torque. A shredder is designed to take large components and shred them down to random, smaller components, normally in the range of 1-2 inches and larger. This report will evaluate size reduction as one of the pretreatment options for infectious carcasses prior to disposal. No effort will be made to evaluate specific processors/milling units.

2.1.2 Application

2.1.2.1 On-site Slaughter Size Reduction

On-site slaughter and/or quartering of carcasses are size reduction alternatives for select carcass disposal circumstances. Mobile facilities require trained personnel (butchers and assistant butchers), electrical power, propane, potable water, wastewater holding, biological waste holding/disposal, non-biological waste holding/disposal, and manual or mechanical carcass handling. On-site slaughter does not alter the presence of infectious agents in the carcass material; however, biosecurity training, equipment, and processes would be required to contain any agents. On-site slaughtering creates issues to treat the wastewater generated and the processed carcass material. Processed carcass material can be loaded and shipped in waterproof containers such as plastic cartons or plastic lined boxes. Wastewater management would require collection and treatment before discharge or release of treated water. Quartered carcasses could be wrapped or boxed similar to packaging as is done with boxed beef in meat processing facilities. Quartering has been done on a trial basis with viscera removed and placed in plastic bags for transport and carcasses ground for composting (Rozeboom et al., 2012). Unless there is immediate transport, refrigeration would be required to prevent spoilage and odors. There are several manufacturers of mobile slaughter/processing units that could be utilized for on-site slaughter or carcass size reduction.

Capital cost estimates for a mobile facility with tractor trailer and holding/kill equipment, but not including supplies and small equipment, range from $210,000 to $280,000.

The estimated daily throughput for these systems is 14 head for cattle, 28 for swine, and 42 for sheep. This on-site method would be appropriate only in limited circumstances where small numbers of carcasses are involved.

2.1.2.2 Carcass Crushing and Grinding

Carcass grinding presents a viable alternative for on-site size reduction. Grinding requires less skilled labor than slaughter, provides continuous throughput, and results in output that can be managed as a semi-liquid through pumping and packaging providing ease in handling with increased biosecurity. Marcondes et al. (2012) reported various correlations of the physical and chemical compositions of bovine carcasses. For an average cattle with empty body weight of 206 kg (minimum = 99.7 kg and maximum = 323 kg), the average water content reported by Marcondes et al. (2012) was 57.98% (minimum = 43.91% and maximum = 73.54%). Appropriate containment and treatment of the released liquid, if any, should be considered. In addition, grinding can improve subsequent disposition processes for carcasses, including the ability to mix the output with inactivating agents to decrease or eliminate the pathogens.

Large commercial grinders such as the Anco Crusher® (Greensboro, North Carolina) or Haarslev PB 30/60 Crusher (Sonderso, Denmark) can grind whole cattle carcasses (Figure 1). These and similar grinders are capable of grinding 10,000 to 110,000 lb per hour.

The output is semi-viscous and can be handled through pumps into closed containers, dump trailers, gravity tankers, or piston tankers, increasing the biosecurity of the output. Pumping requires either a portable or fixed power source capable of supplying an approximately 75-100 horsepower motor. A forklift, skid loader, claw loader, or front end loader is required to lift the carcasses to the level of the grinder hopper. Trained personnel are required to operate the generator, grinder, loaders, and to control material management. Personnel require additional training in safety, PPE, decontamination, and biosecurity.

A typical commercial crusher costs approximately $140,000 and can be loaded on a flatbed trailer and operated by one person. The cost for grinding is estimated at approximately $6/head of cattle carcasses (total carcass weight considered to be about 1,000 lb each) (National Agricultural Biosecurity Council [NABC], 2004).

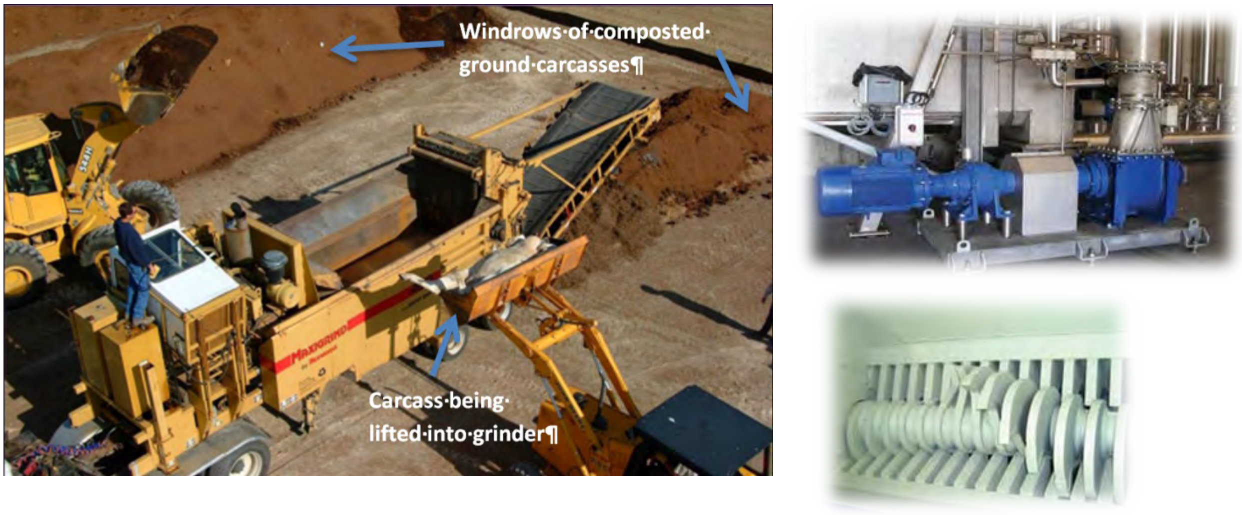


Figure 1. Large-scale Mobile Carcass Grinder.

On-site grinding for size reduction is advantageous for rendering, composting, burial, landfill, and incineration and reduces the risk associated with transporting whole carcasses. For example, decomposition of the carcasses can be sped up by up to 50 percent by grinding them before composting (Mukhtar et al., 2008). The advantages and disadvantages of on-site size reduction are shown in Table 2.

Table 2. Advantages and Disadvantages of On-site Size Reduction

Advantages	Disadvantages
• Mobile on-site • Low environmental impact • Very high throughput capacity • Few safety issues for operators • Ease in handling and transport of processed material • Accelerated decomposition	• Cost of capital equipment • Operating cost of machinery • Potential aerosol production • Groundwater contamination if untreated effluents are released • Soil pollution if the carcasses are accumulated on the ground faster than the processing rate.

The STI shredder and steaming system (STI Biosafe, Indianapolis, Indiana) includes HEPA filtration system above the shredder to prevent any aerosols from escaping. The life span of viruses outside of the host should be considered before requiring mobile systems fabric tunnels, covering, or air filtration systems. Some infectious agents such as FMD virus have been shown to be transmitted easily by aerosols (Gloster et al., 2004). Research has indicated these infectious aerosols would be able to travel as far as 10 to 40 miles over land and more over water. The grinding process has the potential for aerosolization that could contaminate surrounding areas. Miller (2013) has indicated that the grinding of infectious carcasses prior to composting is not recommended unless aerosols are controlled. Due to aerosol dispersion, grinding should be performed within a facility with a covered structure such as a barn or tent enclosure with enhanced air handling capability or with a system that operates under negative air pressure. Other pathogens that present an aerosol inhalation risk to humans, including anthrax, may not be conducive to grinding without the requirement for enhanced dispersant reduction, air handling equipment, specialized biosecurity training, and utilization of PPE.

The United Kingdom's Department for Environment, Food and Rural Affairs (DEFRA) and the Animal and Plant Health Agency recently updated their recommendations that the animal by-product (ABP) material should be crushed to small pieces between 0.79-inches and 5.9-inches in width and height (the exact size limit is different for each of the approved methods) (DEFRA, 2014). There is no limit to the length of the piece. Their suggestion was to use any machinery to crush the material, e.g., mincers, cutters or breakers. The guidance indicated six approved processing methods with regard to time and temperature combinations for the processed ABPs (Table 3). ABPs are divided into three categories, based on the risks they pose. Category 1 (high risk) includes carcasses and all body parts of animals suspected of being infected with TSE (transmissible spongiform encephalopathy) and specified risk material (body parts that pose a particular disease risk, e.g., cow spinal cords). Category 2 (high risk) includes animals rejected from abattoirs due to having infectious diseases, carcasses containing residues from authorized treatments, carcasses of animals killed for disease control purposes, carcasses of dead livestock, and digestive tract content. Category 3 (low risk) includes carcasses or body parts passed fit for humans to eat at a slaughterhouse, products or foods of animal origin originally meant for human consumption but withdrawn for commercial reasons, not because it is unfit to eat, hides and skins from slaughterhouses, and processed animal proteins (PAPs). Category 1 and Category 2 ABP material must be pressure sterilized (Method 1 in the Table 3), while Category 3 material can be processed using any of the methods in Table 3. The European Commission Scientific Steering Committee approved alkaline hydrolysis for TSE-infected material needs to be digested for six hours, while US-based facility disposing of CWD-infected carcasses uses an eight-hour-long digestion process to ensure destruction of any prion contaminated material (NABC, 2004).

Table 3. Maximum Size of the Animal By-Products (ABPs) for Various Processing Conditions

Pressure Sterilization Method Name*	Maximum Size of Material to be Treated (mm)	Core Temperature (˚C)	Time at Core Temperature	Remarks
Method 1	50	133	20 minutes without interruption	Minimum pressure of 3 bars (2 bars above normal atmospheric pressure) to be maintained by removing all air from the sterilization chamber and replacing with steam
Method 2	150	120 110 100	50 minutes 120 minutes 125 minutes	Material to be processed in batches, one after another. Feeding more material into the cooker while one batch is processing is not recommended.
Method 3	30	120 110 100	13 minutes 55 minutes 95 minutes	
Method 4	30	130 120 110 100	3 minutes 8 minutes 13 minutes 16 minutes	Fat to be added before heating.
Method 5	20	110 80	60 minutes 120 minutes	Before processing ABPs to be heated until coagulation (begin to solidify), fat and water to be removed by pressing and the leftover solid material to be treated.
Method 6 (for aquatic species)	50 30	90 70	60 minutes 60 minutes	To be mixed with formic acid to pH 4.0 or lower and to be stored for 24 hours before further treatment.

* The chapter III of Annex IV of Regulation (EU) No. 142/2011 defines the Method 1 through Method 6 as follows:

Method 1: Reduction - If the particle size of the animal by-products to be processed is more than 50 millimeters, the animal by-products must be reduced in size using appropriate equipment, set so that the particle size after reduction is no greater than 50 millimeters. The effectiveness of the equipment must be checked daily and its condition recorded. If checks disclose the existence of particles larger than 50 millimeters, the process must be stopped and repairs made before the process is resumed. Time, temperature and pressure - The animal by-products with the particle size of no greater than 50 millimeters must be heated to a core temperature of more than 133 °C for at least 20 minutes without interruption at a pressure (absolute) of at least 3 bars. The pressure must be produced by the evacuation of all air in the sterilization chamber and the replacement of the air by steam (‘saturated steam’); the heat treatment may be applied as the sole process or as a pre- or post-process sterilization phase. The processing may be carried out in batch or continuous systems.

Method 2: Reduction - If the particle size of the animal by-products to be processed is more than 150 millimeters, the animal by-products must be reduced in size using appropriate equipment, set so that the particle size after reduction is no greater than 150 millimeters. The effectiveness of the equipment must be checked daily and its condition recorded. If checks disclose the existence of particles larger than 150 millimeters, the process must be stopped and repairs made before the process is resumed. Time, temperature and pressure - After reduction the animal by-products must be heated in a manner which ensures that a core temperature greater than 100 °C is achieved for at least 125 minutes, a core temperature greater than 110 °C is achieved for at least 120 minutes and a core temperature greater than 120 °C is achieved for at least 50 minutes. The core temperatures may be achieved consecutively or through a coincidental combination of the time periods indicated. The processing must be carried out in a batch system.

Method 3: Reduction - If the particle size of the animal by-products to be processed is more than 30 millimeters, the animal by-products must be reduced in size using appropriate equipment, set so that the particle size after reduction is no greater than 30 millimeters. The effectiveness of the equipment must be checked daily and its condition recorded. If checks disclose the existence of particles larger than 30 millimeters, the process must be stopped and repairs made before the process is resumed. Time, temperature and pressure - After reduction the animal by-products must be heated in a manner that ensures that a core temperature greater than 100 °C is achieved for at least 95 minutes, a core temperature greater than 110 °C is achieved for at least 55 minutes and a core temperature greater than 120 °C is achieved for at least 13 minutes. The core temperatures may be achieved consecutively or through a coincidental combination of the time periods indicated. The processing may be carried out in batch or continuous systems.

Method 4: Reduction - If the particle size of the animal by-products to be processed is more than 30 millimeters, the animal by-products must be reduced in size using appropriate equipment, set so that the particle size after reduction is no greater than 30 millimeters. The effectiveness of the equipment must be checked daily and its condition recorded. If checks disclose the existence of particles larger than 30 millimeters, the process must be stopped and repairs made before the process is resumed. Time, temperature and pressure - After reduction the animal by-products must be placed in a vessel with added fat and heated in a manner that ensures that a core temperature greater than 100 °C is achieved for at least 16 minutes, a core temperature greater than 110 °C is achieved for at least 13 minutes, a core temperature greater than 120 °C is achieved for at least eight minutes and a core temperature greater than 130 °C is achieved for at least three minutes. The core temperatures may be achieved consecutively or through a coincidental combination of the time periods indicated. The processing may be carried out in batch or continuous systems.

Method 5: Reduction - If the particle size of the animal by-products to be processed is more than 20 millimeters, the animal by-products must be reduced in size using appropriate equipment, set so that the particle size after reduction is no greater than 20 millimeters. The effectiveness of the equipment must be checked daily and its condition recorded. If checks disclose the existence of particles larger than 20 millimeters, the process must be stopped and repairs made before the process is resumed. Time, temperature and pressure - After reduction the animal by-products must be heated until they coagulate and then pressed so that fat and water are removed from the proteinaceous material. The proteinaceous material must then be heated in a manner that ensures that a core temperature greater than 80 °C is achieved for at least 120 minutes and a core temperature greater than 100 °C is achieved for at least 60 minutes. The core temperatures may be achieved consecutively or through a coincidental combination of the time periods indicated. The processing may be carried out in batch or continuous systems.

Method 6: Reduction - The animal by-products must be reduced to a particle size that is no greater than:
(a) 50 mm, in case of heat treatment in accordance with the following Time, temperature and pressure - After reduction, the mixture must be heated to: (a) a core temperature of at least 90 °C for at least 60 minutes; or (b) 30 mm, in case of heat treatment in accordance with a core temperature of at least 70 °C for at least 60 minutes. They must then be mixed with formic acid to reduce and maintain the pH to 4.0 or lower. The mixture must be stored for at least 24 hours pending further treatment. When using a continuous flow system, the progression of the product through the heat converter must be controlled by means of mechanical commands limiting its displacement in such way that at the end of the heat treatment operation the product has undergone a cycle that is sufficient in both time and temperature. The processing may be carried out in batch or continuous systems.

2.1.3 Operational Capacity

On-site slaughter has limited throughput capacity (daily capacity: 14 head cattle, 28 swine, or 42 sheep) and would be appropriate only in extremely limited mortality scenarios (Dunlop, 2014). The grinders (such as tub grinder, vertical grinder, and other units), mixers, and accessories are available at different throughputs, capacities ranging from 20,000 lbs per hour to 450,000 lbs per hour (NABC, 2004). On-site crushers are available to process whole carcasses at the rate of 100,000 lbs per hour to 140,000 lbs per hour (Communication with Haarslev Industries, 2014). Power requirements and capacities of sample size reduction equipment are shown in Table 4.

Table 4. Typical Motor Ratings and Capacities of Size Reduction Equipment

Type	Motor Rating (Horsepower)	Capacity (ton/hour)
Hammermill	30-900	4-225
Paper and wood shredder	2-100	0.5-15
Rotary auger with counter knife	22-335	1-65
Rotary shear shredder	7.5-600	0.2-100
Shear shredder (belt type)	5-110	5-125
Tub grinder	80-990	10-100
Vertical grinder	100-400	4-225
Large-capacity vertical grinder	1,000-2,000	50-225

Notes: Adapted from NABC, 2004.

