Definition and objectives

Carcass composting is a disposal process that conceals animal carcasses under a blanket of organic material to promote decomposition at elevated temperatures.

Initially in this process, mesophilic microorganisms (those that grow in moderate temperatures, from 77 to 104 °F, or 25 to 40 ºC) heat the pile to about 104 °F (40 ºC). At this stage, naturally occurring thermophilic microorganisms (those adapted to living at high temperatures) convert the organic nitrogen and carbon compounds into a stable and relatively homogenous mixture of bacterial biomass and humic acid. In the compost pile, the organic nitrogen is mainly from animal sources and the carbon compounds are mainly from plant sources.

The objectives of carcass composting are to:

- Provide the proper conditions for carcass biodegradation.
- Inactivate some of the pathogens that can spread diseases in soil, plants, animals and humans.
- Prevent livestock carcasses from generating environmental pollutants, such as the leaching of nitrogen and sulfur compounds to groundwater and the odors that can reduce the quality of life and decrease property values.
- Convert the carcasses into useful end products for agricultural lands.

Several factors should be considered when choosing the type of carcass composting system. These include costs, system capacity, procedure speed, transportation concerns, environmental risks and the availability of resources (Table 1).
Table 1. Methods considerations for carcass composting.

<table>
<thead>
<tr>
<th>Consideration</th>
<th>Outdoor windrow composting</th>
<th>In-house windrow composting</th>
<th>Carcass bin composting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transportation concerns(^1)</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Pathogens inactivated</td>
<td>Viruses and bacteria</td>
<td>Viruses and bacteria</td>
<td>Viruses and bacteria</td>
</tr>
<tr>
<td>Capacity for carcass disposal(^2)</td>
<td>Large</td>
<td>Large</td>
<td>Small</td>
</tr>
<tr>
<td>Environmental risk</td>
<td>Medium</td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td>Regulatory restrictions</td>
<td>Medium</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Cost(^3)</td>
<td>Medium</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Availability of resources</td>
<td>Medium</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Procedure speed</td>
<td>Low</td>
<td>High</td>
<td>Medium</td>
</tr>
</tbody>
</table>

\(^1\) If the disaster area meets the disposal site requirements for carcass composting, there is no need for off-site transportation.

\(^2\) Animal carcasses (tons): Small = < 100 tons; Medium = 100–299 tons; Large = 300 or more tons

\(^3\) Cost estimate (per ton): Low = < $50; Medium = $50–100; High = $100 and more (The cutoff points may vary, depending on factors such as carcass load and types, transportation and available disposal facilities.)
Composting phases and systems

Carcass composting has two principal phases: the **active phase** and the **curing phase**. The composting method can occur in three major conventional systems: **outside windrow composting**, **in-house windrow composting** and **carcass bin composting**.

The first phase of carcass composting is characterized by aerobic (in the presence of oxygen) reactions, high temperatures and large reductions in biodegradable solids. This phase has the potential to produce significant odors.

A properly constructed carcass composting pile should have:
- An oxygen concentration of more than 5 percent.
- Particle sizes of the co-composting materials ranging from 0.5 to 2 inches.
- A pile porosity of less than 40 percent.
- Bulk densities ranging from 800 to 1,200 pounds per cubic yard.
- An average pH of 5.5 to 9.0.

The first phase of a carcass composting operation should raise the core temperature of the pile to about 135 to 140 °F within 15 days and maintain it for several days for poultry or ground carcasses, to weeks for larger intact carcasses. Under these conditions, *Mycobacterium tuberculosis* and *Salmonella* will be destroyed. If the core temperature is maintained at 149 °F for 1 to 2 days, the pathogenic bacterial activity and weed seed germination will be reduced considerably.

During the composting process, the mesophilic and thermophilic species of three groups of microorganisms—bacteria, actinomycetes and fungi—are active. These microorganisms produce a variety of antibiotics.
that destroy pathogens such as Salmonella, Shigella, polioviruses, enteroviruses, parasite cysts and Ascaris ova.

In the first phase of composting, the volume and weight of the pile may decrease by as much as 50 percent. The porosity of the pile also will decrease. As the lack of airspaces makes less oxygen available to the microbes, the compost pile becomes anaerobic, which increases the potential for odors. During Phase I, it is vital that the compost has adequate aeration to maintain a uniform temperature and moisture content throughout the pile.

The first or active phase of carcass composting takes 3 to 12 weeks, depending on the type and weight of carcasses. Most of the biomass components stabilize during this period.

In the second or curing phase, aeration is not a critical factor. During this period, a series of slow-rate reactions such as the breakdown of lignin occur at temperatures below 105 °F.

At the end of Phase II, the internal temperature of the compost pile ranges from 77 to 86 °F (25 to 30 °C), the bulk density is reduced by 25 percent, and the finished product appears dark brown to black and is free of unpleasant odors when turned.

Figure 1 shows the temperature changes of the carcasses during the two phases of outside windrow composting. Figure 2 shows the average temperatures of carcasses during in-house windrow composting.

The time required for Phase II of composting differs according to the carcass size:
- Small carcasses (poultry): 10 days
- Medium-sized carcasses (sheep and swine): 90 and 180 days
- Heavy carcasses (cattle and horses): 240 days
Figure 1. Example of internal carcass temperatures during the first 63 days the carcasses are placed in a windrow compost pile. (Courtesy of Dr. John Kube of Elanco Animal Health, Greenfield, IN)
Figure 2. An example of a daily log of internal poultry carcass temperatures during 45 days of in-house windrow composting. (Courtesy of Dr. Nathaniel Talbante of the University of Maryland College Park and Rob Malone of the University of Delaware)
**Speeding decomposition**

You can speed the decomposition of the carcasses considerably—by up to 50 percent—by grinding them before composting. Grinding provides uniform porosity and suitable conditions for aeration. It also eliminates the need to mechanically turn the carcasses three times during the two phases, a common requirement when intact carcasses are composted.

Organic co-composting materials such as peanut shells, wood chips and tree trimmings are less absorbent than straw for intact carcasses. Grinding these materials with the carcasses makes them readily available for the composting process. These organic materials are smaller (less than 2 inches) than straw.

Carcass grinding also reduces the maximum weight ratio of the bulking agent to carcass from:
- 4:1 to 1:4 for carcass bin composting
- 3:1 to 1:3 for in-house windrow composting
- 3:1 to 1:3 for outside windrow composting

**Use of biofilters**

A biofilter is a layer of organic materials (mainly from plants) placed over the compost pile to:
- Deodorize the gases released from the active pile.
- Maintain the proper moisture, pH, nutrients and temperature in the pile.
- Enhance the microbial activities in the pile.

For the first 3 days, a compost pile covered with a biofilter layer has very pronounced odor and gaseous emissions. Later, the odor level is reduced by more than 80 percent.
**End product**

The end product of carcass composting is a homogenous, dark brown, soil-like material called “humus.” This material contains mostly mesophilic bacteria and is suitable for use as a soil amendment.

Some carcass parts, such as pieces of skull, hooves, teeth and large bones, may remain intact in windrows (outside and in-house) and in carcass bin compost piles but are not identifiable in ground carcass composting. However, these materials are relatively small and brittle or rubbery and degrade when exposed to nature.