2.1.4 Environmental Issues Associated with On-site Size Reduction

Grinding presents few environmental issues that are distinct from other comparable carcass disposition processes. The most commonly cited issue is aerosol formation (liquid and solid particles suspended in the air) with either the crushing process for multiple dispositions or with grinding and material movement in composting. Lesiow and Ockerman (1999) reported viscosities of semimembranosus ground bulls muscle after 24 and 48 hours after thermal and shear force treatment ranged between 51.6 and 270.27 Pascal-second. Mechanically separated and ground material is viscous, and high shear rates can deteriorate emulsion stability. During processing, the viscosity of ground material is reduced through the addition of water. Water addition in amount sufficient to reduce viscosity to aid conveyance may result in product having unacceptably high levels of water in the finished product. Typical water additions may range from 0.5 to 3.0 gallons per minute with processed ground material flow rates ranging from 400 to 1000 lbs/minute in a meat pumping system (Schnell et al. 2005). If ground carcasses results in a slurry form after processing, the semi-viscous liquid may be prohibited from landfill disposal. An aerosol with a diameter of 5 microns or less can remain airborne for a long period of time, spread wide distances, and is easily inhaled. Particles with a diameter larger than 5 microns tend to settle rapidly and can contaminate skin, other surfaces, and ventilation systems. Research to understand the fate and transport of aerosols from a variety of size reduction equipment operations and the attenuation of those aerosols are required. Grinding, when used for burial and landfill, has the potential for more rapid decomposition as well as more rapidly discharge of fluids as leachate. All fluids should be contained and further degraded. The Council for Agricultural Science and Technology indicated that the safe distance from the carcasses to the leachate collection system generally is approximately 40 vertical feet and 60 horizontal feet from any side slope of the landfill (CAST, 2009). The impacts of these rapid decomposition and leachate discharge events are not well documented in comparison to non-ground carcass disposition. Diaz et al. (2005) discussed the importance of separation and management of liquid waste from the treated solids. The addition and/or release of liquid by size reduction brings complexity in operation as eventually the liquid has to be managed prior to discharge into the environment. Diaz et al. (2005) recognized that a special permit was required in some locations prior to treatment and discharge of liquid or this type of discharge. A case in point is the regulation of solid waste in Washington State. The Solid Waste Division of Washington State's waste acceptance rule indicates that carcasses of animals exposed to pathogens, the bedding and other waste from such animals can be accepted if treated according to Title 10 (King County Board of Health Solid Waste Regulation Title 10 provides guidance on solid waste handling, storage, collection, transportation, treatment, utilization, processing and final disposal of all solid waste generated within King County, Seattle, Washington, including issuance of permits and enforcement) of the Code of the King County Board of Health and this waste is accepted only at limited landfill locations (at the Cedar Hills Landfill for King County) and must be accompanied by a Waste Clearance Decision (King County, 2000).

Grinding and storing or grinding of carcasses and storage in chemicals (e.g., inorganic acid) or heat-treatment in sealed units should have little environmental impact. Storage in sealed containers is expected to have little environmental impact unless preservative is leaked into the environment. Grinding may improve subsequent eradication of pathogens; however, unless dispersion is contained, grinding may constitute a risk at times of disease outbreaks (e.g., avian influenza) (NABC, 2004).

2.1.5 How On-site Size Reduction Tracks to Each of the Six Disposal Options

This section describes applicability of on-site size reduction treatments against the six selected disposal options. The tick and check marks (√ and ×, respectively, in the following sections) against the disposal option provides information on the general acceptability of size reduction pretreatment (√ indicates acceptable and × indicates not acceptable).

2.1.5.1 Rendering (√)

Crushing and grinding are conventional pretreatment for rendering and are typically part of a two-step process. On-farm grinding would serve as the first step in sizing (pre-breaking stage) and saves subsequent time and cost for the renderer. Currently most carcasses are transported at ambient temperature and transportation time is generally restricted to 24 hours. Disinfectants, chemical stabilizers, or euthanasia solutions may introduce contamination risks and can make the carcasses economically non-viable for renderers to process, depending on the types of chemicals present in the additives. Rendering serves as an option to extract fat products for biofuel and to direct the proteins to non-feed uses such as fertilizer. Even if the processed bone and meat product need to be landfilled, rendering would make it more feasible than burial of the whole carcass due to decreased volume and decreased decomposition time.

2.1.5.2 Burial (√)

On-site size reduction through crushing or grinding decreases the carcass volume, increases the surface area speeding up decomposition (Lo et al., 1993), and increases the release rate for leachate. The fluid release was cited to be as high as 4.5 gallons per adult bovine carcass within the first 60 days after burial (NABC, 2004). More research would need to be conducted to compare rate of fluid/leachate release from ground carcasses versus whole carcasses. The addition of amendments for fluid control are reported to add up to 25% to the buried volume (Meeker, 2006). Concerns about leachate contamination have been raised (NABC, 2004; Pratt et al., 2012). Pratt and Fonstad (2010) reported presence of organisms found in livestock burial sites with highest abundance near the surface (up to 2.5 meter), while organisms associated with sulfate reduction were concentrated just below the burial depth (4.5-4.8 meter). These authors reported that the microbial community at the burial site (3.75 meter) was dominated by anaerobic microorganisms. Similarities with domestic septic tanks have been indicated, and suggestions were made to control environmental issues through legislation. Gwyther et al. (2011) indicated that environmental risk factors should be evaluated in terms of existing agricultural practices to determine relative risks. The overall advantages and disadvantages for burial and landfills in carcass disposal have been addressed (CAST, 2009), and the addition of on-site size reduction does not impact this disposal option. However, it is important to access and contact local burial and landfill regulations and authorities, as appropriate.

2.1.5.3 Landfill (√)

Landfill issues are similar to burial issues in terms of decreased carcass volume, increased surface area for more rapid decomposition, and an increased fluid leachate release. The generation of liquid wastes was cited to be as high as 4.5 gallons of fluid per adult bovine carcass within the first 60 days after burial (NABC, 2004). Additional research data and evaluation studies are required to compare rate of fluid/leachate release from ground carcasses versus whole carcasses. Concerns about leachate contamination have been raised (NABC, 2004), but studies have not documented environmental problems (such as gas and odor emissions) associated with landfill (Gwyther et al., 2011). The overall advantages and disadvantages for landfills in carcass disposal have been addressed (CAST, 2009). Unless ground material is considered liquid, the addition of on-site size reduction does not impact this disposal option.

2.1.5.4 Composting (√)

Grinding carcasses and mixing with organic material prior to composting are viable options. Composting time can be significantly reduced (up to 50 percent) due to uniform porosity of substrates and improving conditions for aeration. Co-composting of organic material can be incorporated into the grinding process to decrease the ratio of co-composting material. Composting is applicable to smaller carcasses such as poultry and swine than cattle (CAST, 2009) and whole cattle (Washington State University, 2008; Flynn and Hagevoort, 2013; Oregon Department of Agriculture, 2013). Mukhtar et al. (2003) reported composting whole carcasses, such as those resulting from cow mortality, in static piles using saw dust, or grinding cow carcasses prior to composting in windrows. While dissecting or grinding mortality enhances carcass biodegradation during composting, it may be a less attractive option for individuals maintaining an on-farm large-carcass composting operation. In practice, a successful composting operation that requires minimum amount of labor and inputs including cleaving or grinding of carcasses, additional moisture, forced aeration or frequent turning will be more attractive.

The key size reduction equipment required for windrow composting includes tub grinders, tub mills, hammer mills, continuous pug mills, and vertical grinders. The transfer of the ground carcass materials and other organic additives to the composting area via belt conveyer can generate dust and cause aerosolization of finer particles. The mixing time for composting varies from 5 minutes to 45 minutes and higher mixing times can increase particle dispersions and may limit overall composting throughput capacity (NABC, 2004).

2.1.5.5 Incineration (√)

Incinerators are available in a variety of types and capacities depending on the needs. For incineration, the EPA and state environmental protection divisions regulate the permitting process. The latest regulations are the EPA standard for incinerators which are: 40 Code of Federal Regulations (CFR) Part 60: Standards of Performance for New Stationary Sources and Emission Guidelines for Existing Sources: Hospital/Medical/Infectious Waste Incinerators; Final Rule (September 15, 1997) and amendments to that regulation made on October 6, 2009. Under the current regulations (40CFR60.51c), infected animal carcasses are considered medical waste. Incinerators for pathological wastes with secondary gas retention chambers are difficult to feed, particularly if large animals are to be processed. Carcasses have to be dissected or butchered to provide pieces small enough to fit through the feed door and these pieces may be heavy, difficult, and potentially dangerous to handle. These incinerators for pathological wastes are available with a top loading large door that adds considerably to the cost and is usually still not adequately sized for whole equine, bovine, or porcine carcasses. Units are available with a top-fed ram that loads tissues into the side door of the burn chamber. However, large animals must be quartered or further reduced in size before loading into the hopper of the ram. On-site grinding (pre-breaking) could be the first step in the rendering process with subsequent incineration, especially when whole carcasses cannot be processed through batch feeding (NABC 2004). On-site grinding allows for increased biosecurity with transportation in sealed tankers, continuous flow off-loading, and pre-breaking for size reduction to decrease the incineration time. During the 2001 FMD outbreak in The Netherlands, diseased animals were first rendered and then the resultant meat, bone meal, and tallow were taken to incineration plants. In Japan, cattle testing positive for BSE are disposed by incineration after size reduction (NABC, 2004). Most incineration plants in the U.S. cannot handle whole carcasses due to the capacity of the feed systems. However, the upstream system can handle processed material through grinding/crushing (NABC, 2004).

In Europe, a proprietary technology, Biomal™, was deployed to handle biomass waste (19400 lbs per hour capacity plant) for the Konvex and S.E.P. (Scandinavian Energy Project) (Figure 2). Raw material was crushed and ground and then pumped to a fluidized bed boiler where it was co-combusted together with a base fuel such as wood chips, peat or municipal waste. Energy was recovered from the animal by-products by producing renewable heat and electricity (high calorimetric heating value of approximately 7.6 to 8.3 MJ/kg fuel or approximately 0.0011 Megawatt-hour (MWh)/lb), and the net outcome of energy was considerably increased (Virta and Svärd, 2006).

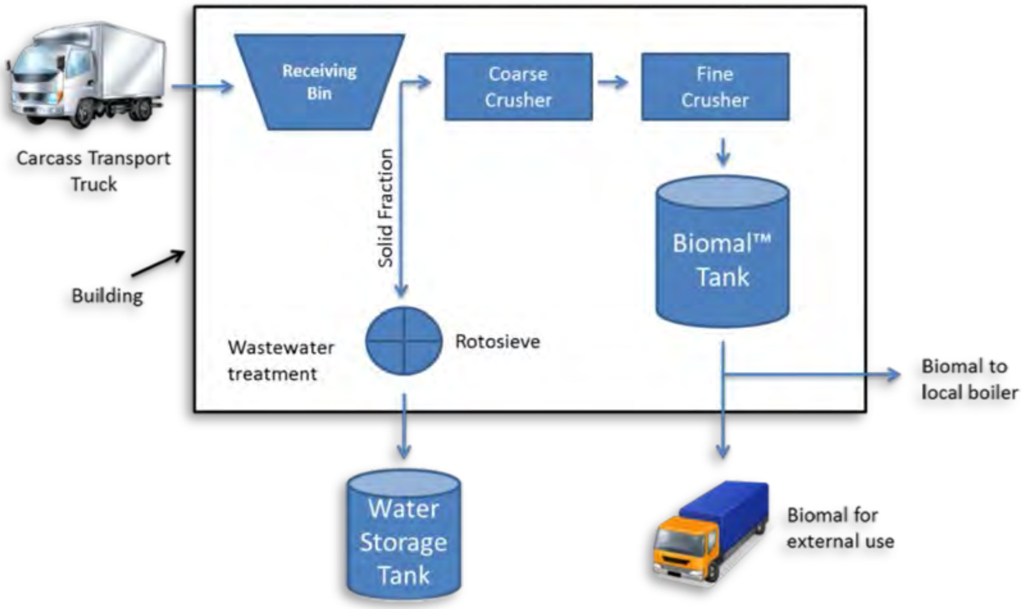


Figure 2. The Biomal™ Process.

2.1.5.6 *Burning (√)*

Grinding/crushing could be used as a pretreatment for burning of carcasses and would enhance the process efficiency if fluid material could be extracted and leave muscle and fat as the primary materials to be burned.

2.1.6 Vendors and Cost for On-site Size Reduction

Vendor of Mobile Slaughter Units

- Brother Body and Equipment, Crestline, Ohio
- Craftsman Industries, St. Charles, Missouri
- Featherlite Trailers, Cresco, Iowa

- Renewable Harvest Mobile Meat Processing, Hastings, Nebraska
- Haarslev Industries, Inc., Kansas City, Missouri
- Walinga, Wayland, Michigan
- Trivan, Ferndale, Washington
- Scan American Corporation, Kansas City, Missouri
- Titus, Inc., Plymouth, Indiana
- Industrial Hardfacing, Inc., Lamoni, Iowa
- SSI Shredding Systems, Inc. Wilsonville, Oregon

Cost of Crushers/Grinders

Costs for grinding/crushing consider only the incremental additional costs of carcass disposition. Other associated costs such as euthanasia, PPE, disinfection, carcass handling, transportation, landfill, burial, composting, incineration, and alternate disposition factors remain largely the same without regard to the grinding process. The following items provide the typical costs (obtained during 2014) from representative models/brands from sample vendors:

• Haarslev PB 30/60	$149,353 (basic crusher without frame or trailer at factory)
• Anco Crusher	$140,000
• Maxigrind	$89,000 (used)
• Vermeer TG7000 Tub Grinder	$350,000 (used)
• Trivan Mobile Processing Unit	$210,000
• Reitz-Prebreaker Unit	$100,000 new; $50,000 used

2.2 Digestion

2.2.1 Definition

Digestion is a process that liquefies carcasses under acidic conditions, either using lactic acid or phosphoric acid. Lactic acid fermentation uses bacteria to ferment the material into primarily methane, carbon dioxide, and water. Phosphoric acid preservation essentially pickles the carcasses or biomass.

Lactic acid fermentation is a process by which lactic acid bacteria are added to ground carcasses with fermentable carbohydrates to produce lactic acid under anaerobic conditions. These bacteria may produce volatile acids, hydrogen peroxide, and antibiotic-like compounds that inhibit many bacteria. A variety of animal carcasses can be treated with lactic acid fermentation, including cattle, swine, poultry, sheep, goats, fish, and wild birds (Mukhtar et al., 2008).

In the phosphoric acid preservation process, phosphoric acid is added directly to ground or small pieces of carcasses. The phosphoric acid disrupts the membrane functions of the microorganisms, reducing their disease-causing activity.

2.2.2 Application

Digestion is best achieved by first grinding the carcasses. Not only does grinding accelerate digestion, it makes the biomaterial easier to transfer to fermentation and storage tanks. A large digester can accommodate both the whole carcass and smaller pieces to reduce animal and microbial tissues to a sterile slurry. A typical 8-foot diameter mobile tissue digester (4000 lb capacity stainless steel tank to handle three cows) (Figure 3 – left) at the Wisconsin Veterinary Diagnostic Laboratory in Madison can break down carcasses into their basic building blocks (liquid mixture of amino acids, peptides, sugars, nutrients, and bone fragments). The bone fragments are separated from the liquid, and due to the brittleness of bone fragments they can be broken up and composted or used as fertilizer after appropriate inactivation of pathogens. The inserts of the digester show the sufficient capacity of a large tank to handle a crane-hoisted cow carcass to bagged deer heads (Figure 3 – right). Norwesco® (St. Bonifacius, Minnesota) manufactures tanks with capacity as large as 6,025 gallons. Ground carcasses can be added directly to the tank along with additives to aid fermentation.

The process of lactic acid fermentation creates an acidic pH that pickles carcasses, enabling them to be preserved for up to four months if they remain immersed at the proper chemical concentrations. Fermentation can be initiated by simply adding manure to ground carcasses; or more precisely, ground carcasses can be mixed with the following compounds:

- A fermentable carbohydrate such as glucose, sucrose, or lactose at a ratio of 10 percent by weight
- Whey, at 17 percent by weight
- Molasses or condensed brewer’s solubles, at 20 percent by weight
- And/or finely ground corn, at 20 to 24 percent by weight

Fermentation can be accelerated by adding starter cultures of *Lactobacillus* species. Despite careful planning and execution of the digestion process, lactic acid fermentation fails over 10 percent of the time (Mukhtar et al., 2008) due to the high nitrogen content in carcasses leading to high ammonia concentrations, which inhibits anaerobic digestion. In phosphoric acid preservation, phosphoric acid is added to ground carcasses. The phosphoric acid disrupts the membrane functions of the microorganisms, reducing their disease-causing activity. *Salmonella* spp., *Campylobacter jejuni*, fecal coliforms, and streptococci are destroyed in this process. However, neither lactic acid fermentation nor phosphoric acid preservation inactivates prions, such as TSE.

Figure 3. Digester showing Cow Carcass and Bagged Deer Heads
(photographs are shown with permission - courtesy of Jeff Miller, University of Wisconsin-Madison)

The key advantages and disadvantages of pretreatment of carcasses by digestion are shown in Table 5.

Table 5. Advantages and Disadvantages of Digestion

Advantages	Disadvantages
• Long-term storage • Kills pathogenic bacteria • Cost of storage is relatively low compared to cold storage • Increased biosecurity while minimizing the need for frequent transportation • Produces several co-products: biomethane, combined heat and power, compressed natural gas, soil amendments.	• If a digester is not available on site, the carcasses must be transported, increasing the risk of spreading the infectious agent(s) • The transmissible spongiform encephalopathy agent is not inactivated; lactic acid fermentation fails over 10 percent of the time • The capacity is relatively low (< cows per year). • Carcass pre-processing, such as grinding, is recommended. • Higher capital cost than composting. Operation requires skilled technicians.

2.2.3 Operational Capacity

Dimension of the digester dictates the scale of this process. Mukhtar et al. (2008) reported that the volume of the digester required for anaerobic fermentation of 1,000 cow carcasses (1,540 lbs per cow, or 1.54 million lbs capacity) is 7 million cubic feet, with a loading rate of 0.05 lb per cubic foot per day of volatile solids. The volume of the digester can be determined by calculating 1 lb of carcass per 4.4 cubic feet per day (0.33 lb per cubic meter (m^3) per hour) (Mukhtar et al., 2008).

Prior to digestion, carcasses need to be macerated to maximize decomposition and avoid clogging of pumps. Martin et al. (2012) reported that two sources of suitable equipment are Supreme International Limited of Wetaskiwin, Alberta, Canada and Karl Schnell, Inc., New London, Wisconsin, the United States (U.S.) distributor for Karl Schnell GmbH and Company of Winterbach, Germany. Supreme International manufactures feed processing equipment as well as equipment for cutting and blending a variety of organic wastes. Mortality processing should be performed in an enclosed facility with a receiving and a processing area and the appropriate equipment for the transfer of the carcasses from the receiving area into the macerating unit. The addition of manure to the maceration unit may be necessary to facilitate the production of a slurry that can be transferred by gravity or pumping. Due to the substantial cost of the required maceration equipment and the other infrastructure requirements, Martin et al. (2012) reported that on-site disposal of dairy cattle mortalities by digestion is suitable only for very large operations. The cost of a suitable maceration unit varies between $50,000 and $250,000, depending on the manufacturer. For smaller operations, delivery of carcasses to a centralized digestion operation or use of a portable maceration unit owned cooperatively or by a third party could be options.

2.2.4 Environmental Issues Associated with Digestion

Phosphoric acid preservation is essentially odor free; however, lactic acid fermentation of animal carcasses produces volatile and odorous compounds (such as carbon dioxide, ammonia, hydrogen sulfide, methane, and volatile organic compounds) within the digester. No notable emissions are associated with digestion methods.

After 30 days at 80°F, lactic acid digestion of poultry carcasses, for example, produces about 4 to 5 % lactic acid, 0.2 % acetic acid, 0.2 % ethanol, and 0.2 to 0.3 % ammonia-nitrogen. The treated materials maintain a composition of 63 to 67 % water, 11 to 14 % protein, 13 to 14 % fat, and 2 to 3 % ash, which is similar to the composition of the original materials.

Digested materials should be tested for pathogens of interest before they are released onto land or discharged in water.

2.2.5 How Digestion Tracks to Each of the Six Disposal Options

2.2.5.1 Rendering (√)

An advantage of acid preservation is that most rendering companies accept carcasses pickled in acid as they are ready for cooking and meat and bone meal production. In addition, lactic acid fermentation and phosphoric acid preservation eliminate the need for renderers to pick up the carcasses every day (Mukhtar et al., 2008). However, if the carcasses are known to be contaminated with prions, renderers cannot accept the digested material.

2.2.5.2 Burial (√)

The digestate material (end products that include liquid and solid fertilizers) may be released into the ground if prior testing confirms disease-causing microorganisms have been killed (Gwyther et al., 2011). If the digestate is disposed as burial or landfill options, it may be desirable to monitor water quality (surface water and shallow groundwater). However, if the digestate is applied at rates that are agronomically safe with respect to nutrients and trace metals, the environmental impacts should be minimal (NABC, 2004).

2.2.5.3 Landfill (√)

A digester produces two key products: biogas (65% to 75% methane) and digestate. Total solid content is important in the determination of land application of the digestate. The total solids are comprised of various nutrients and form the bulk of the dry matter found in the untreated material that comes out of the digester after the digester has digested the material down to extract biogas. The standard of digestate by carcass digestion for land application can be assessed on three criteria: chemical (heavy metals, persistent organic compounds and macro-elements), biological (pathogens) and physical (appearance and odor) aspects. Some tissue, such as bone and teeth, may remain after the digestion process. This material can be ground and disposed in landfills as solid waste or composted according to state and local solid waste regulations.

2.2.5.4 Composting (√)

Digested carcasses could be composted on site, if testing shows the pathogen(s) of interest have been killed in the process and there is minimal risk of releasing the waste onto the land.

2.2.5.5 Incineration (√)

The digested liquid waste may be suitable for incineration, depending on the volume restrictions of the incineration facility. The incinerator hearth should be selected/designed to contain any free liquid anticipated in the feed stream (Environment Canada, 2010). Free liquids can drain into air ports if they are situated below the liquid level in the incinerator. Liquid may also leak through the doors of a standard flat hearth incinerator and damage their seals. Leaks in other areas can lead to poor combustion performance. The auxiliary burner may need to be larger to dry the wet digested feed material in a reasonable amount of time. Digested carcasses should not cause liquid leaks from the primary chamber even though they contain high levels of moisture. Animal wastes should only be charged to an incinerator that is capable of completely calcining the bones in order to ensure that all pathogens are destroyed in the incinerator.

2.2.5.6 Burning (×)

The digested liquid waste is not suitable for burning.

2.2.6 Vendors and Cost for Digestion

Selected names of the vendors are indicated below.

- Bio-Response Solutions, Inc., Pittsboro, Indiana
- BioSAFE Engineering, LLC, Brownsburg, Indiana
- Progressive Recovery Inc., Dupo, Illinois
- RCM International LLC, Berkeley, California
- Weltec Biopower, San Jose, California
- AgroEnergien Meiners, Varel, Germany
- DLS EnviroSolutions Inc., Ontario, Canada
- Valorga, Montpellier, France

Digester costs vary by type, size, and site specific circumstances. Crenshaw (2009) provided an estimate of project cost components for a typical complete mix digester (1350 head, 200 kW) as follows:

Mix Tank	$27,079
Manure Pumping and Mixing Equipment	$47,108
Piping	$80,502
Digester Effluent System	$23,970
Post-Digestion Solids Separation System	$77,360
Engine-Generator Set and Building	$355,637
Hydrogen Sulfide (H_2S) Treatment	$25,000
Installation Labor	$54,972
Estimated Utility Charges	$30,000
Start-up Fuel	$18,212
Contingencies	$53,359
Engineering and Site Assistance	$88,039
Total Project Cost	$1,208,759

Wright and Inglis (2003) estimated the initial investment for a large-scale digestion system to be $1,032,800. The system includes the digester vessel, electrical and heating system, solids and liquids separation, liquid storage, and other materials. The annual capacity of a system of this size would be 637,000 lbs, or 850 cows per year.

If the carcasses, preferably ground, could be safely and efficiently transported, they could be dispatched to several sites with existing manure-based digesters, saving time and capital costs. The number of digesters on large-scale livestock operations topped 171 facilities (AgStar, 2010). These digesters are often used for biogas production, adding value to this option.

2.3 Bioreduction

2.3.1 Definition

Bioreduction is the aerobic or anaerobic biodegradation of animal by-products or whole carcasses in a partially sealed vessel, where the contents are mildly heated and aerated. Williams et al. (2008) indicated that the bioreduction should not be mistaken for digestion. The physical integrity is maintained within a bioreduction system, with an air-vent being the only opening to the atmosphere. Bioreduction is a method which simultaneously permits storage and reduction in the volume of carcasses and relies on internal enteric microorganisms and enzymes to drive decomposition. Carcass material is placed in a watertight vessel, where the contents are heated (to 40 ± 2 °C) and actively aerated with a pump. In contrast to anaerobic digestion, the process relies on an aqueous environment to promote microbial degradation of organic material (Gwyther et al., 2011). Significant research and field implementations of anaerobic digestion have been reported (Williams et al., 2008; Tetra Tech, 2011). Bioreduction is also described as complete bio-digestion and liquefaction of carcasses. The bioreduction vessels can be buried in the ground, so the overall footprint of the operation is reduced. Bioreduction of carcasses can take place at psychrophilic (<20 ˚C), mesophilic (20–45 ˚C) and thermophilic (45–60 ˚C) temperatures and high time–temperature combination affects the physico-chemical conditions within the system and reduce the survival of pathogenic agents (Gwyther et al., 2011). TSEs are not destroyed at the operational temperatures of bioreduction. Therefore, digestate potentially contaminated with TSEs requires additional treatment (e.g., secondary heat treatment) to satisfy biosecurity concerns. Typical in-ground bioreduction vessels are shown in Figure 4.

The combination of a mesophilic temperature and high bacterial population leads to rapid degradation of carcasses due to microbial and enzymatic breakdown of protein material; and ultimately the reduction in volume of waste to be disposed. The changes in physicochemical parameters, enzymatic activity, gas emissions and microbial communities have been reported to vary even for the same feedstock and bioreduction vessel (Gwyther et al., 2014). Acetylesterases showed the highest activity during initial stages, with a subsequent increase in lipase towards the end. Despite active aeration of the vessels, conditions were redox-constrained, leading to the emission of gases associated with anaerobic conditions, namely ammonia and hydrogen sulfide. Bioreduction does not generate renewable energy as anaerobic digestion does and may also require more expensive infrastructure than composting (Gwyther et al., 2013). However, the liquidation of carcasses coupled with evaporation during bioreduction reduces the volume of waste for disposal and hence the frequency of collection, which may offer operators both simplicity of use and a financial saving.

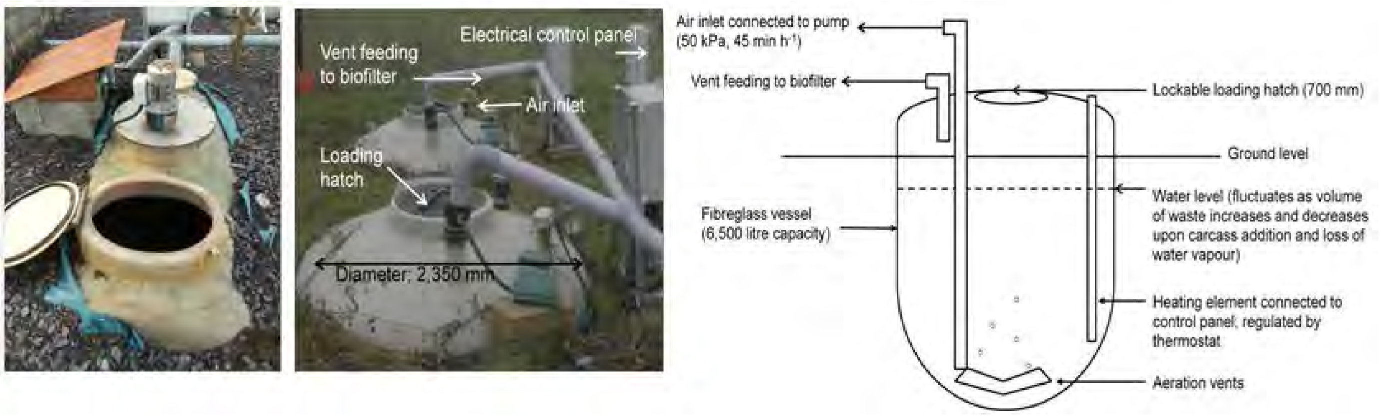
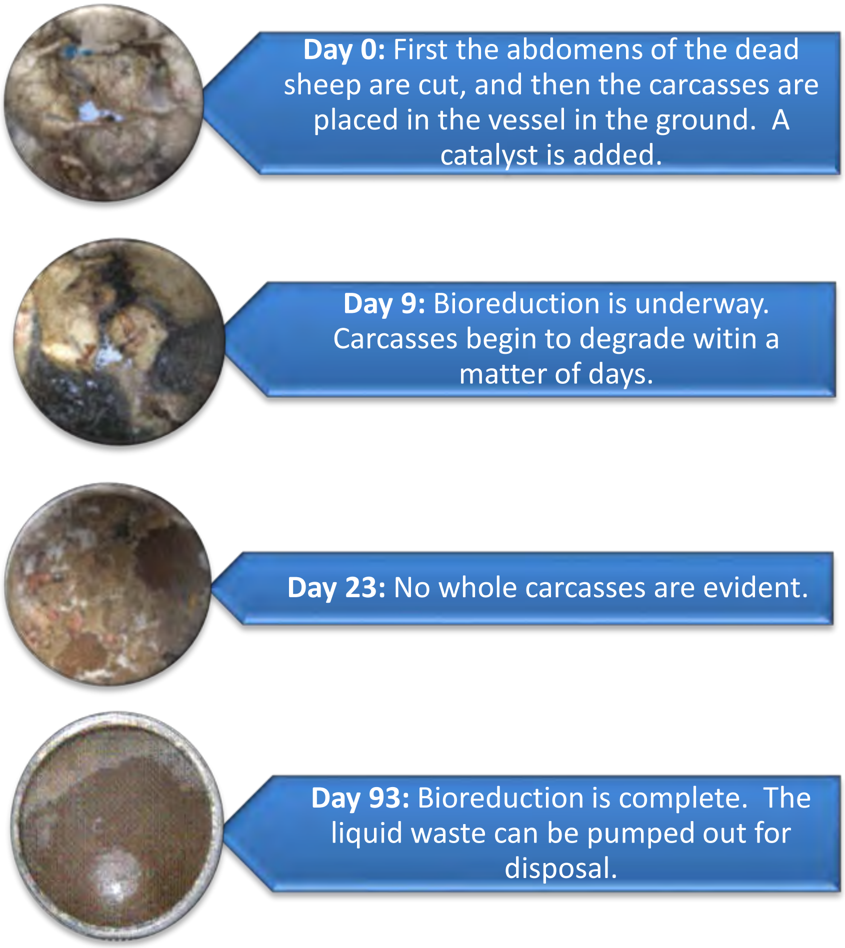


Figure 4. Types of In-ground Bioreduction Vessels and Cross-Sectional Diagram

(Modified after Williams et al., 2009 and European Food Safety Authority, 2013)

2.3.2 Application

Researchers at Bangor University in North Wales, United Kingdom, have developed an alternative method for managing livestock mortalities. Williams et al. (2009) conducted a study on bioreduction of sheep carcasses in a vessel constructed of high density polypropylene and thermostable fiberglass. The vessel interior was coated with a biphenolic type of resin to provide chemical resistance to acids and alkalis and an orthophthalic resin to enhance the strength of laminates (Gutiérrez et al., 2003). The vessel measured 2.5 m in diameter and 3 m high with an internal capacity of 6.5 m^3. The vessel was buried on the sheep farm grounds and filled halfway with water. The vessel was constantly heated to 40 ± 2 °C by a heating element. Two experiments were conducted: (1) a single input of nine dead sheep and vessel sealed for three months (three independent repeated experiments for a total of 27 sheep); and (2) continuous addition of dead animals (89 sheep and 11 bags of lambs) over 12 months. In each experiment, a skin incision was made in the abdomen of the sheep prior to placing in the vessel, to facilitate biodegradation. In addition, a commercial catalyst was added to the vessel. In each vessel, there was a complete bio-digestion and liquefaction of the sheep carcasses. Figure 5 demonstrates the carcass breakdown over three months.



Day 0: First the abdomens of the dead sheep are cut, and then the carcasses are placed in the vessel in the ground. A catalyst is added.

Day 9: Bioreduction is underway. Carcasses begin to degrade witin a matter of days.

Day 23: No whole carcasses are evident.

Day 93: Bioreduction is complete. The liquid waste can be pumped out for disposal.

Figure 5. Carcass Breakdown by In-vessel Bioreduction

(Adapted from Williams et al., 2009).

Gas emissions and the fluid waste were tested for bacteria by a variety of microbiology techniques. No *Campylobacter* spp., *Salmonellae* spp., *Escherichia coli* O157, *E. coli*, or coliforms were recovered from any samples of gaseous emissions. No *Campylobacter* spp. or *Salmonellae* spp. were recovered from the fluid waste. However, low numbers of generic *E. coli* were detected.

Gwyther et al. (2012) repeated the experiments above in a laboratory setting. *Salmonella enterica* (serovars Senftenberg and Poona), *Enterococcus faecalis*, *Campylobacter jejuni*, *Campylobacter coli*, and a *lux*-marked strain of *E. coli* O157 were inoculated into laboratory-scale bioreduction vessels containing sheep carcasses. After three months, only *E. faecalis* remained detectable (Gwyther et al., 2012).

Overall, the data on the effectiveness of bioreduction are limited. There has been some research into various accelerants for enhancing decomposition. Further, some attempt has been made to evaluate the usefulness of bioreduction for neutralizing pathogens. Enzymatic breakdown of proteins (proteolysis) during bioreduction is believed to be likely to lead to the degradation of TSEs; however, there are concerns that TSEs could remain at the bottom of the vessel. Williams et al. (2009) found that pathogens were reduced in numbers even when the vessel was stagnant, without aeration or heating.

2.3.3 Operational Capacity

On a small scale, such as under 100 sheep, bioreduction is a safe and effective on-farm method for disposing of carcasses. The average loading capacity of bioreduction system was reported to be approximately 2.75 lbs per hour (Williams et al., 2008).

2.3.4 Environmental Issues Associated with Bioreduction

The chemical composition of the liquid waste of bioreduction varies over time, but this liquid waste generally contains non-purgeable organic carbon, nitrate, ammonia, phosphate, calcium, potassium, sodium, and dissolved oxygen (O_2). The pH is roughly 8.7 after the three-month process.

Research data suggest that the environmental effects of in-vessel bioreduction are minimal. Williams et al. (2009) reported that there were no differences in gaseous composition in comparison to ambient air samples on any occasion at distances of five meters away from the vessels. These authors could not detect any carbon monoxide at any sampling event during their test trial period. However, in the anaerobic environment, when the vessel lid was sealed, the bacterial breakdown of sulfates in organic matter produced hydrogen sulfide (H_2S) in the absence of O_2. This process can lead to an occasional "rotten egg" smell of hydrogen sulfide gas. The composition of gaseous emissions varies with bacterial alternations throughout the bioreduction process. Application of wood chip biofilter through which exhaust pipes are vented showed reduction in malodor due to adherence of odorous molecules to the organic fraction of the biofilter, enabling subsequent microbial degradation (Gwyther et al., 2013).