Overall, the decomposition rate of intact carcasses in a properly managed compost pile during the two phases (mainly the first phase) is about 2.2 pounds (1 kilogram) per day.
Outdoor windrow composting: Description

The goal of outside windrow composting is the natural decomposition of dead animals. Carcasses are buried above ground in a static pile (trapezoidal shape) with no walls or roofs. They are buried beneath a mound of organic materials and in the presence of oxygen.

The carcass windrow piles are mounded to shed rainfall; to better control moisture, temperature, gases and odors; and to maintain an adequate biofilter cover. The recommended height for a pile is 5 to 7 feet (1.5 to 2.1 meters).

An advantage of outdoor windrow composting is that it can be adapted for a large number of dead animals after a catastrophic event. This method is feasible for any size of animal, and the length of a windrow can be increased to accommodate additional carcasses. This method also enables the workers to load, unload and turn the pile from all sides.

However, because outdoor windrow compost piles are built in open spaces unprotected from weather, rain or wind, they are exposed to more adverse weather conditions than are other methods. These conditions can affect the degradation process of outdoor windrow compost piles.

Windrow composting of ground carcasses also requires more care and protection against health hazards during material preparation and pile formation. Figures 3 through 9 show the different stages of intact and ground carcass composting.
Composting

Figure 3. Carcasses on top of a windrow base before being covered. (Courtesy of Dr. John Kube of Elanco Animal Health, Greenfield, IN)

Figure 4. Carcasses partially covered in a windrow pile with carbon amendments. (Courtesy of Dr. John Kube of Elanco Animal Health, Greenfield, IN)
Figure 5. Contents of a cattle carcass windrow without initial grinding after 2 months of active composting. Note the steam rising from the exposed windrow. (Courtesy of Dr. John Kube of Elanco Animal Health, Greenfield, IN)
Figure 6. Loading of a carcass into a large-scale carcass grinder and windrows of composted ground carcasses. (Courtesy of Dr. John Kube of Elanco Animal Health, Greenfield, IN)
Figure 7. Ground carcass mixed with amendments ready for composting. (Courtesy of Dr. John Kube of Elanco Animal Health, Greenfield, IN)
Figure 8. A 200-foot-long windrow of 65 ground carcasses. (*Courtesy of Dr. John Kube of Elanco Animal Health, Greenfield, IN*)

Figure 9. A view of composting windrows of ground carcasses. (*Courtesy of Dr. John Kube of Elanco Animal Health, Greenfield, IN*)
In-house windrow composting: Description

An in-house windrow composting pile is built inside a livestock barn or house to reduce labor, minimize the workers’ exposure to pathogens, reduce biosecurity risks and minimize exposure to the elements.

Carcass in-house composting occurs in a poultry house after birds infected with transmissible diseases such as avian influenza are euthanized. One method of euthanizing is the foaming technique (Figs. 10 and 11). Chemicals in the foam, such as mixtures of hydrocarbon surfactants, alcohols, propylene glycol, solvents and stabilizers, produce foam bubbles that close up the breathing passages of birds (called hypoxia), causing death.

In-house windrow composting limits the transmission of diseases from the farm, reduces the risks of groundwater and air pollution, allays public concerns over disease exposure and protects the composting piles from extreme weather conditions.

This composting method is relatively low cost and uses readily available farm equipment. This system of composting protects the pile from scavengers and, to some extent, from outside disease vectors.

This method degrades carcasses efficiently, quickly and in a controlled manner, containing the disease inside the barn and inactivating the pathogens in the carcasses and litter for poultry. It also probably provides enhanced composting because environmental
Composting

parameters such as moisture and temperature can be controlled more easily in an in-house windrow composting system than in outdoor windrow composting systems. In addition, there is no need to transport contaminated carcasses.

Figure 11 shows two views of a windrow composting pile inside a poultry house.

Microbial activity (mesophilic and thermophilic) within a well-constructed in-house windrow composting pile can generate and maintain temperatures in the range of 130 to 150 °F (54 to 66 °C) for several weeks, which is sufficient to inactivate the avian influenza virus with generous margins of error.
Figure 11. The euthanizing of diseased turkeys. (Courtesy of Eric S. Bendfeldt, Virginia Cooperative Extension, Blacksburg, VA)
Figure 12. Two views of preparing windrow piles for in-house composting. (Courtesy of Eric S. Bendfeldt, Virginia Cooperative Extension, Blacksburg, VA)
Carcass bin composting: Description

The goal of carcass bin composting is the natural decomposition of dead animals buried in a contained system. The carcasses are buried in a mound of organic material and in the presence of oxygen. The system may be built of any material that is structurally adequate to confine the compost pile material.

The system consists of a:
- Primary bin to actively compost the carcasses (Phase I)
- Secondary bin to cure the carcass compost (Phase II)
- Storage bin to store the mature compost (Phase III)

In bin composting, the contained structure may or may not be covered by a roof. Unroofed bins are simple and inexpensive and can be constructed of large round bales placed end to end to form three-sided enclosures (bale composters). Although the pile is protected from predators, pests and runoff, it is susceptible to precipitation and weather variations.

Roofed bins have the advantages of reduced weather effects, less unwanted moisture, potentially less leaching from the pile, and better working conditions for the operator during inclement weather.

Although carcass bin composting is a more environmentally controlled process than is outside windrow composting, it is not feasible for handling large amounts of farm carcasses.
Coordination and jurisdictional considerations

The decision on whether to use composting for carcass disposal should be made jointly by the members of an incident command structure that has been established by state or local authorities.

Local authorities must have an inter-county memorandum of understanding in place so that the carcasses can be easily transported to the county where the nearest facility for composting is located. If the carcasses are to be transported to nearby counties for composting, the incident command structure must consider the added problems of transportation safety and contamination of other properties.

Composting should be undertaken only with the explicit approval by the institutions and agencies that are competent in making determinations about protecting the integrity of the environment.

States have established orders of priority for carcass disposal, and the incident command structure must exhaust the higher disposal priorities before undertaking composting activities.
Pollution and other property damage considerations

The exercise of police power gives wide discretion to governmental entities and agencies in making decisions about carcass disposal to protect public health. However, this police power does not shield the governmental entities from nuisance actions if the proper precautions are not taken.

The main challenge in the composting process is to make sure that the materials used to build the system are impervious to water and rot resistant. If constructed properly, composting systems usually pose no problems of odors or flies. However, the failure to build the compost facility properly could trigger nuisance or other types of lawsuits. Sovereign immunity may not be a defense to such an action.

Because injury to people or property could also trigger suits similar to those based on nuisance, the decision to use composting must be made jointly by the members of the appropriate technical group within the incident command structure.
Planning considerations

When planning to dispose of carcasses by composting, include in the discussions people from many fields of expertise: private contractors, heavy machinery operators, animal producers and personnel from regulatory agencies, fire departments, transportation departments, the Extension service, parks and recreation departments, the USDA-Natural Resources Conservation Service, county roads and public works departments and other first responders.