While bioreduction is an effective method for reducing bacterial load, there are limits to the number of carcasses that can be processed based on the dimensions of the vessel. Large-scale experimental data are not available. Also, the geographical location must be considered. Earthquake-prone areas, flood-prone areas, and areas with shallow bedrock may not be suitable for in-ground vessels. Finally, the ramp-up time to install a vessel may impact how quickly carcasses can be disposed. In case of emergency or in rural areas, it may not be feasible to purchase and install a vessel in a timely manner to reduce the spread of infection. Established facilities such as livestock production facilities where known infectious risks exist and could be identified early could benefit from having on-site vessels ready to use at the first sign of an outbreak. Large operations could consider using multiple vessels in tandem to increase the number of carcasses that could be processed at a time.

A panel from European Food Safety Authority (2013) evaluated a bioreduction method for on-farm containment of ABPs of ovine origin (such as fallen sheep and placentas). This bioreduction system consisted of the aerobic degradation of ABPs in a vented, leak-proof vessel (called a "bioreducer" and directly buried in the soil), containing water, where the contents are heated (temperature 30 to 42 °C) and aerated (aeration under a pressure of 40 to 55 kilopascals (kPa). The temperature and pressure conditions create a favorable environment for bacterial degradation of carcasses resulting in their partial breakdown and a volume reduction through the loss of water vapor. The bioreducer was linked to a pipe for gaseous emissions equipped with appropriate filters (biofilter bed placed outdoors and made of wood chips and compost) to prevent the transmission of diseases communicable to humans and animals. The panel concluded that this system can reduce the risks related to pathogens such as non-spore forming bacteria and viruses. However, it is highly improbable that the risks related to more resistant biological agents (e.g., bacterial spores and TSE agents) can be reduced. The Panel noted major deficiencies in relation to the risks associated with interdependent processes, in particular, as regards to the biofilter, the opening of the bioreducer and the ability to sample for TSE surveillance. The biofilter was not demonstrated to be effective in containing the risk of aerogenic transmission of biological agents. A risk of release of pathogens to the environment when opening the bioreducer was identified.

The key advantages and disadvantages of pretreatment of carcasses by bioreduction are shown in Table 6.

Table 6. Advantages and Disadvantages of Bioreduction

Advantages	Disadvantages
• Field and laboratory results showed that the bacterial load is significantly reduced and some pathogens are eliminated • The entire pretreatment and disposal process could be performed on-site with no need for transporting carcasses • Provides a method for storing dead animals thereby reducing the number of collections and transports • Overall biomass is reduced	• Research data are only available for small-scale operations • Not known to destroy prions • The geographical location and/or terrain limits where vessels can be installed • May require additive (wood chip) to reduce malodor and reduce leaching to soil/groundwater.

In conclusion, bioreduction reduces the volume of biomaterial left over for disposal and kills some pathogenic bacteria; however, further research is needed to determine if prions and certain other infectious agents are destroyed through bioreduction.

2.3.5 How Bioreduction Tracks to Each of the Six Disposal Options

2.3.5.1 Rendering (√)

The slurry that remains at the end of the 90-day bioreduction may be acceptable to a rendering plant. However, testing for the absence of the pathogen of interest and biosecurity steps may be necessary prior to shipping to the rendering plant.

2.3.5.2 Burial (×)

While there is some evidence that bioreduction eliminates pathogens, additional tests and evaluation are needed. In the event of a large-scale die-off due to a TSE, burial of the bioreduction waste poses potential release to subsurface system and nearby water sources and can impact the risk related to the transport of the contaminants.

2.3.5.3 Landfill (×)

There are limitations on the volume and content of liquid waste that landfills can accept. In the event of a large-scale operation of a pretreatment facility, disposal of the bioreduction wastes may not be feasible.

2.3.5.4 Composting (√)

Composting may be an attractive disposal method if done on the farm. The entire process from in-vessel bioreduction to on-farm composting would eliminate the need to transport carcasses and/or slurry to another site for final disposal.

2.3.5.5 Incineration (√)

The liquid waste from bioreduction is suitable for incineration (Williams et al. 2009); however, there may be restrictions on the total volume. Destruction of pathogens (if any, present in the feed material) by incineration is only as good as the least burned material remaining in the bottom of the combustion chamber. Unburned material is often found in the ashes as they are raked out and must be returned to the chamber, putting the operator at risk. TSE agents are not destroyed by conventional incineration or by heating to as much as 600 °C under controlled conditions (CFSPH, 2012). The requisite TSE-destruction temperature is 850 °C and above (NABC, 2004; Ontario Federation of Agriculture, 2014). Thus, a reliable, simple method for destruction of TSE and other pathogenic agents is imperative. Like digestion (Section 2.2.5.5), the liquids can damage an incinerator if proper actions are not taken.

2.3.5.6 Burning (×)

After bioreduction, the material is in the form of a liquid slurry, and it is therefore not combustible.

2.3.6 Vendors and Cost for Bioreduction

No commercially available units were identified. In the research conducted by Williams et al., one vessel imported from Spain cost approximately $12,000 (Williams et al., 2009). Williams et al. (2008) have reported a detailed cost analysis of bioreduction that include stock (89 sheep, 11 bags of lamb) based on a twelve month trial period. The key components of this cost analysis include set-up (one vessel procurement and installation, electrical connection, fencing), operation (water, electricity, and ingestor product supplement), and liquor disposal.

2.4 Alkaline Hydrolysis

2.4.1 Definition of Alkaline Hydrolysis

Alkaline hydrolysis occurs when sodium hydroxide or potassium hydroxide is mixed with biological materials such as protein, nucleic acids, carbohydrates, and lipids. Heat can be applied (150 °C, or ~300°F) to significantly accelerate the process. The result is a sterile aqueous solution consisting of small peptides, amino acids, sugars, and soaps (Willis, 2003). As the process generally conducted at 150 °C in a 1 normal potassium hydroxide (1N KOH) for greater than 6 hours, the resulting effluent (pH 9-10) needs to be cooled and neutralized prior to disposal. When the alkaline solution is properly treated, it is safe for disposal in wastewater or sewer systems (NABC, 2004; Davidson et al., 2011).

2.4.2 Application of Alkaline Hydrolysis

Alkaline hydrolysis units are either mobile or fixed. Alkaline hydrolysis is carried out in a tissue digester that consists of an insulated, steam-jacketed, stainless-steel pressure vessel with a lid that is manually or automatically clamped. The vessel contains a retainer basket for bone remnants and other materials (e.g., indigestible cellulose-based materials, latex, metal). The vessel is operated at up to 70 psig to achieve a processing temperature of 150°C (NABC, 2004).

The treated product from alkaline hydrolysis may involve additional management requirements. Treated material containing free liquids with a pH ≥12.5 are regulated as unlisted hazardous wastes (corrosivity characteristic) under EPA regulations (40 CFR §261.22). Effluents from alkaline hydrolysis might exceed local discharge limits for pH, biological oxygen demand, chemical oxygen demand, and other criteria. This could preclude disposal of process effluents and residues to the sanitary sewer and under this condition alternative treatment/disposal methods such as drying and landfilling may be required

(Dufault et al., 2003). The resulting aqueous solution can only be released into a sanitary sewer system after temperature control and neutralization treatment along with testing and monitoring of effluent (e.g., for temperature and pH). This process may also produce minerals from bones and teeth (CAST, 2009). Studies have highlighted the use of the product of alkaline hydrolysis as an effective fertilizer with soil neutralizing properties (Gousterova et al., 2008; Kalambura et al., 2008). Alkaline hydrolysis kills pathogens, including *Staphylococcus aureus*, *Mycobacterium fortuitum*, *Candida albicans*, *Bacillus subtilis*, *Pseudomonas aeruginosa*, *Aspergillus fumigatus*, *Mycobacterium bovis* BCG, MS-2 bacteriophage, *Giardia muris*, and TSE (Kaye 1998; Taylor 2000). Mobile digesters, with a capacity of 4,000 lbs per six to eight hours, are mountable on mobile semi-trailers (NABC, 2004). Fixed digesters have capacity up to 10,000 lbs per eight-hour cycle. The digesters require trained personnel to operate (NABC, 2004). The key advantages and disadvantages of pretreatment of carcasses by alkaline hydrolysis are shown in Table 7.

Table 7. Advantages and Disadvantages of Alkaline Hydrolysis

Advantages	Disadvantages
• Inactivation of viruses, bacteria, spores, and transmissible spongiform encephalopathy agents • Sterilization and digestion in one unit • Reduction of waste volume and weight by as much as 97% • No air emission	• Relatively low capacity • Potential issues with disposal of effluent • High pH of effluent must be neutralized prior to disposal in a sewer system

2.4.3 Operational Capacity

Alkaline hydrolysis technologies can handle from 15 to 4,500 kilogram (kg) per load, with treatment cycles ranging from three to eight hours depending on temperature, pressure, alkali concentration, and mixing efficiency (United Nations Environment Programme [UNEP], 2012). Based on the review of various technologies and capital costs provided by vendors around the world, UNEP (2012) reported range of capacities for alkaline hydrolysis units between seven and 4,500 kg per cycle with operating costs varying from $0.10 to $0.19/kg. Based on the resources available from vendors across the U.S., on-site alkaline hydrolysis is limited due to the throughput capacity. BioSAFE Engineering (Brownsburg, Indiana) produces a 4,000 lb capacity tissue digester that can process 4,000 lbs of animal carcasses in six to eight hours, including loading, heat-up, exposure, rinsing, and unloading. Similarly, Bio-Response Solutions produces a trailer mounted mobile unit capable of processing 4,000 lbs (1,814 kg) per 18-20 hour cycle. The largest fixed facility unit has been identified has a capacity of 10,000 lbs. BioSAFE Engineering estimates that a 4,000-lb capacity unit would generate approximately 1,250 gallons (2,500 L) of undiluted hydrolysate and approximately 2,500 gallons (9,466 L) of total effluent (including hydrolysate, cooling water, rinse water, and co-flush water).

The typical installation requirements for alkaline hydrolysis include enclosure and foundation, water supply, steam (unless an electric or gas-fired steam generator is used), electrical connections, air. A typical preventive maintenance schedule includes visual checks on piping, valves, filters, O-rings, as well as checking and lubricating lid gaskets. For units that use a pump seal barrier fluid, the barrier fluid should be checked regularly for leaks. Other maintenance requirements include oil changes, O-ring replacements, and checking the accuracy of the pump pressure gauge and other monitoring sensors. The circulating pump or mechanical mixing arm is generally the part that requires the most maintenance. Figure 6 provides examples of mobile and on-site self-contained alkaline hydrolysis units.

Figure 6. Types of Alkaline Hydrolysis Units.

2.4.4 Environmental Issues Associated with Alkaline Hydrolysis

UNEP (2012) reported that alkaline hydrolysis converts tissues, organs and body parts into peptides, amino acids, soaps, salts, sugars, and ammonia. When the process is complete, a soapy ammonia odor can be detected in the immediate vicinity of the unit and is generally dissipated by natural ventilation. During this decomposition, the effluents from an alkaline hydrolysis unit can range from 100 liters per load for a 15 kg unit to 24,000 liters per load for a large 4,500 kg unit. The effluent has a pH of approximately 11 and generally has to be discharged at a slow rate, diluted or neutralized by bubbling carbon dioxide depending on local regulations. UNEP (2012) reported that the tests of the effluent showed relatively high biological oxygen demand, chemical oxygen demand, suspended solids, organic nitrogen and ammonia but were within effluent discharge limits. The solid residues of alkaline hydrolysis are calcium from friable bone fragments, and any plastics, non-reactive metals, rubber, or ceramics. Solid residues are sterile, and they can be recovered. Calcium from alkaline hydrolysis has been used as a soil conditioner. The by-products of low pressure alkaline hydrolysis units are generally in the form of a slurry with hard bone fragments. The slurry coagulates and forms a hard solid when it cools. The hydrolysate is a sterile, coffee-colored alkali solution with soap-like odor and high dry matter content, which can be used like liquid fertilizer due to high organic matter content and enriched with nitrogen, phosphorus, and potassium compared to common organic fertilizers (Kalambura et al., 2008).

The solid waste from alkaline hydrolysis is minimal, approximately 2 to 3% of total mass and consists of minerals. This solid waste could easily be handled by burial. The effluent could be disposed of in local sewers if the pH is below 11, the temperature is below 140°F, and biological oxygen demand is within the regulatory range and accepted by the municipality.

To meet local sewer district system pH requirements with upper limits of 9 to 10, carbon dioxide is bubbled through the hydrolysate that is normally between a pH of 10.3 to 11.5 to lower the pH to a range of 8 or less (NABC, 2004).

2.4.5 How Alkaline Hydrolysis Tracks to Each of the Six Disposal Options

2.4.5.1 Rendering (×)

The end products of alkaline hydrolysis are effluent and mineral constituents which are not usable in the rendering process.

2.4.5.2 Burial (√)

The solid waste from alkaline hydrolysis is minimal, approximately 2 to 3% of total mass and consists of minerals. This solid waste could easily be handled by burial. As the process hydrolyzes biologic material reducing the organic components and destroys pathogens (Willis, 2003; Idaho OnePlan, 2014). This treated effluent can be suitable as a fertilizer or as a feed in biogas and biodiesel waste recycling applications (Idaho OnePlan 2014). Disposal activities to be performed in consultations with local regulators as the local rules varies. For example, it is illegal in Idaho to leave the carcass of any animal within ¼ mile of any inhabited dwellings, public highways, or streams of water for more than 24 hours. If the exposure of or burial within 200 feet of these areas pollutes or contaminates water, a misdemeanor citation could be issued. Cremation of any animal carcass within ¼ mile of a city, town, or village is also a violation of the law.

2.4.5.3 Landfill (√)

EPA does not have any specific or unique regulations on disposal of medical wastes at landfills. Although it may not be directly applicable to a livestock disease response, EPA does have regulations governing emissions from hospital/medical/infectious waste incinerators as well as requirements under the Federal Insecticide, Fungicide and Rodenticide Act for medical waste treatment technologies that use chemicals for treating the waste. These regulations may affect disposal technologies such as fixed-facility incineration as well as alkaline hydrolysis (USDA, 2012). Though sterile bones could be landfilled, the effluent liquid needs additional treatment and different type of disposal.

2.4.5.4 Composting (×)

The end products of alkaline hydrolysis are effluent and mineral constituents, which are not usable in the composting process.

2.4.5.5 Incineration (×)

The end products of alkaline hydrolysis are effluent and mineral constituents, which are not usable in the incineration process.

2.4.5.6 Burning (×)

The end products of alkaline hydrolysis are not suitable for burning.

2.4.6 Vendors and Cost for Alkaline Hydrolysis

Selected names of the vendors are indicated below.

- Bio-Response Solutions, Inc., Pittsboro, Indiana
- Merrick & Company, Greenwood Village, Colorado
- BioSAFE Engineering, LLC, Brownsburg, Indiana
- Progressive Recovery Inc., Dupo, Illinois
- Peerless Waste Solutions, LLC, Holland, Michigan

Operating costs include operator labor, electricity, chemicals, steam, water, maintenance, and disposal fees. BioSAFE Engineering recommends using $0.10 to $0.20 per lb as an operating cost estimate. For mobile digesters, diesel fuel is needed for electricity generation and propane for steam production. Generally, one lb of steam is needed to sterilize one lb of carcasses. Operating cost or rental cost of a crane for lifting heavy carcasses should also be considered.

BioSAFE Engineering offers a mobile tissue digester with a 4,000 lb (1,814 kg) capacity for $180,000. The company also recommends a 750-gallon propane tank, water supply, 3,750-gallon mobile effluent transfer tank, and a tractor. Alternatively, Bio-Response Solutions M4000 Stainless Steel, 750-4000 lb capacity in single cycle, trailer-mounted, self-contained unit can be used. The typical cost of Bio-Response Solutions M-4000 is $180,000 (bulk purchase pricing is available at $150,000/unit). The total cost of a 2,000-lb digester (capacity: 500 lbs/hr) including digester unit, installation, dehydration and odor, control system, sampling and piping cost is reported to be $1,125, 000 (Mukhtar et al., 2008). Verma (2002) reported that the capital investment for the Tilburg plant, The Netherlands, which consisted of two digesters, each of 3300-m^3 capacity, was $17,500,000.

2.5 Steam Sterilization

2.5.1 Definition

Steam sterilization is the process of destroying microorganisms and infective agents with heated water under pressure. The steam sterilization process is time-, temperature-, and pressure-dependent. In this wet thermal treatment, the waste is first shredded and then exposed to high-pressure, high-temperature steam. Steam sterilization has similarities to the process of autoclave sterilization. The sequence of operations may vary from manufacturer to manufacturer. For example, STI first performs shredding, but there is no pressure under their current STI models. The Rotoclave$^{® \text{ rotating}}$ autoclave (Tempico Manufacturing, Hammond, Louisiana) system includes a pressurized autoclave system, but there is no “pre-shredding” of the waste. The Rotoclave system rotates so that cutting blades can chop up the waste while it is being steamed under pressure. Thus, application of steam can be with or without pressure, and with or without shredding, depending on the system. Given a suitable temperature and contact time, most varieties of microorganism are inactivated by wet thermal disinfection (for example, sporulated bacteria require 121 °C at 100 kPa for 60 minutes).