To minimize the neighbors’ exposure to odors or dust, plan to locate the composting facility far from water resources and downwind of homes and other dwellings (Table 2). The facility should have all-weather access and clearance from underground and overhead utilities. The site also should not interfere with other operations or traffic.

Worker training should include:
• Educating the composting crew about operational procedures, such as those on working safely, receiving and staging dead animals properly and maintaining biosecurity around carcasses
• Training the personnel involved with the on-site carcass composting on proper composting procedures
• Educating the operators of composting companies on how to produce a good organic soil amendment while protecting the environment through proper disposal of composted animal carcasses

Plan also to use personal protective equipment, including working suits, disposable overboots, disposable gloves and respirators according to Occupational Safety and Health Administration (OSHA) standards for train-
ing, equipment maintenance and composting in confined spaces.

Consider the issues related to sanitizing the equipment such as shredders or grinders and handling, packing, storing and conveying the carcasses to the composting site, as described in the Transportation section of the “General Considerations” chapter in this guide.

Plan to provide ample co-composting materials in the piles. A ratio of carbon to nitrogen (C:N) ranging from 25:1 to 40:1 must be maintained. This will provide the energy needed for the organic materials to decompose as well as minimize the production of odors during the active composting process. The weight ratio of some organic materials to carcasses is specified in Table 2.

Co-composting materials include organic materials such as sawdust (C:N~100), oats (C:N~60), barley straw (C:N~40 to 60), corn silage (C:N~40), poultry litter (C:N~10 to 30), ground corncobs (C:N~100), baled cornstalks (C:N~65), wheat straw (C:N~125), semi-dried screened cattle manure (C:N~20), hay (C:N~15 to 30), leaves (C:N~55), paper pulp or paper mill sludge (C:N~60 to 80), rice hulls (C:N~120), cotton gin trash (C:N~20 to 40), shrub trimmings (C:N~15) and bulking agents such as tree trimmings (C:N~70).

Plan to grind the carcasses and organic materials to speed the composting process and to increase the composting capacity.

The finished composted product of poultry, sheep, swine and cattle carcasses can be applied on coarse-textured soils that are low in organic matter. The product will increase those soils’ organic matter and water-holding capacity. Determine the compost application rates according to crop needs and perform a compost analysis that includes measuring the nitrogen, phosphorus and potassium levels in the end product.
### Table 2. Carcass composting specifications.

<table>
<thead>
<tr>
<th>Consideration</th>
<th>Specification</th>
</tr>
</thead>
</table>
| Carbon sources to mortality ratio                  | 1:1 (w/w)<sup>a</sup>  
                                      | 2:1 (w/w)<sup>b</sup>  
                                      | 4:1 (w/w)<sup>c</sup> |
| Compost site                                       | Height: 3 ft<sup>d</sup>  
                                      | Distance: 300 ft<sup>e</sup>  
                                      | Slope: 1–3%<sup>f</sup> |
| Bin volume (ft³/1,000 lb)                          | Phase I: 150  
                                      | Phase II: 450  
                                      | Storage: 450 |
| Lumber for bin walls (pressure treated)            | Width: 2 ft  
                                      | Length: 6–8 ft  
                                      | Thickness: 1 in studs, 2 x 6 in |
| End product                                        | Organic matter: 35–70%  
                                      | pH: 5.5–8.0  
                                      | Bulk density: 40 lb/ft³  
                                      | Moisture content: 35–40% |

<sup>a</sup> For high C:N materials such as sawdust  
<sup>b</sup> For medium C:N materials such as litter  
<sup>c</sup> For low C:N materials such as straw  
<sup>d</sup> Height of composting site above the high water-table level  
<sup>e</sup> Setback distance from sensitive water resources (such as streams, ponds and wells)  
<sup>f</sup> To provide proper drainage and prevent ponding of water
Planning for outdoor windrow composting

When planning an outdoor windrow composting operation, identify a crowned location (highest point) on which to build the concrete pad or base on the compost site.

To control water infiltration, use low-permeability soil as the initial layer for the composting pile on a concrete pad or on a base.

Provide plastic liners that are 0.24 inch thick and:

- 12 feet wide and the length of the windrow for the composting base of small carcasses (poultry)
- 13 feet wide and the length of the windrow for the composting base of medium carcasses (sheep and swine)
- 15 feet wide and the length of the windrow for the composting base of large carcasses (hogs, sows, cattle and horses)
Planning for in-house windrow composting

For an in-house windrow composting system, plan to establish and train rapid-response teams (with team leaders) within each poultry complex to oversee the sanitation, depopulation and in-house composting processes.

Make sure that the poultry house ceiling is high enough for a loader to build a compost pile to about 4 to 6 feet tall. If it is not high enough, compost the carcasses infected with transmissible diseases in an outdoor windrow system.

Plan to ventilate the in-house area because the composting piles will release large volumes of gases such as ammonia (NH$_3$) that are toxic.

If there is not enough litter in the poultry house, use other supplemental organic materials such as sawdust and woodchips. To calculate the amount of litter required for in-house windrow composting, use the formula in Figure 13.

To ensure proper in-house windrow composting, use skilled compost laborer(s) and operators of skid-steer loaders, and consult with representatives of state and federal agencies, poultry producers and composting experts. Table 3 shows the required number of skid-steer loaders and workers for each broiler house of euthanized poultry.

Plan to provide pressure washers, a tiller attachment, a hay fork, scoops and midsize skid-steer loaders (1.25-1.5 cubic yard bucket), which are more suitable for in-house handling and conveying of materials.

Plan to keep the poultry house depopulated for 2 to 4 weeks after the in-house windrow composting ends to allow for testing to ensure that the composting windrow (if kept in the house) is free of pathogens and for sanitization of the poultry house.
Figure 13. Calculation of the minimum amount of litter or other organic material required for the carcass in-house windrow composting. (Tablante and Malone, 2005)

Given:
• Floor area of poultry house: 20,000 square feet (40 feet x 500 feet)
• Number of broilers in the poultry house: 25,000
• Amount of litter required per pound of carcass weight: 0.8 cubic foot
• Average weight of each broiler: 4 pounds
• Thickness of litter base: about 3 inches

Solution:
• Total carcass weight: 100,000 pounds (4 pounds x 25,000 broilers)
• Ratio of carcass weight to floor area: 5 pounds of carcass weight per square foot (100,000 pounds ÷ 20,000 square feet)
• Required depth of litter: 4 cubic inches of litter required per carcass (5 pounds of carcass weight per square foot x 0.8 cubic foot of litter per pound of carcass weight)
• Additional litter required for each additional inch of litter base: about 1,670 cubic feet (20,000 square feet ÷ 1 inch/12 inches /foot = 1,667 cubic feet)
Table 3. Minimum loader and worker requirements to compost chicken from broiler houses. (*Tablante and Malone, 2005*)

<table>
<thead>
<tr>
<th>Number of poultry houses</th>
<th>Number of skid-steer loaders</th>
<th>Number of workers</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>6</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>8</td>
<td>5</td>
<td>10</td>
</tr>
</tbody>
</table>

Planning for carcass bin composting

When creating a carcass bin composting operation, plan to locate an appropriate composting site as described in Table 2. Use new facilities such as poured concrete, pole construction and hoop houses.