2.5.2 Application

On-site sterilization can be accomplished with a mobile steam sterilizer. These sterilizers have typically been used to handle medical waste. For on-site sterilization, carcasses can be ground or shredded to a 5 cm (2-inch) diameter size prior to sterilizing, allowing for efficient heat transfer and decreasing the sterilization time (NABC, 2004). Alternately whole carcasses including cattle carcasses can be sterilized (Sanchez, 2014).

One example of a mobile system is the BioSAFE Engineering STI Mass Animal Destruction Mobilized System. This system generally includes a utility trailer mounted electrical generator, a trailer-mounted oil-fired steam generator, a trailer-mounted shredder with feed chute, a BioSAFE Engineering trailer with two pressurized steam treatment augers, a trailer-mounted effluent decontamination system, and walking floor trailers to handle treated material (STI, 2014). The mobile STI system includes an effluent decontamination processing system to handle and sterilize the liquid effluent generated by the shredder.

The BioSAFE STI process involves following key steps (STI, 2014):

- Cattle carcasses are loaded into a feed hopper that is under a negative pressure HEPA filter air handling system to control aerosol release. The shredder is positioned just above a hopper that feeds the STI auger. So there is no conveyer belt that moves the shredded material to the STI hopper. It is all designed close together so the HEPA filtration system can work over the shredder and then the material drops directly into the enclosed hopper, which prevents any contamination from aerosols from shredding.
- The feed hopper shreds the carcass to increase the surface area to enhance the sterilization process.
- The shredded carcasses are moved by conveyer system to the BioSAFE Engineering trailer containing two rotating steam augers raising the material to boiling temperatures. The material is heated to 100 ˚C and held at that temperature for one hour in a continuous feed process.
- Fats are removed during sterilization and pumped to an effluent decontamination system to sterilize liquids and fats.
- Fluids are pumped into containers or tankers for transport to rendering or sanitary sewer system.
- Sterilized solid materials are transported for rendering or landfill.
- The system can operate on a 24-hour per day basis.

Tempico's Rotoclave® (Hammond, Louisiana) is another on-site sterilization vendor. The Tempico Rotoclave ® Process involves the following key steps (Sanchez, 2014):

- Whole carcasses (four maximum) are loaded into a vessel which is a static pressure vessel with an internally rotating auger.
- Steam is injected into the system as the carcasses are rotated or tumbled.
- The process takes approximately 90 minutes including loading and unloading.
- Alkali can be added to accomplish alkaline hydrolysis in a single batch process.
- The fluid is pumped for disposition as landfill, fertilizer, or co-combustible incineration product.

Both of the above-mentioned processes require front end loaders, water and fuel resources, and skilled operators to function. Post heating assays of the effluents from BioSAFE Engineering treated materials demonstrate sterilization or killing of microorganisms and spores by this process. Prions are not inactivated and would require an alternate process such as incineration or alkaline hydrolysis.

The key advantages and disadvantages of pretreatment of carcasses by steam sterilization are shown in Table 8.

Table 8. Advantages and Disadvantages of Steam Sterilization

Advantages	Disadvantages
• Inactivates most pathogens • Low environmental impact • Few safety issues for operators • Facilitates safe transport • Creates value-added product	• High capital cost • Requires pre-configured and constructed systems • An inadequate shredder may retard efficiency. • Requires fuel and water logistics more than other technologies discussed in this report • Operational conditions have a pronounced influence on the efficiency of disinfection. May not inactive transmissible spongiform encephalopathy agents.

2.5.3 Operational Capacity

The shredder-steam operation could potentially process 25,000 to 30,000 lb of carcass material per hour (NABC, 2004). The STI Mass Animal Destruction Mobilized System, as a continuous feed process, is rated at 22,000 lbs per hour (STI, 2014). The Tempico Rotoclave® is rated at approximately 3,950 lbs per hour including loading and unloading time (Sanchez, 2014).

2.5.4 Environmental Issues Associated with Steam Sterilization

The shredder-steam operation has few environmental issues. If the carcasses are shredded in a negative pressure system, there are limited concerns about aerosols. If whole carcasses are used, there is limited aerosol production. The end products can be recycled as co-combustible, fertilizer, or rendering product. End products that are buried or placed in a landfill have the potential requirement for leachate control.

2.5.5 How Steam Sterilization Tracks to Each of the Six Disposal Options

2.5.5.1 Rendering (√)

The fluid and solid material could be used for rendering.

2.5.5.2 Burial (√)

Sterilized material solid material can be buried, while the liquid and slurry cannot.

2.5.5.3 Landfill (√)

Sterilized solid material can be placed in a landfill, while the liquid and slurry cannot.

2.5.5.4 Composting (×)

The end products containing the effluent and mineral constituents that are not usable in the composting process.

2.5.5.5 Incineration (√)

Sterilized whole carcasses can be incinerated. The liquid and slurry of fat tissue containing calorific energy could be incinerated.

2.5.5.6 Burning (√)

Sterilized whole carcass material can be disposed by burning. The liquid and slurry of fat tissue containing calorific energy could be burned.

2.5.6 Vendors and Cost for Steam Sterilization

The BioSAFE Engineering (Brownsburg, Indiana) Mass Animal Destruction Mobile System is approximately $1.3 million including sterilizer (cost $200K). The approximate cost of treatment through the mobile animal destruction unit is $0.05 to $0.08 per lb of material (Jones, 2014).

The Tempico Rotoclave® 2.8K fixed system is $1.3 million dollars without installation. A mobile system would require a steam-producing boiler system and cooling unit as well as truck and trailer systems for mounting and transport.

OnSite Sterilization, LLC. (Pottstown, Pennsylvania), San-I-Pak (Tracy, California), Gient (Chongqing, China), and Celitron Medical Technologies (Budapest, Hungary) are some of the suppliers of mobile sterilization systems. However, no published information on the use of these systems for carcass treatment is available.

2.6 Freezing

2.6.1 Definition of Freezing

Freezing of animal carcasses can be done in fixed facilities or mobile units. Freezer types include chest freezers, crust freezers, mobile freezer units, and refrigerated industrial trucks. For large-scale applications, industrial trucks can be used on-site to store and transport carcasses. Although freezing of carcasses may have little implication for decreasing pathogens, this method can be effective in extending the storage time and helping transportation while eliminating or minimizing the decomposition process.

2.6.2 Application of Freezing

Cold storage was successfully used in The Netherlands during a 1997 outbreak of classical swine fever (hog cholera). Euthanized animals were held until released for rendering. By using temporary cold storage, disposal was accomplished almost entirely by the existing rendering capacity (Lund et al., 1997). During the 2002 pseudorabies outbreak in swine in Pennsylvania, refrigerated trucks were successfully used in carcass management. Approximately 15,000 infected hogs were loaded onto refrigerated trucks and euthanized with carbon dioxide. Initially, the carcasses were scheduled to go to rendering facilities; however, the renderers rejected diseased animals. In addition, the rendering disposal option was deemed too slow to accommodate the disposal team. Therefore, the team decided to dispose of the carcasses in landfills and bury some on site. The first load was accepted by the landfill, but a subsequent load of 80,000 lb arrived just after closing time and was not accepted. The trucks returned to the farm and the remaining carcasses were buried on site (NABC, 2004). Some large scale poultry and swine producers use freezing or refrigeration as a pre-processing step in the logistics of disposal. An on-site refrigerated truck is used to store the carcasses until full, then the carcasses are driven to a rendering plant. This approach might not be feasible for large-scale die-offs or even for large carcasses such as cattle, unless they are size-reduced. Freezing the carcasses before and during transport helps safeguard the truck or vessel from leakage of dead animal fluids. However, care should be taken to decontaminating the surfaces of the freezer after use. Some large poultry and swine producers have portable freezer units on their premises. These units have high installation and utility costs and require thawing if the subsequent processing includes size reduction (Mukhtar et al., 2008).

James et al. (2007) conducted experiments to determine whether modification of the conditions during air chilling (temperature, air velocity, and relative humidity) in combination with steam or hot water decontamination treatments could be used to reduce the numbers of pathogens on the surface of poultry carcasses. Carcasses were immersed in hot water or treated with steam, then either chilled by crust freezing (−35 °C for 23 min), chilled at 0 °C, or chilled at 15 °C. The skin was tested for bacterial colony forming units. These authors reported that the most effective method of reducing *Campylobacter jejuni* and *E. coli* was treatment with water at 80°C for 20 seconds followed by crust freezing. Crust freezing alone was not as effective as crust freezing after steam or hot water treatments. However, crust freezing did significantly reduce the bacterial burden on the skin (James et al., 2007).

Chilling systems manufactured by Air Products (Allentown, Pennsylvania) and cryogenic freezing and cooling using liquid nitrogen and carbon dioxide (Linde North America, Inc., Murray Hill, New Jersey) (Figure 7) have been used in scientific experiments and they have reduced bacterial contaminants (Kennedy and Miller 2004; James et al., 2007). Freezing may be a suitable option for reducing disease-causing bacteria prior to grinding or disposing. Freezing may also be used simply to preserve and store carcasses when immediate disposal is not possible or needs to be delayed. For example, preservation of carcasses may be needed so they do not decompose before they can be transported to a rendering plant or incinerator. In a large-scale disposal operation, the disposal facility may not have enough capacity to process all the carcasses before they begin to decompose. In this case, carcasses can be storage in freezer units until disposal.

Figure 7. Examples of Industrial Crust Freezer and Cryogenic Freezers.

UNEP (2012) reported another process called promession applicable to pathological waste, tissues, cadavers, and animal waste. The process involves freezing body parts or cadavers at -18 °C, then submerging the frozen remains in liquid nitrogen at -196 °C, transferring the brittle remains onto a mechanical shaker or vibrating mat where the mechanical action causes the remains to shatter into an organic powder, placing the powder in a vacuum chamber for drying, recovering any recyclable materials such as metals (magnetic separators can be used), and final burial in a biodegradable container. The technology has been used as an alternative to traditional burials or cremation but has the potential for application in the pretreatment of carcasses. Cryogenic freezing might be more appropriate for small operations, however, it might be expensive in case of a large scale emergency.

The key advantages and disadvantages of pretreatment of carcasses by freezing are shown in Table 9.

Table 9. Advantages and Disadvantages of Freezing

Advantages	Disadvantages
• Mobile and on-site freezing facilities are available • Increases biosecurity for transportation • Prolongs storage for delayed disposal • Low cost rental units are available • Allows for flexibility of choosing one or more disposal options	• Mobile units may not be feasible for large-scale die-offs of large animals • Thawing step required before size reduction, rendering, burning, or incineration • Limited bacterial reduction; surface reduction only for some methods of freezing • Energy cost and overall operating cost may be high

2.6.3 Operational Capacity

Crust freezers capable of processing animals larger than poultry were not identified. Mobile freezers and refrigerated trucks limit the freezing option due to limited capacity. Heavy duty refrigerated trucks have capacities as large as 11,000 lb (22 feet × 26 feet). Mobile walk-in freezers were identified with dimensions as large as 8 feet × 20 feet.

2.6.4 Environmental Issues Associated with Freezing

Transportation of frozen carcasses should minimize the risk of disease transmission. Placing dead animals in refrigerated trucks or freezer units on-site slows decomposition, prevents spread of disease to wildlife, and contains the carcasses in a controlled environment for better management.

2.6.5 How Freezing Tracks to Each of the Six Disposal Options

2.6.5.1 Rendering (√)

Refrigerated carcasses can readily be processed by rendering facilities, if they are not rejected due to infection. However, frozen carcasses need to be thawed before size reduction.

2.6.5.2 Burial (√)

Frozen carcasses can be buried on site, if an environmental assessment determines it is acceptable. Care should be taken so that there is no risk of spreading contamination via subsurface soil and groundwater.

2.6.5.3 Landfill (√)

Frozen carcasses can be disposed of in landfills, if not rejected due to infection.

2.6.5.4 Composting (√)

Frozen carcasses can be composted but need to be defrosted before size reduction/grinding.

2.6.5.5 Incineration (√)

Frozen carcasses can be incinerated after thawing.

2.6.5.6 Burning (√)

Frozen carcasses can be burned on site after thawing.

2.6.6 Vendors and Cost for Freezing

There are numerous vendors for freezers and mobile refrigeration systems (e.g., crust freezers, carcass freezers). A few examples are listed below.

- JBT Corporation, Chicago, Illinois
- Linde North America Inc., Murray Hill, New Jersey
- Marel Inc., Lenexa, Kansas
-
- LABRepCo, Horsham, Pennsylvania
- Gram Commercial A/S, Vojens, Denmark
- Polar Leasing Company, Fort Wayne, Indiana

The capital cost of a large-capacity freezer combined with power consumption costs can make this pretreatment an expensive option. Freezers that hold one ton of carcasses are available for approximately $2,000 and require electricity at approximately $1.20 per day or $0.01 per lb ($20 per ton) (Morrow and Ferket, 1993). The actual freezer cost varies with manufacturer, type of unit, and capacity. The typical cost in representative units is as follows: LABRepCo's Futura Silver Series 22-cubic foot manual defrost chest freezer $1,273, rental cost of 8-foot × 20-foot walk-in freezer from Polar Leasing Company is $1,176/month, heavy duty refrigerated truck (11,000-lb capacity) is $185.95/day. The freezers need to be decontaminated after use as appropriate. Selection of appropriate disinfectant and decontaminate procedure should be followed for owned or rental units.

2.7 Physical Inactivation

2.7.1 Definition of Physical Inactivation

Inactivation is the process of eliminating pathogenic microorganisms (excluding bacterial spores) from inanimate objects. Different inactivation methods have different target ranges, not all methods can kill all microorganisms. Inactivation is different from sterilization, which is an absolute condition where all the living microorganisms, including bacterial spores are killed.

2.7.2 Application of Physical Inactivation

Physical inactivation includes application of dry heat (flaming, hot air oven, infrared), moist heat (below 100 ˚C, at 100 ˚C, above 100 ˚C), ultra-high pressure steam, energy (thermal, plasma arc irradiation, pulsed-field electricity, ultrasonic energy, UV light). Modified use of these processes could be considered for an on-site carcass pretreatment in case of a mass livestock mortality incident. The following subsections describe a few representative physical inactivation processes (immersion, spraying/washing, steam) that can be considered for carcass pretreatment.

2.7.2.1 Immersion

Immersion involves dipping carcasses into water vats to dilute the surface concentration of infective agent on the body. This requires a dipping tank, loaders, drying racks, and a wastewater collection capability. If hot or chilled water is used then a heating/cooling mechanism would also be required. Total body cattle dipping vats contain approximately 2,650 or more gallons of water, and the carcass retains approximately 1.3 gallons of water per dip (Junguera, 2014). In the meat industry, immersion of poultry carcasses for decontamination resulted in reductions of microorganisms ranging from 0.1 to 3.3 orders of magnitude (Loretz et al., 2010). This process does not effectively eliminate infective FMD agents for transport based on the quantity ($10^{3.6}$ to $10^{5.0}$) of infective agents of FMD in cattle skin measured by plaque-forming units (PFU) estimated for infectivity (Gailiunas and Cottral, 1966; Sutmoller and Vose, 1997). The immersion in water does not reduce infectious agent significantly and the process ultimately generates significant amount of wastewater, thus, this option was eliminated from further consideration.

2.7.2.2 Spraying/Washing

Spraying/washing involves using pressure sprayers to decrease the surface concentration of infective agent on the carcass. Spraying/washing would require pressure washers, loaders, washing racks, drying racks and a waste water collection capability. The washers can be hand-portable or trailer-mounted and operate in either a gasoline or electrical mode consuming from 1.4 to 4 gallons per minute. The washing process could use either cold or hot water washing. Spraying and washing for carcass surface reduction of microorganisms produce results similar to immersion, but absolute comparisons are difficult due to confounding factors (temperature, time, and contamination levels) between the processes evaluated (Loretz et al., 2010). Similar to immersion, spraying/washing does not effectively eliminate infective FMD agents. Spraying/washing has potential for aerosolizing infectious agents and this process generates large volume of wastewater. This option was eliminated from further consideration.

2.7.2.3 Steam

Steam application to carcasses could be accomplished through the use of a portable steam cleaner that uses super-heated steam to raise temperatures (143 to 188 ºC). The steam would be delivered to the carcass with an application wand similar to the wands used in power washing. The fluid requirements vary from 8 to 88 lbs of steam per hour or approximately 10.6 gallons of water at the high range of use. The equipment delivers the steam at 0 to 180 lb per square inch pressure and requires an electrical power source from 110 to 480 volts depending on the capacity (Grainger, 2014). Meat industries normally treat poultry carcasses with water/steam from 32 ºC to 260 ºC for 0.2 to 3 minutes resulting in the decrease of colony-forming units (d) at the 2.3 log to 5.5 log level, respectively (Loretz et al., 2010). This treatment can also be performed by a batch or a continuous process in which the material is heated in a steam-jacketed vessel to drive off the moisture and simultaneously release the fat. The material can be ground, then heated to release the fat and drive off the moisture and to achieve a uniformly high temperature. The processing times are limited due to the deleterious effect of steam on poultry meat for consumption but would not be limited in mass disposal situations. The steam treatment would require the steam cleaner, loaders, steaming rack, drying rack and a waste water collection capacity. The key advantages and disadvantages of pretreatment of carcasses by steam are shown in Table 10.

Table 10. Advantages and Disadvantages of Steam

Advantages	Disadvantages
• Equipment readily available • Moderate equipment cost • Moderate safety issues • Potential for reduction of surface infectious agents • Low environmental impact	• Some steam applications alone do not reduce surface bacteria • Significant wastewater/environmental impact • Potential for aerosolizing infectious agents • Slow/labor intensive, and it only removes surface pathogens. As decomposition progresses, internal pathogens will also be exposed.

2.7.2.4 Electrolyzed water

Electrolyzed water is a dilute sodium chloride solution that, through electrolysis, dissociates into acidic electrolyzed water with a pH of 2 to 3 and an active chlorine content of 10 to 90 mg/L. Alkaline electrolyzed water that has a pH of 10 to 13 can also be used (Northcutt et al., 2007; Hricova et al., 2008). Considering limited results and applications, this pretreatment method for carcasses was eliminated.

2.7.2.5 Plasma Arc

Plasma pyrolysis uses a highly ionized gas (plasma) to convert electrical energy to heat at temperatures of approximately 1650 °C and higher. Some systems use a plasma arc torch creating a high energy electrical discharge or arc between two electrodes. A carrier gas such as argon passes between the electrodes and transfers the energy to the waste material. Another design is a direct current plasma arc wherein the arc forms between a graphite electrode and the metal in a molten bath of the waste in the treatment chamber. Other systems use a non-transferred arc wherein the anode and the cathode are both part of the plasma torch. Since plasmas generate a high energy electrical discharge, they require significant amounts of electrical energy to operate (cost varies from $76.8 to $86 per ton of processed material). The capital cost of this equipment and accessories are relatively high. A 300 ton per day fixed facility plasma arc plant was priced at $27.4 million (Ducharme, 2010). Vision Plasma Systems, Inc. (Reno, Nevada) has developed a mobile plasma gasification system (costs $5.8 million) for hazardous wastes with a processing capacity of 417 lbs per hour (Waste Management World, 2012). The use of this mobile unit would require grinding/crushing of carcasses to feed into the system. The high capital costs and the high cost per ton processed precluded additional in depth consideration of plasma arc technology as a viable alternative at this time.

2.7.2.6 Ultraviolet (UV) Radiation

Radiation technologies (ionizing radiation, electron beam treatment, germicidal UV-C) have been shown to destroy pathogens. UV radiation has several potential germicidal capabilities for air and surfaces. Challenges to this technology are: (1) inability to penetrate to infectious agent level, (2) temperature to reach effective inactivation, (3) sensitivity of organism, (4) distance from the source of radiation to the surface, and (5) no commercial carcass treatment technologies using irradiative processes are available presently. These limitations preclude further consideration of this process for carcass pretreatment.

2.7.2.7 Ultrasonic Inactivation

Ultrasonic inactivation involves the creation of microbubbles on surfaces that collapse and create a high pressure shock wave. Industrial uses of ultrasound for cleaning could be applied to carcasses. Application of this technology would require large dipping vats and the ability to direct the sound waves appropriately. The time involved in application, the impacts of organic material, and limited surface disinfections precluded further consideration of ultrasound as a large-scale carcass pretreatment option.

2.7.3 Operational Capacity

2.7.3.1 Steam

Based on commercial power washing estimates (PWI, 2014) and the time required for 4 log reduction of organisms (Loretz et al., 2010), it is estimated that one pressure steam washer could process a carcass in 10 to 12 minutes including loading and unloading time, but not including drying time and time for managing waste water, a rate of five to six carcasses per hour (h) per team.

2.7.4 Environmental Issues Associated with Physical Inactivation

2.7.4.1 Steam

The primary environmental concern with steam is the treatment and disposal of wastewater. Steam treatment (10.6 gallons of water per hour) generates less water than spraying or immersion (Grainger, 2014). Transport of contaminants through vapor/mist may require appropriate control measures.

2.7.5 How Physical Inactivation Tracks to Each of the 6 Disposal Options

2.7.5.1 Rendering (√)

Steam applications have no significant impacts on the rendering process.

2.7.5.2 Burial (√)

Steam applications have no significant impacts on the carcass in the burial process. Contaminated wastewater should not be buried.

2.7.5.3 Landfill (√)

Steam applications have no significant impact on the carcass in the landfill process. Contaminated wastewater should not be used in landfill.

2.7.5.4 Composting (√)

Steam applications have no significant impacts on the composting.

2.7.5.5 Incineration (√)

Steam applications have no significant impacts on the incineration process as long as the carcasses are dried.

2.7.5.6 Burning (√)

Steam applications have no significant impacts on the burning process as long as the carcasses are dried.

2.7.6 Vendors and Cost for Physical Inactivation

2.7.6.1 Steam

Stanford University evaluated operating costs and efficiency features for new equipment, and most important retrofits for old equipment. The cost varies from <$3,000 to ≥ $30,000 depending on the water usage (Fitch et al., 2013) for more efficient water. Consolidated Sterilizer Systems, Getinge USA, Inc. and Steris Corporation are suppliers of steam sterilizers. In addition, Grainger lists multiple steam cleaners from portable units starting at $1,795 to large industrial steam cleaners listed at $36,644 to $51,564.

2.8 Chemical Inactivation

2.8.1 Definition

Chemical inactivation is the use of chemical agents to kill/destroy pathogens including bacteria, spores, viruses and prions. A wide variety of chemicals are available and these chemicals include but are not limited to oxidizers (chlorine, hypochlorite, ozone, and peroxide), organic acids (lactic acid, acetic acid, and gluconic acid), organics (benzoates, propionates), bacteriocins (nisin, magainin [antimicrobial peptides]), acidic and basic electrolyzed water. Chemical inactivation can be used in conjunction with other carcass treatment processes, such as size reduction. Depending on the overall treatment scheme, chemical inactivation can be performed during size reduction by addition of chemical additives and mixing, or can be applied on the surface of the whole carcass. Surface chemical inactivation would allow for increased biosafety during loading and transport of carcasses, however, it would not serve to reduce pathogens released during decomposition while in transit.

The chemicals can be categorized in a number of ways as follows:

- Based on consistency

    a) Liquid (e.g., alcohols, phenols)

    b) Gaseous (formaldehyde vapor, ethylene oxide)

    c) Foam (trapped gas in liquid)

- Based on spectrum of activity

    a) High level

    b) Intermediate level

    c) Low level

- Based on mechanism of action

    a) Action on membrane (e.g., alcohol, detergent)

    b) Denaturation of cellular proteins (e.g., alcohol, phenol)

    c) Oxidation of essential sulfhydryl groups of enzymes (e.g., hydrogen peroxide, halogens)

    d) Alkylation of amino, carboxyl and hydroxyl groups (e.g., ethylene oxide, formaldehyde)

    e) Damage to nucleic acids (e.g., ethylene oxide, formaldehyde)

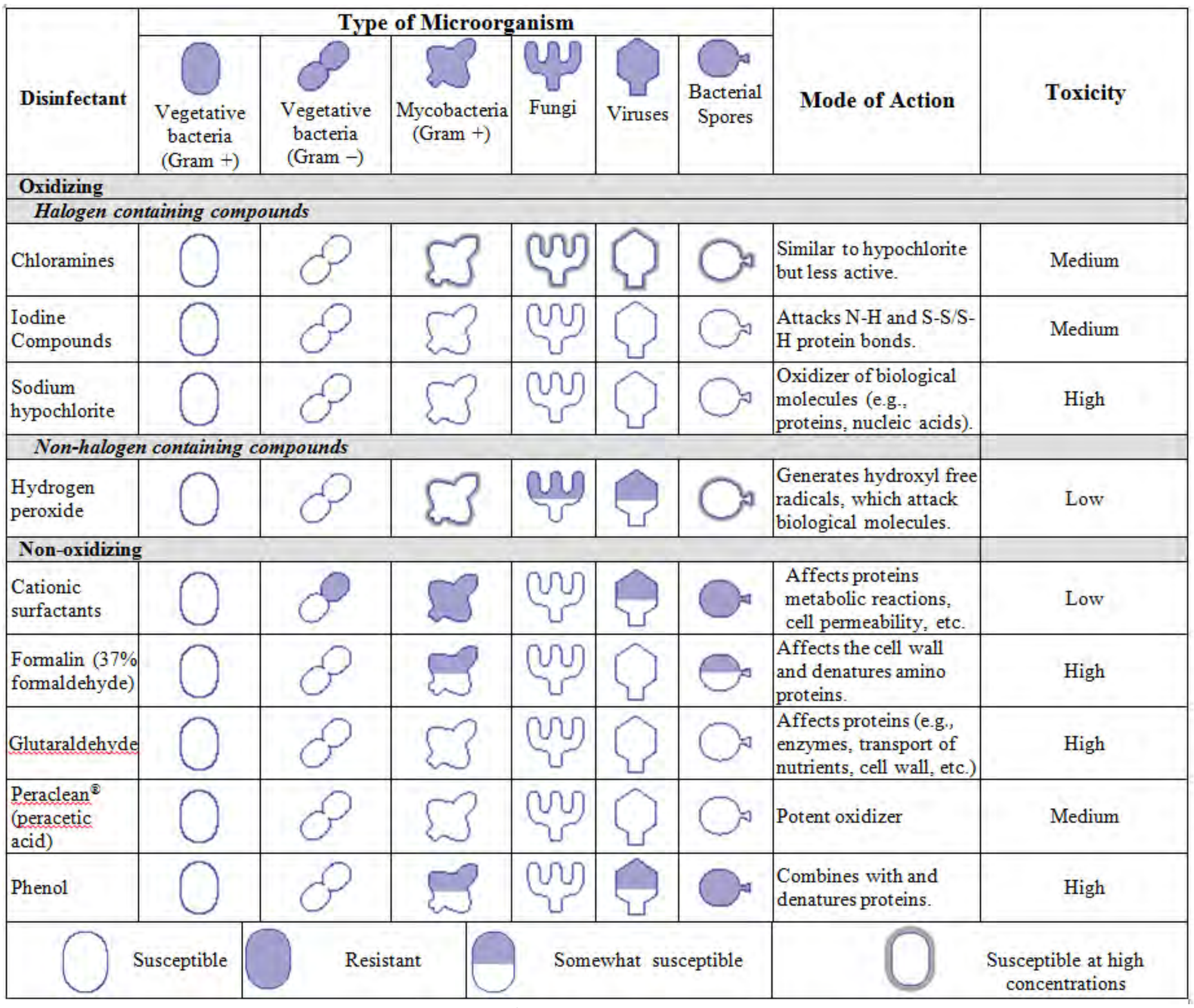
2.8.2 Application

Chemical inactivation has been extensively examined in carcass disposal literature (NABC, 2004; CAST, 2009; Gwyther et al., 2011). Most animal-related chemical inactivation processes refer to inactivation of surfaces (NABC, 2004) or to slaughter processes (Lorenz, 2010). Anthrax and TSEs present special categories of infectious agents. Anthrax spores are highly resistant to many treatment modalities including chemical inactivation. Chemical disinfectants including 10 % formaldehyde, 4 % glutaraldehyde, 3 % hydrogen peroxide, or 1 % peracetic acid have been used in decontamination of surfaces and could be used on carcass surfaces. Application of these types of agents could decrease the numbers of infective spores for transport to final site for disposal by burning or incineration which is the recommended method of anthrax carcass disposal (NABC, 2004). TSEs are highly resistant to chemical inactivation except when combined with additional processing such as alkaline hydrolysis. Strong sodium hypochlorite or hot sodium hydroxide solutions have been suggested for decontamination of TSEs and could be considered for surface decontamination (Kempf, 2003; NABC, 2004; Rutala and Weber, 2010). It should be noted that the results of inactivation studies of prions have been variable because of the use of differing methods, which may have varied according to prion strain (e.g., the differing thermostability of TSEs), prion concentration, prion detection, tissue or composition of the material/animals tested, testing method, exposure container, method of calculating log10 reductions in infectivity, concentration of the disinfectant at the beginning and end of the treatment, cycle parameters of the sterilizer, type of sterilizer, and exposure conditions. Methodological issues have been found to significantly affect the antimicrobial testing results for pathogens and are responsible for the varying results seen with various chemical disinfection methods. In the case of TSEs, since TSEs tend to be located in the nervous system, surface decontamination would have little to no benefit as a pre-treatment for transport to the final disposal process. In the case of spores, such as *Bacillus anthracis* (anthrax), although surface treatment may decrease surface spore numbers, it would not significantly decrease the total spore numbers contained in the carcass and internal spores may migrate during the decomposition process.

Chemical inactivation references for slaughter and processing of carcasses focus on elimination of foodborne organisms such as *E. coli*, *Salmonella* sp., *Campylobacter*, and *Listeria*. The effects on viruses are not reported in recent slaughter carcass reviews (Lorenz, 2010). Typical chemicals cited for use in food carcass decontamination included organic acids (levulinic, acetic, and lactic), chlorinated rinses, and trisodium phosphate. While the food industry would like to eliminate potential pathogens, the target is often reduction due to the effects of chemical treatments on the meat quality. If viral log reduction mirrors bacterial log reduction then these methods would not reduce the viral load to levels that would prevent disease spread without additional intervention.

Chemicals act through any of the following modes of organism inactivation: (1) disruption of membrane, envelope, or capsid lipid or protein constituents; (2) blockage of receptor-ligand interactions essential for infectivity; (3) inhibition of replication of pathogens; (4) alteration of the environment and reduction of susceptibility to infection; and, (5) enhancement of the local immune responses (Chattopadhyay et al., 2004). In addition to the mode of action, there are many other factors that influence the efficacy of chemical inactivation, including the properties of the selected chemical, treatment process, the size and characteristics of the carcass, type and concentration of pathogens, chemical concentration, dosage and contact time, and temperature. A comparison of the efficacy of selected chemicals on selected microorganisms (bacteria, viruses, and bacterial spores) is shown in Table 11. The shape of the symbol represents the type of pathogen, while the degree of shading provides a measure of the susceptibility of the microorganism class to the chemicals.

Table 11. Effects and Mode of Action of Selected Chemical Inactivation Agents
(Chattopadhyay et al., 2004)



Disinfectant	Type of Microorganism						Mode of Action	Toxicity
	Vegetative bacteria (Gram +)	Vegetative bacteria (Gram −)	Mycobacteria (Gram +)	Fungi	Viruses	Bacterial Spores		
Oxidizing								
Halogen containing compounds								
Chloramines	○	○	◎	◎	◎	◎	Similar to hypochlorite but less active.	Medium
Iodine Compounds	○	○	○	○	○	○	Attacks N-H and S-S/S-H protein bonds.	Medium
Sodium hypochlorite	○	○	○	○	○	○	Oxidizer of biological molecules (e.g., proteins, nucleic acids).	High
Non-halogen containing compounds								
Hydrogen peroxide	○	○	◎	◓	◓	◎	Generates hydroxyl free radicals, which attack biological molecules.	Low
Non-oxidizing								
Cationic surfactants	○	◓	●	○	◓	●	Affects proteins metabolic reactions, cell permeability, etc.	Low
Formalin (37% formaldehyde)	○	○	◓	○	○	◓	Affects the cell wall and denatures amino proteins.	High
Glutaraldehyde	○	○	○	○	○	○	Affects proteins (e.g., enzymes, transport of nutrients, cell wall, etc.)	High
Peraclean® (peracetic acid)	○	○	○	○	○	○	Potent oxidizer	Medium
Phenol	○	○	◓	○	◓	●	Combines with and denatures proteins.	High

○ Susceptible

● Resistant

◓ Somewhat susceptible

◎ Susceptible at high concentrations

Note: Prions may not be considered to be what are currently defined as microorganisms, but at the same time they are transmissible and usually resistant to physical and chemical inactivation. Environ LpH (Steris Corp., St. Louis, Missouri), a commercial disinfectant, has been effectively inactivated prions (Race and Raymond, 2004). Prion inactivation occurs with a 1 percent solution of LpH for 10 hours or with a 10 percent LpH solution for one hour. Environ LpH is not as corrosive to surfaces as bleach or NaOH. It should be thoroughly mixed to prepare a treatment solution until uniform consistency can be achieved. User must observe the precautions and safety requirements on the registered product label.

Chemical inactivation processes include application of chemicals through vapor/gas treatment, dipping, and spraying. Due to the challenges of capture and containment of released gas after treatment, this pretreatment option will not be discussed. Carcass dipping would involve adding appropriate chemicals to a dipping vat. The carcasses would need to be moved by a lift loader, immersed, retrieved, and placed on a drying rack. Each carcass retains approximately 1.3 gallons of fluid therefore a waste solution recovery and processing system would have to be deployed (Junguera, 2014). The contact time would be determined by the type and concentration of chemical used, desired level of reduction in the microorganisms, and temperature. The dipping process would treat only the surface of the body and would require extremity, head, and rectal covering to prevent infectious agent leakage. Chemicals could also be sprayed with a low pressure sprayer. The spraying action has the potential to create aerosols that need to be controlled. The carcass can be lifted by high loader onto a spraying rack, and then the carcass may be sprayed and dried. Similar to the dipping process, waste fluid generated from the process needs to be captured and treated prior to appropriate discharge. The chemicals can also be added in a grinding/crushing process and mixed to allow thorough contact time. This procedure would allow greater surface area contact with infective organisms by the inactivating agent and allow the inactivation to continue in a closed container or tanker system while in storage or transit to the final disposition site. In all cases of chemical disinfectant use biosecurity training, material handling and safety training would be required. PPE would be required for safety of the operators during application. The key advantages and disadvantages of pretreatment of carcasses by chemical inactivation are shown in Table 12.