For low-cost options, use existing facilities such as machine sheds, corn cribs or cattle sheds if their ceilings are high enough to allow the front-end or skid loader to lift and turn the compost in the composting site.

Use modular bins by building compartments in the bins, which will increase the capacity and efficiency of the bin composting.

Enclose the bins on three sides, leaving an opening wide enough to accommodate a front-end loader.

Plan for the primary (Phase I), secondary (Phase II) and storage (Phase III) bin volumes as prescribed in Table 2.
For outside windrow composting, the composting site must be fenced to prevent access by livestock and scavenging animals.

Create a moisture barrier by spreading appropriate plastic liners on selected crushed and compacted rock, particularly if the water table is high or the site drains poorly.

For the composting process, use the appropriate grinding or milling equipment, including tub grinders, tub mills, hammer mills, continuous mix pug mills (machines in which materials are mixed, blended or kneaded into a desired consistency) and vertical grinders. Similarly, use a bale processor to grind baled cornstalks, hay, straw and grass.

Grind the co-composting materials for 15 to 45 minutes to provide enough air space between the compost materials. If a large crusher (able to handle more than 8,000 pounds per day) is available, grind the carcasses to 1 to 2 inches along with the organic materials to provide uniform raw materials for the composting process.

Do not mix the organic materials for more than 5 minutes. Prolonged mixing decreases the particle size because of breakage, reducing the air spaces in the compost pile.

To produce homogenous materials for the composting operations, use suitable batch mixers (either truck- or wagon-mounted), including mixers with augers, rotating paddles, rotating drum mixers or slats on a continuous chain.

Reduce the amount of fresh organic materials needed by mixing in separated solids from liquid manure or the finished composted carcasses from a previous composting batch (up to 50 percent by volume of the co-com-
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posting materials). These can be used to re-cycle the heat and bacteria in a new windrow. The handling volume of the finished compost is reduced if it is partially recycled as a co-composting material for a new windrow.

Use skid-steer or front-end loaders to:

- Build and maintain the composting piles for forming windrows
- Lift and place the carcasses on the compost piles
- Mix the co-composting materials properly
- Cover the carcasses
- Move the compost as needed for aeration
- Feed a compost screener or shredder with the finished product (Figs. 6 and 7).

Use organic materials and bulking agents to build the windrow pile for small, medium, large or very large carcasses as shown in Figures 14, 15 and 16.

Do not stack medium-sized, large or very large carcasses on top of one another. Do not stack small carcasses more than the thickness specified in Figure 14 without an appropriate layer of co-composting materials between two carcasses.

Cover the compost pile with a biofilter layer during Phase I (active) and Phase II (curing) of composting to reduce odors, preserve moisture and prevent access by insects and birds (as the most important carriers of disease microorganisms). This layer will prevent the transmission of many microorganisms from the carcasses to livestock or humans.

A minimum biofilter depth of 0.5 foot is recommended.
Figure 14. Cross-sectional dimensions (not to scale) of a trapezoidal windrow for small carcasses (such as poultry). (Source: A. Kalbasi and S. Mukhtar (2006), Biological and Agricultural Engineering Department, Texas A&M University)

- Plastic liner, 0.24 in thick, used as an impermeable layer under the composting materials
- Three layers of mixed organic materials containing plant and animal sources (such as litter) to enrich bacterial activities; they are used as a base layer and between carcass layers, each up to 1 ft thick
- Layer of bulking agent, such as wood chips, 0.5 ft thick
- Layers of poultry carcasses, each layer up 1 ft thick containing more than one row
- Biofilter layer containing mainly plant organic materials on top and two sides of the windrow, up to 1 ft thick

Bottom width (BW) = 15 ft (3.6 m); top width (TW) = 5 ft (1.5 m); height (H) depends on the thickness of carcasses
Figure 15. Cross-sectional dimensions (not to scale) of a trapezoidal windrow for medium carcasses (such as sheep and swine). *(Source: A. Kalbasi and S. Mukhtar (2006), Biological and Agricultural Engineering Department, Texas A&M University)*

- Plastic liner with thickness of 0.24 in used as an impermeable layer under the composting materials
- Two layers of mixed organic materials containing plant and animal sources (such as litter) to enrich bacterial activities; they are used as a base layer and top of carcasses, 1.5 and 1 ft thick
- Layer of moistened bulking agent, 1 to 1.5 ft thick
- Layer of medium-sized carcasses
- Biofilter layer containing mainly plant organic materials on top and two sides of the windrow, 1 ft thick

*Bottom width (BW) = 13 ft (3.9 m); top width (TW) = 1 ft (3 m); height (H) depends on the carcass thickness*
Figure 16. Cross-sectional dimensions (not to scale) of a trapezoidal windrow for large (hogs and sows) and heavy (cattle and horses) carcasses. *(Source: A. Kalbasi and S. Mukhtar (2006), Biological and Agricultural Engineering Department, Texas A&M University)*

- Plastic liner, 0.24 in thick, used as an impermeable layer underneath composting materials
- Two layers of mixed organic materials containing plant and animal sources (such as litter), 2 and 1 ft thick, respectively, used to enrich bacterial activities are used as a base layer and top of carcasses
- Layer of moistened bulking agent, 1.5–2 ft thick
- Layer of large or heavy carcasses
- Biofilter layer containing mainly plant organic materials on top and two sides of the windrow, 1 ft thick

*Bottom width (BW) = 15 ft (4.5 m); top width (TW) = 1 ft (3 m); height (H) = depends on the carcass thickness*
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Use self-propelled or towed windrow turners to adequately mix the ground carcasses and organic materials during Phase II of the intact outdoor windrow composting processes. Windrow turner capacities range from 800 to 3,000 tons per hour.

To haul water or other effluent and spray it on the windrows, use pump trucks, honey wagons with pumps or tanker trucks with side-delivery flail-type spreaders.

Maintain the moisture content in the carcass compost pile in a range of 40 to 60 percent (wet basis). Use analytical equipment or the hand-squeeze method to test the windrow moisture content.

If the compost moisture content in Phase I is low (less than 40 percent) and the pile temperature is very high (150 °F), rake back the compost pile biofilter cover (up to 1 foot) and add enough water (see the hand-squeeze method) to bring the compost moisture level to nearly 50 percent.

The hand-squeeze method

Squeeze a handful of compost material firmly several times to form a ball. If the ball crumbles or breaks into fragments, the moisture content is much less than 50 percent. If it remains intact after being gently bounced three or four times, the moisture content is nearly 50 percent. If the ball texture is slimy with a musty soil-like odor and liquid squeezes out, the moisture content is more than 50 percent.

If the carcasses are infected with diseases that can be transmitted to humans, personal protective equipment must be worn.

If liquid begins to leach out of the pile, spread an absorbent organic material such as sawdust around the pile.
If the compost temperature does not rise to expected levels within the first 2 weeks of composting, evaluate the initial pile formulation for proper C:N ratio (30:1) and the mixture of co-composting materials and carcasses. Control water run-on to and runoff from the composting site. Divert all runoff from nearby animal production facilities and treat it through a vegetative filter strip or infiltration area.