Table 12. Advantages and Disadvantages of Chemical Inactivation

Advantages	Disadvantages
• Commercially available • Ease of application with little training of personnel • Flexible to apply on site or centralized facility in combination with grinding	• Environmental concerns on spillage and final disposal • Surface treatment may not be effective • Some of the chemicals can be harmful • Storage prior to use and treatment of large volume of effluents may be required

Chemical treatment of carcasses might not be a stand-alone treatment because of the high dosages required to kill organisms. However, a higher kill can be accomplished when the chemical is applied in conjunction with other treatments, such as rendering and heat treatment (Loretz et al., 2010).

2.8.3 Operational Capacity

Chemical disinfection with grinding/shredding typically uses multi-stage size reduction operations. The first grinder cuts open the bags, if any, and any fibrous materials are cut into short pieces. The second grinder then cuts and grinds the material in the presence of a fine mist of disinfectant fluid, until it is able to pass through a sieve into a third grinder, which further reduces the size of the material. The ground waste is then soaked with disinfectant fluid as it passes into an air classifier. The solid particles and the fluid are then mixed with disinfectant fluid for a period of not less than 15 minutes (Queensland, 2000). The material is then de-watered and removed for disposal. The waste can then be disposed as permitted by regulatory authority. Any chemical disinfection system must hold appropriate approval and environmental authority for receiving and treating regulated wastes. Another chemical treatment system involves shredding and the use of a chemical using the simultaneous shredding and chemical disinfection to render it.

Surface chemical inactivation relies primarily on spraying or dipping carcasses with the chemical agent through low pressure spraying. Based on the similarity to other surface treatment techniques, it is estimated that approximately 5 to 6 minutes will be required per carcass, including the loading, unloading and spraying time. Vat dipping in chemical inactivation agent would require additional time for chemical inactivation over vat dipping in water only. Immersion time used by the meat industries for microbial decontamination ranges from 8 to 60 minutes (Loretz et al., 2010). Using an average of 30 minutes per carcass including loading and unloading time, using six tanks and 18 drying racks would allow for processing of 12 carcasses per hour. Additional time would need to be required for heating/chilling water and managing chemical solution waste fluid. Bagging extremities would require additional personnel, but could be accomplished at the same time as drying and would not add time to the process. Surface chemical inactivation has been eliminated from further consideration.

2.8.4 Environmental Issues Associated with Chemical Inactivation

Chemical inactivating compounds are regulated by the EPA. EPA-registered products must be applied as per the manufacturer’s instructions and Globally Harmonized System of Classification and Labeling of Chemicals (29 CFR 1910.1200) should be followed. The chemicals should be handled, controlled, and disposed in accordance with local, state and federal regulations.

2.8.5 How Chemical Inactivation Tracks to Each of the Six Disposal Options

2.8.5.1 Rendering (√)

Depending on the chemical and its concentration, rendering could be performed (National Renderers Association, Inc., 2008). Appropriate care should be taken to address corrosivity of the chemicals, if any.

2.8.5.2 Burial (√)

Carcasses treated with chemical inactivating agents may be buried if permitted by local, state, and federal regulations. Liquid wastewater containing chemicals should be separated from the solid carcass material and treated separately and should not be buried.

2.8.5.3 Landfill (√)

Carcasses treated with chemical inactivating agents may be landfilled if permitted by local, state, and federal regulations. Liquid wastewater containing chemicals should be separated from the solid carcass material and treated separately and should not be discharged to landfill.

2.8.5.4 Composting (×)

Carcasses treated with chemical inactivating agents that are biodegradable may be composted if permitted by local, state, and federal regulations. Addition of recalcitrant inactivating chemicals to carcasses can inhibit decomposition and composting organisms. Carcasses treated with recalcitrant chemical inactivating agents should not be composted. Liquid wastewater containing chemicals should be separated from the solid carcass material and treated separately and should not be composted.

2.8.5.5 Incineration (√)

Carcasses treated with chemical inactivating agents may be incinerated if permitted by local, state, and federal regulations. Many chemical inactivating agents, if any present as residue on the carcasses, are destroyed upon incineration. Liquid wastewater containing chemicals should be separated from the solid carcass material and treated separately and should not be incinerated.

2.8.5.6 Burning (√)

Carcasses treated with chemical inactivating agents may be burned if permitted by local, state, and federal regulations. Many chemical inactivating agents, if any present as residue on the carcasses, are destroyed during the burning. Liquid wastewater containing chemicals should be separated from the solid carcass material and treated separately and should not be burned.

2.8.6 Vendors and Cost for Chemical Inactivation

There are numerous vendors of chemicals. The costs are dependent on various design parameters. A few examples are indicated below.

- 2% lactic acid costs approximately $0.35 per gallon (Buege and Ingham, 2003).
- Assuming a carcass weighed 1000 lbs, it would take 50 lb of acetic acid for a ground/crushed carcass to reach a 5% mixture. At $0.57 per lb of acetic acid, it would cost $28.50 per carcass to treat.
- 10% sodium hypochlorite (bleach) costs $0.40 to 0.60 per gallon. A 1:10 sodium hypochlorite to ground carcass ratio would cost $5.20 to $7.80 to treat a carcass.

2.9 Additives/Sorbents

2.9.1 Definition

The additive/sorbent is a supplemental material mixed with or otherwise added to create a favorable condition by keeping away insects and rodents, increase movement of oxygen throughout the processed material, and absorb excess liquid produced by the decomposing carcass. Additive/sorbent materials (like wood chips, corn silage, straw/manure, rice hulks, and ground cornstalks) help keep the processed material porous, and permeable to gas. Smaller materials (like, sawdust) help absorb the liquid due to water holding capacities and contribute more compaction properties. These additives are also a carbon source needed to sustain the microbes. A combination of suitable additives with appropriate water holding capacities, porosity, gas permeability, and compaction can allow optimal oxygen passage while absorbing any excess liquid. In addition, additives/sorbents reduce potential spread of organisms during transport of processed or unprocessed material.

2.9.2 Application

Reviews on carcass disposal by various researchers did not indicate additives/sorbents as a primary treatment of carcasses (NABC, 2004; CAST, 2009; Gwyther et al., 2011, 2012). However, these materials play a significant role by absorbing fluids and odors as a treatment process auxiliary to various carcass disposal methods. Additives/sorbents that are locally available as natural or by-products are relatively cheaper than the commercially available synthetic products. Steaming the wood chip or wood shaving treated carcass material may weaken the wood prior to rendering (Erickson and Hillstrom, 1974). High carbon materials (like hardwood sawdust, ground cardboard, and ground newsprint) are preferred for composting because the carbon is more available since it decomposes more rapidly. Emergency response to hazardous material spills and management routinely use a variety of sorbents such as pads, sheets, and porous material to soak and attenuate chemicals and biologicals. Certain porous soaking materials (like, polypropylene pulp) do not neutralize, but effectively remove fluids by capillary action. Proprietary co-polymers (like, Pig ® Absorb-&-Lock® Bio-fluids) use chemical neutralizers and/or oxidants to inactivate organisms. Lime and its by-products have both sorptive properties and inactivation. Lime in the form of quicklime (CaO) or hydrated lime ($Ca(OH)_2$) can provide disinfection by raising the pH of the waste to 12 or increasing the temperature by exothermic reaction, which are beyond the tolerance ranges of most enteric pathogens. The disinfection efficacy of quicklime is also attributed to the dehydration of the carcass. With reduced water availability, bacteria will need more energy to sorb water from the litter for metabolic processes, making survival more difficult. Alkaline lime kiln dust and hydrated lime were effectively used in polyethylene vaults (CAST, 2009) while other organic materials were used as a co-composting material. The application of additives/sorbents requires special material handling equipment depending on the type of additives.

Various materials can be used large carcass composting as a carbon source, including materials such as sawdust, straw, corn stover (mature cured stalks of corn with the ears removed and used as feed for livestock), poultry litter, ground corn cobs, baled corn stalks, wheat straw, semi-dried screened manure, hay, shavings, paper, silage, leaves, peat, rice hulls, cotton gin trash, yard wastes, and matured compost. In addition, bulking agents or amendments also provide some nutrients for composting. The bulking agents usually have bigger particle sizes than carbon sources and thus maintain adequate air spaces (around 25-35% porosity) within the compost pile by preventing packing of materials (USDA-NRCS, 2011). Bulking agents typically include materials such as sludge cake, spent horse bedding (a mixture of horse manure and pinewood shavings), wood chips, refuse-derived pellets, rotting hay bales, peanut shells, and tree trimmings.

The advantages and disadvantages of application of natural organic, inorganic and commercial sorbents are shown in Table 13.

Table 13. Advantages and Disadvantages of Additives/Sorbents

Advantages	Disadvantages
Natural Organic Sorbents[1]	
• Material locally available • Sustainable and low environmental impact • Enhances efficacies of burial, landfill, composting, and incineration • Few safety issues for operators • Facilitates safe transport and disposition of carcass material • Low to moderate cost per carcass	• Does not inactivate infectious agents • Hard materials (wood chips) might not be rendered. • Dependent on the amount of sorbent addition, increase in volume of material can increase disposal cost
Inorganic Sorbents[2]	
• Low environmental impact • Enhances efficacies of burial and landfill • Moderately safe for operators • Facilitates safe transport and disposition of carcass material • Moderate cost per carcass	• Eliminates rendering as a disposal option • Does not inactivate infectious agents • Unknown impact on composting. • Volatile toxics, if present, may not be suitable for incineration and burning
Commercial (Chemical) Sorbents[3]	
• Certain active ingredients can kill pathogens • Low environmental impact • Enhances efficacies of burial, landfill, and incineration • Moderately safe for operators	• Chemical neutralizers, if present, can negatively impact rendering and composting • High cost • Several of these additives do not inactivate infectious agents

1 Corn silage, straw/manure, ground cornstalks, wood chips, rice hulks, and others that are available from nature.
2 Quicklime, hydrated lime, alkaline lime kiln dust, and others.
3 Polymeric (like, Pig ® Absorb-&-Lock® Bio-fluids, New Pig Corp., Tipton, PA) and porous materials.

2.9.3 Operational Capacity

Additives/sorbents can be used in all scales of operation, and this pretreatment option is limited only by the availability of material and the ability to move it. Amount of the additive required for a carcass is dependent on carcass size and type), type of sorbent, and treatment option. For example, about 12 cubic yards of cover material is needed per 1000 lb animal composted (USDA-NRCS, 2011). This translates to approximately 1 ton of ground hay or straw, 2800 lbs of ground cornstalks, or 6400 lbs of corn silage. Carcasses over 150 lbs needs to be placed in one layer for windrow composting and covered with a 24-inch layer of wood chips. Layer animals and wood chips can achieve a finished height of 5 to 7 feet with the top layer comprising of 24-inches of wood chips to curtail odor (Donaldson and Moruza, 2010). If the large volume of additives/sorbents are applied, the volume of material to be treated and ultimately disposed will also increase. The increase in volume may impact operational capacity, labor, energy consumption, and cost.

2.9.4 Environmental Issues Associated with Additives/Sorbents

Natural absorbents present little environmental or health safety risk. Eye and respiratory PPE would be required to address the dust and flying objects. Commercial sorbents containing acidic/alkaline materials as neutralizers or oxidants (chlorine compounds) may require appropriate care during operation, handling and disposal.

2.9.5 How the Additives/Sorbents Option Tracks to Each of the Six Disposal Options

2.9.5.1 Rendering (√)

Most of the additives are soft and do not cause corrosion of the contact machinery. Hard or corrosive ingredients, if present in the additives, can make the treated carcass material unusable for rendering.

2.9.5.2 Burial (√)

Natural organic, inorganic, and commercial sorbents can be used in burial and would aid in limiting the flow of leachate into groundwater sources as well as control odors.

2.9.5.3 Landfill (√)

Landfill issues would be similar to burial as the sorbents restrict the flow of leachate and control odors.

2.9.5.4 Composting (√)

Natural organic sorbents promote the composting by providing an additional carbon source and retarding the flow of leachate. Active chemical ingredients of commercial sorbents may not be biodegradable and can hinder the composting by inhibiting the activity of microbes.

2.9.5.5 Incineration (√)

Additives/sorbents mixed with carcass material can be incinerated. These materials would increase the combustibility and enhance incineration efficiency. The sorbents containing high ash or inert materials will not promote combustion.

2.9.5.6 Burning (√)

Like incineration, combustible sorbents can help burning.

2.9.6 Vendors and Cost for Additives/Sorbents

Natural organic sorbents (sawdust, wood shavings, corn stalks, wheat straw, and poultry litter) are available from local stores and their costs are dependent on sources. Wood shavings cost ranges from \$16/ton to \$90/ton with an average of \$54/ton, poultry litter ranged from \$10/ton to \$35/ton, wheat straw \$54.77/ton, and corn stover is \$72/ton. Inorganic sorbents (kiln lime and hydrated lime - EnvironLime® and Calciment®) are approximately \$11.40/ton. Commercial sorbents (Pig® Absorb-&-Lock® Bio-fluids Absorbent) are expensive and their costs range from \$21,125/ton to \$21,875/ton. Polypropylene pulp ranges from \$19,600/ton to \$22,000/ton.

2.10 Encapsulation

2.10.1 Definition of Encapsulation

On-site carcass foam encapsulation is the treatment of the carcass with cementaceous materials (such as Portland cement, gypsum cement, pozzolanic flyash, aluminum, dolomitic lime matrix), Plaster of Paris, commercial encapsulant (such as Isolyser® [Ecolab Inc., St. Paul, Minnesota]), or polyurethane foam. These materials, when fully reacted, will encase the carcass in a solid protective matrix.

2.10.2 Application of Encapsulation

On-site encapsulation of carcasses is limited in the biological or agricultural literature. Based on its use in remediation and decontamination industries, encapsulation is feasible for on-site stabilization/solidification/covering of animal carcasses to prevent disease spread on transport. Cement and lime based materials are commonly used as solidification and stabilization of various types of wastes. These types of solidified materials can pose challenge handling, transporting, and processing due to the physical and chemical properties (bulk density, hardness, inorganic cementaceous material content, and others) and impact overall treatment and disposal cost. There is limited information available on foam encapsulation in waste handling. Polyurethane spray foam could be used to encapsulate carcasses. The foam is a batch of two chemicals called A-side (typically a 50/50 mixture of methylene diphenyl diisocyanate (MDI) and polymeric methylene diphenyl diisocyanate (pMDI) or MDI-based diisocyanate and B-side (polyol resin blend) (American Chemistry Council, 2014).

Some of the chemicals present in the stabilizing/encapsulating material can be hazardous, when used in high volume pressurized situations and require safety training and PPE including canister air, face mask, and full skin protection. Due to the fluid contained in a carcass, closed cell foam would be required for carcass treatment (Duncan, 2014). Polyurethane foam can be sprayed by hand on a variety of surfaces. Figure 8 illustrates an application of foam delivery system with insert showing an operator wearing PPE during foam application. The spray material must be stored and handled with care to prevent inactivation and additional environmental issues. The components typically must be stored between 7.2 and 23.9 ˚C. Upon application the foam takes between 5 and 60 minutes to become tack-free and 8 to 24 hours for full curing (American Chemistry Council, 2014). Once completely cured, encased carcasses could be moved by front loader or fork lift onto a conveyance. Bed lining would still be required to address potential encased carcass leaking due to incomplete coverage or stress cracking of the polyurethane encasement on handling (Duncan, 2014).

Figure 8. Application of Foam and Delivery System.

The advantages and disadvantages of encapsulation of carcasses are shown in Table 14.

Table 14. Advantages and Disadvantages of Encapsulation

Advantages	Disadvantages
• Both mobile and on-site treatment facilities are available • Properly encased (stabilized and unbreached) material can prevent disease spread during transport • Pathogen inactivation possible through lime/alkaline treatment	• High cost per carcass • Low throughput • No significant pathogen inactivation

2.10.3 Operational Capacity

Estimation of encapsulation via foam spaying can be conducted based on installation capacities available on home installations. To spray 49 square feet of space takes approximately two hours (including set up time) and the total curing time is 8 to 24 hours (American Chemistry Council, 2014). Since cattle would have to be rotated to spray the entire carcass, additional time for handling would be required. Spray Polyurethane Foam Alliance (SPFA) estimates that a single carcass could be sprayed in 5 to 6 minutes (Duncan 2014). However, it would take an additional 5 to 60 minutes for the carcass handling and pre-processing steps prior to the encapsulation. Considering these factors, it is estimated that three teams could process six carcasses per hour or 48 carcasses in an eight-hour shift.

2.10.4 Environmental Issues Associated with Encapsulation

Polyurethane encasement can pose environmental issues including safety in handling the product, safe disposal of containers, air emissions on spraying, and disposition of spray product.

2.10.5 How Encapsulation Tracks to Each of the Six Disposal Options

2.10.5.1 Rendering (×)

Encapsulation of carcasses makes them unusable for rendering.