Use disposable gloves to handle and test the temperature, moisture and odor of the pile. To monitor and record the physical and chemical properties of the composting system, provide the necessary instruments and supplies, including long-stemmed thermometers, pH meters, bulk-density testing devices, odor-testing materials (resealable plastic bags) and log books to record the composting activities and status along with test results.

Insert a temperature probe carefully and straight down into each quadrant of the pile to allow daily and weekly monitoring of internal temperatures at depths of 10, 20, 30 and 40 inches after stabilization during Phases I and II of composting. Use the average to represent the compost pile temperature.

Maintain the air spaces in the windrow piles by turning (or lifting and dropping) the compost materials rather than pushing them to a new space.

Use windrow turners or bucket loaders and rotating-tiller turners (rototillers) to turn the windrow composting piles. If a bucket loader is used, the bucket contents should be discharged in a cascading manner rather than dropped as a single mass for greater pile aeration.

After the carcass compost has matured, recycle or store the finished product to begin another pile afterward or, where appropriate, land-apply the finished product as a soil amendment or as a fertilizer.
**Odor evaluation for compost**

To evaluate the odor of the compost pile during the Phase I, place two handfuls of material in a resealable plastic bag. Close the bag and let it sit for an hour, or place it in sunlight for 5 to 10 minutes.

If immediately after the bag is opened, the compost has a musty soil odor (dirt cellar odor), it is ready for Phase II.

If the compost has a sweetish odor (such as like that of slightly burnt cookies), the decomposition process needs a couple more weeks to mature.

If the compost odor is like that of rotting meat or flesh, if it is overpowering, reminiscent of manure, or if it has a strong ammonia smell but less of a manure odor, the compost process is not complete (mainly because the internal temperature is less than 130 °F and the pile is anaerobic) and requires more organic materials and aeration for temperatures to rise to acceptable levels.
In-house windrow composting: Procedures for Phase I

Begin the procedures for in-house windrow composting by making a list of the available supplies, equipment and materials. Collect site-specific data such as the age of the birds, the depth of the litter in each part of the house, the moisture and condition of the litter, the location of the carcasses, the access to the end doors for delivery of the co-composting material and compost removal, the ability to turn the piles, the poultry house dimensions, the ceiling height, and the number and average weight of the carcasses.

Unless specified otherwise in this procedure, follow the processing steps regarding organic material preparation, mixing, pile formation and turning as described in the section on outside windrow composting.

Before euthanizing the birds, let them consume all the feed, turn off the fans, close the curtains and raise the feeders and waterers in the barn. Preparations must be made in a manner that does not create an animal welfare issue.

Provide a minimum of 1.5 pounds of litter (at a density of 30 pounds per cubic foot) per pound of bird: Place 1 pound of litter per pound of bird in the layer, and use the remaining 0.5 pound for the cap and cover.

Create a windrow base of litter about 1 foot thick with a 10- to 12-foot-wide base. Scoop the dead birds with a loader and lay them on top of the base. Spread the carcasses evenly with a rake or pitchfork.

Repeat the layering procedure of litter and poultry carcasses as described in Figure 14. If the poultry house is not tall enough for a 6-foot-high windrow, make only two layers to keep the pile less than 4 feet tall.

To construct windrows in free-span houses, till the caked litter in the house to form a good base 4 to 6 inches deep for the windrow. Avoid
compacting the windrow base with equipment traffic. Use any remaining litter to cap the windrow.

Use a tiller attached to a skid-steer loader or tractor-driven power take-off (PTO) vehicle to shred the carcasses. To ensure adequate shredding, make at least two passes of the tiller with sharp tines at a high rotational speed. An alternative to shredding is to crush the carcasses under the rubber tires of a skid-steer loader.

Every day during composting, monitor and record the temperatures of the compost pile. Measure the temperature at the outside edges and from inside the center of the pile every 20 feet along the length of the windrow. Turn the windrow pile when its temperature drops below about 125 °F (52 °C) or 10 to 14 days after the composting process begins. After turning the windrow, the temperature should equal or exceed that in an unturned windrow.

If the windrow temperature peaks and drops below 105 °F within the first 2 weeks, aerate the compost by slowly lifting it with a hay fork along the length of the pile. This method does not disturb the cap but allows oxygen into the pile. If no fork is available or space is limited, the pile can be completely turned and recapped.

About 3 to 4 weeks after the windrow is built, inspect the material in the pile to evaluate the decomposition of the carcasses. At this stage, the carcasses should be reduced to bones and feathers, with little flesh remaining.

Inspect the decomposition of all fleshy materials and sample and test the pile to verify that the targeted virus has been eliminated. After complete pathogen inactivation has been confirmed, move the pile from inside the poultry house to an outdoor location (after 6 weeks of composting) and store it for 2 to 3 weeks in a litter storage shed or another appropriate roofed site with an impervious base (plastic sheet) for additional curing.
Two new fact sheets provide details on in-house poultry composting have been published:

- *Guidelines for In-House Composting Poultry Mortality as a Rapid Response to Avian Influenza*, by the Virginia Department of Environmental Quality and Virginia Cooperative Extension
- *In-House Composting of Poultry Mortality due to Catastrophic Disease*, by the University of Maryland–College Park and the University of Delaware

**Procedures for Phase I: Carcass bin composting**

When building composting bins, determine their volume based on the amount of storage required and the specifications in Table 2 for Phases I and II. Build bin composters of any material (such as concrete, wood and hay bales) that is structurally adequate to confine the compost pile material and resist lateral loads.

Simple, economical structures can be made by placing large, round bales end to end to form three-sided enclosures or bins. These are sometimes called bale composters.

Locate the structure in a free space with (preferred) or without a roof and situate the structure so as to protect the pile from predators, pests and precipitation runoff.

Build a 5-inch-thick impervious compacted or concrete floor with a weight-bearing foundation to accommodate the heavy machinery, to allow for all-weather use and to
Procedures

prevent the contamination of the soil and surrounding areas.

To improve accessibility during wet weather, build and pave the access ways (10 to 28 feet wide) to the primary, secondary and storage bins with concrete, fly ash or compacted crushed rock.

Build a concrete bin by using a concrete floor along with a poured bin wall 6 inches thick. The bin entrance should be at least 2 feet wider than the loading bucket.

The bins should be between 5 and 6 feet tall. Determine the width of the bins by the width of carcass-handling equipment. However, to ease pile handling and to minimize the bin construction costs, do not make the bins wider than 8 feet.

Design the bin front so that the carcasses need not be lifted above the door. Accomplish this with removable drop boards that slide into a vertical channel at each end of the bin or with doors that split horizontally, whichever is more practical.

Design hinged doors to swing back flat against the adjoining bins and allow the doors to swing open by using removable hinge pins at both ends. Allow the top of the door to fold down for easier loading of the lower portion of the bin.

Before adding carcasses to a fresh bin, build a 1.5- to 2-foot-thick base (substrate) of co-composting material such as sawdust or a litter-shavings mixture, including up to 50 percent composted manure and straw.

Rake back 6 inches of the co-composting material and place the first layer of carcasses inside the bin. Leave a minimum base depth of 1 foot to absorb the carcass fluids and leachate (runoff fluid). Surround and cover the first layer of carcasses with the co-composting
material.

To ensure that the carcasses are subjected to peak temperatures, place them at least 8 to 12 inches from the sides, front and rear of the compost bin. Spread the organic material so that it can be placed completely around each carcass and between the carcass layers.

Provide a 1-foot-thick layer of inactive materials (organic material with very low moisture and very low compaction) between the layers of carcasses to insulate and maintain the compost temperature.

Immediately after placement, cover the carcasses with a 1-foot-thick layer of biofilter materials. Check the carcasses daily to ensure that they are surrounded by the cover material. Continue to cover any exposed parts to control leachate or odors that attract flies, vermin or predators.

In a farrowing operation, place the fetal and nursery pigs in bins separate from the sows, as the pigs require a shorter composting time.

Alternatively, if a sow has been in a bin for a few weeks, finish by filling it with baby pigs that may require only a couple of months before the turning process.

In a log book, record the bin number, date, time and ambient and compost temperatures every day.
Procedures for Phase II: Outdoor windrow composting, in-house windrow composting and carcass bin composting

In Phase II of the carcass composting process, add moisture to the partially composted materials to reheat and reactivate the compost pile and to obtain an acceptable end product. After moving the pile to the secondary storage area, add moisture if necessary and cover the compost pile with a minimum of 4 inches of co-composting materials. This will insulate the pile, reduce the potential for odors, discourage predators and ensure the decomposition of the remaining carcass parts.

The composted finished product can be identified by a brown color (similar to humus) and a faint or lack of unpleasant odor upon pile turning.

Commercial stability tests for odor concentrations, carbon dioxide production, oxygen consumption rate, NH₃ concentration, color and seed germination are available to confirm that the compost is suitable for land application.
Table 4. Personal protective equipment guidelines for composting.

<table>
<thead>
<tr>
<th>Nature of work</th>
<th>Mask/respirator&lt;sup&gt;a, b, c&lt;/sup&gt;</th>
<th>Protective clothing&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Eye/hearing protection&lt;sup&gt;b, c&lt;/sup&gt;</th>
<th>Gloves&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Head/foot protection</th>
</tr>
</thead>
</table>
| Zoonotic agent                         | Disposable particulate respirator (N95, N99 or N100); half or full facepiece | Impermeable to liquids; consider based on heat situation | Eyes: Full facepiece respirator or indirectly vented goggles; contact lenses should not be worn under goggles or safety glasses; consider prescription safety goggles  
**Hearing**: Consider disposable earplugs if necessary | Gloves:  
Heavy duty (15–18 mil) chemical resistant gloves that can be disinfected or disposed | Feet: For workers handling carcasses, steel toe/steel shank waterproof boots; for others, steel-toed work shoes or boots  
**Head**: Hard hat |
| Non-zoonotic agent                     | None recommended unless for foot-and-mouth disease       |                                                  |                                                  |                          |                      |
| No direct handling of contaminated material | None recommended                                           | Protective coveralls                             | Eyes: Safety eyewear, if needed  
**Hearing**: Earplugs or muffs if working around noise hazards | Work gloves if necessary | Feet: Steel-toed work shoes or boots  
**Head**: Hard hat |

<sup>a</sup>See [www.safetyequipment.org](http://www.safetyequipment.org) for a list of vendors from OSHA.

<sup>b</sup>For information on a full respiratory protection program, see [www.osha.gov/SLTC/respiratoryprotection/index](http://www.osha.gov/SLTC/respiratoryprotection/index).

<sup>c</sup>Regulations governing use of personal protective equipment in hazardous waste operations can be found at 29 CFR 1910.134 and 29 CFR 1910.156 and are summarized in the Safety section of this guide.
Safety

Composting

Diseases of concern

In composting, the diseases of concern include those caused by viruses, bacteria and prions.

**Viruses and non-spore-forming bacteria:** Composting is an effective method of eliminating viral and non-spore-forming bacteria. Precautions must be taken to prevent inhalation of airborne pathogens.

While the carcasses are being transported and handled on site, the use of personal protective equipment is essential for worker safety. Under proper conditions, these types of diseases can be inactivated by the composting method.

Diseases include Q fever, foot-and-mouth disease, vesicular stomatitis, Rift Valley fever, brucellosis (melitensis, abortus, suis and canis), rinderpest, contagious bovine pleuropneumonia, glanders, Japanese encephalitis, African swine fever, classical swine fever, highly pathogenic avian influenza and tularemia.

**Spore-forming bacteria:** Any bacteria that will form endospores should not be composted because the temperatures will not be high enough to inactivate this type of bacteria.

Diseases include anthrax.

**Prions:** Extremely high temperatures are necessary to destroy prion-infected carcasses. Carcasses suspected of contamination with prion diseases should not be composted because the temperatures reached will not be high enough to inactivate these agents.

Diseases include bovine spongiform encephalopathy, chronic wasting disease and scrapie.
Notes on safety

**Heat stress:** See the guidelines on heat stress in the safety section in the General considerations chapter of this guide.

**First aid:** First aid should be available to the employees at all times.

**Safety observers:** Movement of heavy equipment is dangerous; use caution and a safety observer.

**Specialized equipment:** Grinders and crushers are sometimes used in composting operations. Use care when near this dangerous equipment.

**Watch for loose or dangling clothing, equipment or hair when working around this equipment; use a safety observer.**
Of paramount importance in preventing diseases from spreading from the compost site is the control of scavenging animals. Insects, birds and other animals may come into contact with diseased animals and can become vectors, spreading the disease outside the site or containment area.

Carefully follow the engineering guidelines for compost sites to prevent easy access by vermin to contaminated material.

The area on site where animal carcasses are being deposited should be closed to all nonessential vehicles and personnel. All other vehicles should be kept clear of the area accepting animal carcasses.

Equipment and truck drivers should remain in their vehicles while on the composting site; provide another set of personnel on the ground to open tailgates and unload carcasses.

Decontamination of vehicles and any contaminated personnel must occur before the vehicles leave the disposal site. For more information on these procedures, see the Safety and Biosecurity section of the “General Considerations” chapter in this guide.
Groundwater pollution

Before beginning any composting work, it is essential that you coordinate closely with state and local health and public works authorities.

State, county and local regulations differ on the distances that composting sites can be located away from bodies of water, the groundwater table and other natural features.

Your state and local health and public works authorities can provide guidance on these regulations.

Nearby landfill operators may be able to provide information on the depth to groundwater tables and on the appropriate points of contact in the state and local agencies having jurisdiction over any burial or composting activity.

Soil pollution

No soil pollution concerns are associated with composting of contaminated animals unless the composting sites are uncontrolled or inadequately engineered.

Some tissue may remain after the composting process. This tissue can be ground and disposed of in landfills as solid waste in accordance with state and local solid waste regulations.