2.10.5.2 Burial (√)

Polyurethane encased carcasses could be buried. No data were available on the effect on decomposition of the carcass. Leachate release can be retarded by usage of a water resistant seal. Currently polyurethane foam can be buried. However, polyurethane wastes are not biodegradable. Several countries, such as Australia, Germany, The Netherlands, Sweden, Denmark, and Switzerland, have regulations prohibiting the use of non-biodegradable polyurethane foam for land disposal. New EU regulations also banned high carbon content material in landfills (Yang et al., 2012).

2.10.5.3 Landfill (√)

Like burial, a carcass can be encapsulated prior to landfill disposal subject to meeting the regulatory issues.

2.10.5.4 Composting (×)

Encapsulated carcasses are not appropriate for composting.

2.10.5.5 Incineration (√)

Polyurethane encapsulated carcasses can be incinerated and the polymeric carbon contributes to the co-combustion of the carcass providing 7,000 kcal heat energy per kg of foam. The foam volume is reduced to 1% on incineration (Yang et al., 2012). However, drying/curing of the encasement would require additional treatment. Proper capture/scrubbing of volatiles and other toxins released from incineration of encapsulated material may be required to prevent air pollution.

2.10.5.6 Burning (√)

Like incineration, the encapsulated carcasses can be burned. Proper care to be taken to entrap volatiles and other toxins, if any, released from burning of encapsulated material.

2.10.6 Vendors and Cost for Encapsulation

Insultech Spray Foam, LLC (Springfield, Missouri) estimates that the foam costs approximately $ 1.00 to $1.65 per square foot at a 1-inch thick application. The Spray Polyurethane Foam Alliance estimates the costs at $1.00 per board foot (1 inch × 1 foot × 1 foot) (Duncan, 2014). Berman (2003) reported the body surface area of various livestock including dairy cattle. Assuming average weight of a cow (500 kg), the estimated median surface area, as per Berman (2003), is 45 square feet (5 square meters). With foam spray costs at approximately $1.65/square foot, the approximate cost of encapsulation would be $75 per carcass. There are numerous manufacturers of high pressure polyurethane spray foam machines (Polyurethane Foam Association - www.pfa.org) with price ranging from $2,000 to $18,000. Rusmar Foam Technologies (West Chester, Pennsylvania) manufactures and provides foam products that are impermeable to seal surfaces using self-contained and portable foam generating system with coverage capacities vary from 4,500 feet^2 to 10,000 feet^2 for all-weather conditions. The cost of a drum containing 450 pound of foam chemicals ranges between $383 and $1620, with the cost of equipment (model NTC-8 with a capacity of 8 gallons per minute or 90 feet^2 per minute) at $24,500 (rental cost of equipment = $2000 per month (Bielan, 2015).

2.11 Packaging

2.11.1 Definition of Packaging

On-site carcass packaging or wrapping is containment of the carcass within a flexible or rigid container. Packaging can be done by rigid, leak-proof, break-proof packaging, or permanently closed, with sufficient absorbent material included to sorb and retain the liquid present.

2.11.2 Application of Packaging

Existing literature on carcass disposal does not reference packaging, bagging or wrapping as either a standard or novel approach to on-site management of carcasses (NABC, 2004, CAST, 2009; Gwyther et al., 2012). Packaging materials (wrapping or container systems), unless they are waterproof, can allow permeation and/or penetration of the sterilization agent and maintain sterility of the processed carcasses. Canadian Cooperative Wildlife Health Centre Ontario indicated that double-bagged carcasses can be wrapped in several layers of newspaper, which insulates the carcasses and absorbs fluid (Barker, 2005). A freezer pack (not wet ice) may be wrapped in the newspaper with the chilled carcass, but is unnecessary with frozen carcasses. The carcass in newspaper may be placed in an outer plastic bag such as a heavy-duty garbage bag, and to be sealed securely. Appropriate care needs to be taken to avoid leakage or breakage of packaged carcass during transport. Wrapping of large bales can be adapted to cover carcasses on a farm. Figure 9 shows a John Deere Frontier Inline Bale Wrapper used for hay bales. One mil (0.001”) polyethylene wrap in 5,000 to 6,000 foot rolls costs $80.00 per roll. This amount of wrap would cover 25 to 30 bales and can work at the pace of 25 to 30 bales per hour (Sears et al., 2007). No sources of bags specifically designed for cattle were found during the literature review. Alaska Game Bags (alaskagamebags.com) offers transport bags as large as 36 inch × 72 inch, which can hold large quarters of animals such as elk and moose. Human remains are routinely transported in pouches (bags) designated as Human Remains Pouches. Further study is required to determine the feasibility of these techniques in practice.

Figure 9. Wrapping Possibilities of Animal Carcasses.

The advantages and disadvantages of packaging of carcasses are shown in Table 15.

Table 15. Advantages and Disadvantages of Packaging

Advantages	Disadvantages
• Mobile and on site packaging are available • Low environmental impact • Moderate throughput capability • Few safety issues for operators • Moderate cost per carcass	• Unwrapping of carcasses may be needed prior to certain disposal procedures • If not sealed properly, there might be potential for leakage • It aids the transport and handling, however, it does not reduce the infectivity

2.11.3 Operational Capacity

Assuming that the carcasses could be wrapped at the same rate as bales, 25 to 30 carcasses could be processed per hour or 200 to 240 per eight hour shift per wrapping team (Sears et al., 2007)

2.11.4 Environmental Issues Associated with Packaging

The bagging or wrapping process presents minimal environmental issues. The wrapping material needs to be disposed as waste via burning, incineration, landfill, or burial.

2.11.5 How Packaging Tracks to Each of the Six Disposal Options

2.11.5.1 Rendering (×)

Packaging does not preclude the material from being rendered. However, packaging, bagging, or wrapping would require removal of the material prior to rendering, and destruction or disposal of the wrapping with consideration of biosecurity issues. The removal of packaging may need to be done manually and adds an additional step to the rendering process. The packaging materials need to be disposed appropriately. These requirements may result in additional processing time and economic burden to the rendering facility, making it a less feasible pretreatment option.

2.11.5.2 Burial (√)

Burial of packaged, bagged, or wrapped carcasses could decrease the rate of decomposition and decrease the rate of leachate release.

2.11.5.3 Landfill (√)

Landfill issues would be similar to burial. Landfill of packaged, bagged, or wrapped carcasses could decrease the rate of decomposition and decrease the rate of leachate release.

2.11.5.4 Composting (×)

Commercially available packaging materials are not degradable. The packaging materials need to be disposed separately.

2.11.5.5 Incineration (√)

Packaging materials have a minimal effect on incineration. Incineration plants and large incinerators are capable of receiving and handling packages of whole carcasses or processed carcass material (Simpson 2014). However, smaller incinerators with limited capacity may not be able to handle large number of whole animal carcasses. The handling of packaged whole carcasses can be addressed by adding a crushing/grinding step before incineration. Select incinerators have the capability of handling whole carcasses. Proper capture/scrubbing of volatiles and other toxins, if released, from incineration of packaging material may be required to prevent air pollution.

2.11.5.6 Burning (√)

Packaging materials have a minimal effect on burning. Cellulosic material, if any, can aid burning. Proper care to be taken to entrap volatiles and other toxins, if any, released from burning of packaging material.

2.11.6 Vendors and Cost for Packaging

2.11.6.1 Hay Bale Type Carcass Wrapping

Bale wrappers range from $8,000 to $24,000 (Sears et al., 2007). Several models (e.g., LW1166 and LW1266) of cover materials and applicators are available from John Deere (Frontier Equipment, 2010) and others (Klein and Dahlen, 2014). The cost of polyethylene wrapping plastic is $80 per roll, and one roll can handle 25 to 30 bales. If the same rate were applied to carcasses, this would equate to $2.67 to $3.20 per carcass (Sears et al., 2007).

2.11.6.2 Carcass Bagging

No commercial sources for cattle carcass bags were identified. Alaska Game Bags (Sparta, TN) offers large game transport bags for $26.95 each. Polyethylene sealed containers have been used to contain BSE-infected carcasses and disposed as landfill (Figure 10).

Figure 10. Polyethylene Sealed container for Landfilling BSE-Infected Carcasses (Photos courtesy of USDA APHIS Veterinary Services, Blue Incident Management Team, 2012).

3 Summary

This report identified, screened and evaluated various pretreatment options for infectious animal carcasses. The key objectives of these carcass pretreatment processes are to reduce the volume of the biomass and/or inactivate/contain infectious agents. The selection of a specific treatment or a combination of treatments is dependent on the type of outbreak, impacted livestock, location of the incident, available resources, and other factors. In the event of a natural disaster such as a tornado striking a pig farm, the priority is to manage the large number of dead animals in a timely manner. One approach could be to grind the carcasses, then transport to a rendering plant. Conversely, in the event of an outbreak of a communicable disease, it may be necessary to disinfect the carcasses with a decontaminant before handling and processing. The selection of inactivating agent and its application depend on the nature of the pathogen and how it is transmitted. For example, *Campylobacter* on the skin of poultry can be treated with a chemical spray or steam plus freezing. However, prions in the neural tissues of livestock require a more involved process such as high temperature incineration.

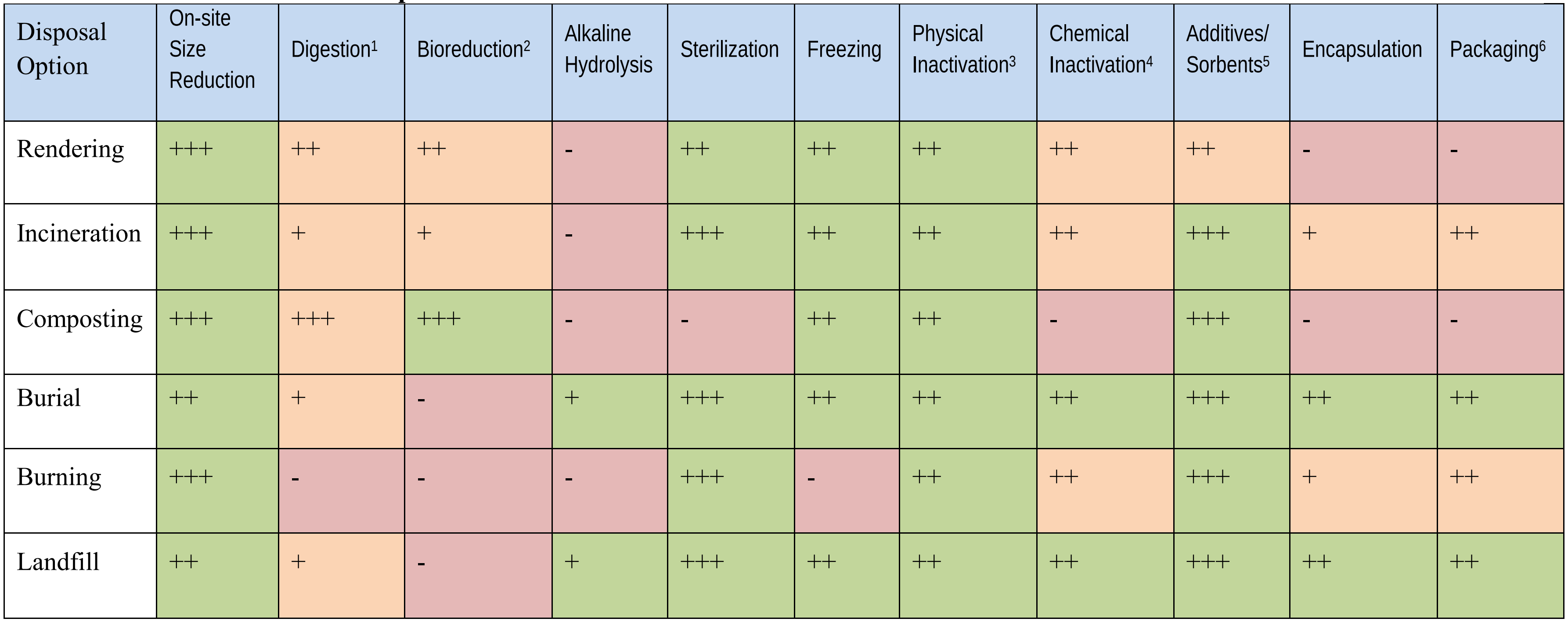
Each of the eleven pretreatment options offers unique advantages and disadvantages. None of these treatments, individually or in combination, should be considered absolute. The pretreatment scheme needs to be approached on a case by case basis. While reducing carcasses to a viscous or semi-viscous slurry may be helpful for transportation, the challenges of alkaline hydrolysis, digestion, and bioreduction are reaction time (weeks to months), release through leakage, or leaching. Some of the pretreatment options (such as on-site size reduction, chemical and physical inactivation, and steam sterilization) may require additional care to capture aerosols generated during the treatment. Additives/sorbents enhance burial, landfill, composting, and incineration but can be expensive and may increase the volume of processed material. Encapsulation and packaging involve additional cost due to the selection of stabilizer/covering material and treatment prior to disposal. Liquefaction, increase in moisture content, and release of fluids after pretreatment may pose challenges for incineration and burial. The capacity of rendering facilities and the availability of land for burial or composting may limit how much biomass can be processed by any or combination of these methods. Two or more pretreatment/disposal methods can be selected so as not to overburden a processing site. Parallel treatment schemes can be considered by using treatment of part of the feed material by selected methods, while treating the remaining part of the feed material by other method(s). For example, carcasses could be size reduced and a portion can be transported for rendering, while another portion can be composted or digested at the site. Table 16 lists a few examples of favorable applications of each pretreatment methods.

Table 16. The Favorable Applications of the Pretreatment Options

Pretreatment Options	Favorable Applications
On-site Size Reduction	Grinds carcasses to reduce size for transport and to use in subsequent processes such as composting, rendering, and digestion; high throughput applications
Alkaline Hydrolysis	Destroys prions; reduces waste volume and weight by as much as 97%. However, it generates significant amount of liquid waste that requires additional treatment.
Steam Sterilization	Sterilizes for shredded mass
Encapsulation	Safe handling; protection of the immediate environment (not during process of wrapping)
Digestion	Reduces total volume under certain conditions and may take long time
Additives/Sorbents	Enhances or accelerate disposal processes
Bioreduction	Reduces total volume and some bacterial pathogens; disposes of animals over time without the need to transport off site; effective for small quantities of biomass
Freezing	Delays decomposition; safe transportation; large capacity transport to disposal site(s); decontamination of freezer may be necessary
Inactivation	Eliminates most pathogenic microorganisms for safe transport and handling
Packaging	Safe transportation to disposal site; safe handling

Table 17 summarizes the pretreatment methods for infectious carcasses against the six disposal options. The various pretreatment methods have been color coded based on three categories: a) ideal, b) subject to acceptability of the characteristics of the feedstock by the processing facility/plant, and c) not suitable. Qualitative ratings have been provided with "+" and "-" categories for each treatment methods against six disposal options, while single or multiple + signs denote qualitative importance of the criteria, and – signs indicate not applicable. Once the carcass disposal option is selected for a site by considering various factors for a site, then the pretreatment technology scheme that best meets the need can be selected.

Table 17. Carcass Pretreatment Options Matrix Based on Extensive Evaluation



Disposal Option	On-site Size Reduction	Digestion[1]	Bioreduction[2]	Alkaline Hydrolysis	Sterilization	Freezing	Physical Inactivation[3]	Chemical Inactivation[4]	Additives/ Sorbents[5]	Encapsulation	Packaging[6]
Rendering	+++	++	++	-	++	++	++	++	++	-	-
Incineration	+++	+	+	-	+++	++	++	++	+++	+	++
Composting	+++	+++	+++	-	-	++	++	-	+++	-	-
Burial	++	+	-	+	+++	++	++	++	+++	++	++
Burning	+++	-	-	-	+++	-	++	++	+++	+	++
Landfill	++	+	-	+	+++	++	++	++	+++	++	++

Notes: Several of the pretreatments may have overlapping processes. Some of the activities can be conducted at centralized or mobile locations. +++, ++ and + denote qualitative importance of the criteria (+++ > ++ > +), and – indicate not applicable.

Color Key

🟩 Ideal 🟧 Subject to acceptability of characteristics of feedstock by the processing facility/plant 🟥 Not Suitable

Example of Color and Qualitative Ranking Codes: The green color cells of the Table indicate the treatment options that are ideal, however, +++ indicates more implementability of the treatment than the ++ or + marked treatments.

1. Digestion includes key processes including liquefaction, fermentation, and preservation.
2. Bioreduction includes both aerobic and anaerobic subcategories.
3. Physical inactivation includes application of water, ultra-high pressure steam, energy (thermal, plasma arc irradiation, pulsed-field electricity, ultrasonic energy, UV light).
4. Chemical inactivation includes but is not limited to oxidizers (chlorine, hypochlorite, ozone, and peroxide), organic acids (lactic acid, acetic acid, and gluconic acid), organics (benzoates, propionates), bacteriocins (nisin, magainin [antimicrobial peptides]). Biological treatments (such as use of bacteriophage/bacteriocins) are also included under this category.
5. Corn silage, straw/manure, ground cornstalks, saw dust, wood chips, rice hulks, and other organic sorbent materials with appropriate water holding capacities, porosity, gas permeability, compaction, and ability to maintain desired O2 concentrations.
6. Packaging involved mainly during transport and storage of untreated or treated carcasses.

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