All waste will be monitored and tested before shipment of potentially dangerous materials.
Air pollution

There are no notable emissions for the composting methods described if the guidelines in this manual are followed carefully. The air-pollution concerns associated with composting are limited to the on-site workers, who will need personal protective equipment to minimize their exposure to airborne or aerosolized agents.
Composting costs

The cost breakdown relating to composting destruction follows the general specification in the overall direct/indirect economic cost section. Figure 17 shows the components of direct and indirect costs.

For specific indirect cost items, see the “General Considerations” chapter of this guide.

Direct costs

The direct fixed cost of composting carcasses depends on the facility’s capacity. The initial investments for two major carcass facilities—windrow composting and bin composting—differ dramatically. Table 5 shows the initial investment and direct fixed cost estimates for windrow composting with an annual capacity of 10,000 tons per acre. Table 6 shows the direct-variable cost estimates of on-site composting.
Table 5. Initial investment and annual direct fixed cost estimates of windrow composting with an annual capacity of 10,000 tons per acre.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Land</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Land a</td>
<td>1,618</td>
<td>97</td>
<td>97</td>
</tr>
<tr>
<td>Sediment b</td>
<td>705</td>
<td>20</td>
<td>78</td>
</tr>
<tr>
<td>Fencing ($6.75/ft)c</td>
<td>7,353</td>
<td>20</td>
<td>809</td>
</tr>
<tr>
<td><strong>Subtotal</strong></td>
<td><strong>9,676</strong></td>
<td></td>
<td><strong>984</strong></td>
</tr>
<tr>
<td>Surfacing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grading compaction</td>
<td>6,589</td>
<td>20</td>
<td>725</td>
</tr>
<tr>
<td>2 in. asphalt</td>
<td>82,096</td>
<td>10</td>
<td>13,135</td>
</tr>
<tr>
<td>4 in. asphalt</td>
<td>94,727</td>
<td>10</td>
<td>15,156</td>
</tr>
<tr>
<td>6 in. asphalt</td>
<td>189,453</td>
<td>15</td>
<td>23,997</td>
</tr>
<tr>
<td><strong>Subtotal</strong></td>
<td><strong>372,865</strong></td>
<td></td>
<td><strong>53,013</strong></td>
</tr>
<tr>
<td>Equipment and machinery c</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water pump</td>
<td>587</td>
<td>10</td>
<td>94</td>
</tr>
<tr>
<td>Thermometer</td>
<td>261</td>
<td>10</td>
<td>42</td>
</tr>
<tr>
<td>Scale</td>
<td>19,572</td>
<td>20</td>
<td>2,153</td>
</tr>
<tr>
<td>Front-end loader</td>
<td>146,135</td>
<td>10</td>
<td>23,382</td>
</tr>
<tr>
<td>Compost turner</td>
<td>168,316</td>
<td>10</td>
<td>26,931</td>
</tr>
<tr>
<td>Screening system</td>
<td>87,616</td>
<td>10</td>
<td>14,018</td>
</tr>
<tr>
<td>Shredding system</td>
<td>118,669</td>
<td>10</td>
<td>18,987</td>
</tr>
<tr>
<td><strong>Subtotal</strong></td>
<td><strong>541,156</strong></td>
<td></td>
<td><strong>85,607</strong></td>
</tr>
<tr>
<td><strong>Total investment cost</strong></td>
<td><strong>592,697</strong></td>
<td></td>
<td><strong>139,604</strong></td>
</tr>
</tbody>
</table>


* Dollars per acre  
* Dollars per linear foot  
* Dollars per unit

**Note:** The annual interest rate is assumed to be 6 percent.
Table 6. Estimates of direct variable cost items of on-site composting of animal carcasses.

<table>
<thead>
<tr>
<th></th>
<th>Cattle</th>
<th>Calves</th>
<th>Weaned hogs</th>
<th>Preweaned hogs</th>
<th>Others (sheep, lambs, goats)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Estimated average variable cost per carcass</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Labor</td>
<td>$18.88</td>
<td>$6.74</td>
<td>$3.17</td>
<td>$0.14</td>
<td>$1.83</td>
</tr>
<tr>
<td>Equipment</td>
<td>$23.57</td>
<td>$8.42</td>
<td>$4.20</td>
<td>$0.19</td>
<td>$2.51</td>
</tr>
<tr>
<td>Composting material (sawdust)</td>
<td>$6.10</td>
<td>$2.17</td>
<td>$1.09</td>
<td>$0.05</td>
<td>$0.63</td>
</tr>
<tr>
<td>Permitting</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Transportation</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td><strong>Average variable cost per carcass</strong></td>
<td>$48.55</td>
<td>$17.33</td>
<td>$8.46</td>
<td>$0.38</td>
<td>$4.97</td>
</tr>
</tbody>
</table>

| **Estimated average cost per ton** |        |        |             |                |                               |
| Labor               | $50.34 | $50.71 | $47.65      | $47.50         | $47.49                        |
| Equipment           | $62.84 | $63.29 | $63.20      | $63.00         | $65.23                        |
| Composting material (sawdust) | $16.28 | $16.28 | $16.33      | $16.28         | $16.28                        |
| Permitting          | n/a    | n/a    | n/a         | n/a            | n/a                           |
| Transportation      | n/a    | n/a    | n/a         | n/a            | n/a                           |
| **Average variable cost per ton** | $129.46| $130.28| $127.18     | $126.78        | $129.00                       |

Source: Livestock mortality and burial cost in 2002 by Sparks Companies, cited in the National Agricultural Biosecurity Center Consortium for Carcass Disposal (NABCCD) Working Group report
If the hourly labor cost and equipment cost are $10 and $35, respectively, the formulas to estimate the **direct variable costs (DVC)** are

- **By number of carcasses:**
  \[
  DVC = 48.55Q_{\text{cattle}} + 17.33Q_{\text{calves}} + 8.46Q_{\text{weaned hogs}} + 0.38Q_{\text{preweaned hogs}} + 4.97Q_{\text{others}}
  \]
  Where \(Q_i\) is the total number of carcasses in animal category \(i\).

- **By weight:**
  \[
  DVC = 142.71W_{\text{cattle}} + 143.61W_{\text{calves}} + 140.19W_{\text{weaned hogs}} + 139.75W_{\text{preweaned hogs}} + 142.20W_{\text{others}}
  \]
  Where \(W_i\) is the total weight in tons of animal category \(i\).

(Figure continued on next page)
If the hourly labor cost and equipment cost are $C_L$ and $C_E$, rather than $10$ and $35$, respectively, the formulas to estimate the **direct variable cost (DVC)** are

- **By number of carcasses:**
  \[
  DVC = (1.89C_L + 0.67C_E + 6.10)Q_{cattle} + (0.67C_L + 0.24C_E + 2.17)Q_{calves} + (0.32C_L + 0.12C_E + 1.09)Q_{weaned~hogs} + (0.01C_L + 0.01C_E + 0.05)Q_{preweaned~hogs} + (0.18C_L + 0.07C_E + 0.63)Q_{others}
  \]
  Where $Q_i$ is the total mortality of animal category $i$.

- **By weight:**
  \[
  DVC = (5.03C_L + 1.8C_E + 16.3)W_{cattle} + (5.07C_L + 1.8C_E + 16.3)W_{calves} + (4.76C_L + 1.8C_E + 16.3)W_{weaned~hogs} + (4.75C_L + 1.86C_E + 16.3)W_{preweaned~hogs} + (4.75C_L + 1.86C_E + 16.3)W_{others}
  \]
  Where $W_i$ is the total weight in tons of animal category $i$.

Besides labor, equipment and composting material costs, disposal costs include transportation cost, which depends mainly on the distance that the animal carcasses are moved.
Rendering

Definition and objectives

In a carcass rendering procedure, animal carcasses are broken down thermally and sterilized in a sealed and controllable container using pressurized steam; the process converts the carcasses into safe, nutritional and valuable products.

The objective of rendering is to convert farm carcasses, except those infected with transmissible spongiform encephalopathy (TSE) viruses, into pathogen-free feed protein and other valuable end products while reducing the negative effects of the carcasses on people and the environment.

Carcass rendering separates the fat, protein and water from a variety of dead animals and sterilizes the final products and byproducts, which include tallow, meat, bone meal and wastewater.

Rendering should not be used for carcasses infected with TSE viruses. These materials should be disposed of by incineration or alkaline hydrolysis.

Although carcass rendering occurs as dry or wet rendering, either in a batch or continuous flow mode, only dry rendering is discussed here. The processing steps for rendering are illustrated in Figure 1.

A rendering plant should process at least 60 to 70 tons of carcasses per day, assuming 20 working hours per day to justify the processing costs. Independent rendering facilities may not be able to process large numbers of animal carcasses. Storing the livestock carcasses on site could extend a facility’s capacity.

The raw materials used by independent rendering plants include the relatively fresh...
carcasses of cattle, pigs, goats, sheep, poultry and other animals that perish during transport or natural disasters or because of animal diseases.

Improper carcass rendering can produce over- and under-heating. Although overheated products have lower feed values, they do not pose hazards to human health. Under-processing conditions will reduce the efficiency of the fat extraction and may generate contaminated products and byproducts that can spread diseases to soil, plants, animals and people. The resulting health hazards or aesthetic concerns, such as odors, can reduce the quality of life and decrease property values near a rendering plant.

Proper rendering inactivates most biological contaminants except prions and hardy organisms such as *Salmonella*. It also produces meat and bone meal at a volume of 20 percent of that of the raw carcasses.

Although the risk of spreading prions has been very low, feeding proteins of mammalian origin to cattle and other ruminant animals (such as sheep and goats) is prohibited. This feed rule has prevented emerging problems related to this issue.

The carcasses used for rendering are primarily ground to particle sizes ranging from 0.4 to 1.2 inches (10 to 30 millimeters). Larger particles would require much more time for their cores to reach the desired temperature.

The ground carcasses are fed at ambient temperatures into a horizontal and cylindrical cooking vessel equipped with a heating system (such as a steam-jacketed shell along with an agitator, a rotating steam-heated shaft and bundles, and rotating steam-heated disks). The carcasses are then rapidly heated to 212 °F (100 °C).
The agitating and heating system converts the fat into a hot slurry that optimizes the heat transfer to the raw material. After most of the free moisture has evaporated, the temperature of the cooked material quickly rises to 245 to 285 °F (depending on the equipment design), which is maintained for at least 30 or 10 minutes, respectively. When the moisture content of the mixed materials falls below 10 percent, the resulting meal is deep-fried in hot fat.

Continuous dry rendering units are equipped with automatic controls for chopping large particles and grinding and uniformly mixing the raw material. Revolving beater shafts facilitate the further breakdown of fatty tissues and maintain the amount of time and the temperature required for the cooking process.

The heating, cooking and separation processes occur simultaneously, with no need for manual operation. Figure 2 illustrates two general views of the equipment used in a rendering plant.
Description of a continuous dry rendering system

As shown in Figure 1, animal carcasses are received in temporary storage or raw material bins (1), conveyed by a raw material conveyor (2) and discharged across a magnet (3) to remove any ferrous metal contaminations.

A raw material grinder (4) reduces the raw material to a uniform particle size for handling and improved heat transfer in the cooking step. The ground raw material is fed at a controlled rate from a metering bin (5) into a continuous cooker (6).

The discharge is transported to a drainer conveyor (7). The drainer conveyor separates the liquid fat from the solids, which are then conveyed from the drainer conveyor by a discharge conveyor (8).

In the discharge conveyor, the solids from the drainer conveyor are combined with the solids discharged from the settling tank (10) and from the decanter-type centrifuge (11).

The solids from the discharge conveyor go to the screw presses (9), which reduce the fat content of the solids to 10 to 12 percent. The solids that bypass the screw presses in the form of pressed cake go to the pressed cake conveyor for further processing into meal.

The fat removed in the screw presses goes to the pressed fat conveyor (12), which separates the large particles from the liquid fat and returns them to the discharge conveyor. The fat from the pressed fat conveyor is pumped to the settling tank (10). Fat discharged from the drainer conveyor (7) goes into the settling tank (10).

In the settling tank, the heavier bone and protein particles settle to the bottom, where they are discharged by the screw conveyor (not shown) into the discharge conveyor (8). Liquid fat from the settling tank is pumped
into the centrifuge (11), which removes the residual solid impurities from the fat. The solids from the centrifuge go to the discharge conveyor (8). The clarified fat is transported for further processing or for storage as finished fat.

Water vapor exits the continuous cooker (6) through a vapor duct system that generally includes an entrainment trap to separate and return the entrained particles to the continuous cooker. The vapor duct system transports the vapor stream to an air-cooled condenser (13), which condenses the water vapor. Other forms of condensers, such as direct contact or indirect shell and tube units, may be used.

Noncondensable gases are removed from the condenser by a noncondensable fan. Odorous gases generated at various points in the process are collected by a ductwork system and are transported along with the noncondensable gases from the condenser to an odor-control system (not shown) to neutralize odors.
Figure 1. A schematic diagram of machinery, equipment and material flow in a continuous dry rendering process. *(Adapted from a diagram courtesy of Dr. David Meeker of National Renderers Association, Alexandria, VA)*
Figure 2. Two views of the equipment used for rendering processes. (Courtesy of Dr. David Meeker of National Renderers Association, Alexandria, VA)
Coordination and jurisdictional considerations

The decision to use rendering as a carcass-disposal option should be made jointly by the members of the appropriate technical group within the incident command structure established by the state or local authorities.

Local authorities must have an inter-county memorandum of understanding in place so that the carcasses can be easily transported through nearby counties to the nearest rendering facility.

If carcasses are to be transported out of the county for rendering, the incident command structure must consider the added problems of transportation safety and the possible contamination of other property.

Rendering should be undertaken only with the explicit approval by the institutions and agencies that are competent to make determinations about protecting the integrity of the environment.

States have established orders of priority for carcass disposal, and the incident command structure must exhaust the higher disposal priorities before undertaking a rendering activity.

Converting a rendering plant into a “disposal rendering” plant may result in situations in which the incident command structure may be responsible for its decontamination or other forms of restitution before returning the facility. In addition, the incident command structure may have “bought” the plant by using it in such a manner.
Pollution and other property damage considerations

The exercise of police power gives governmental entities and agencies wide discretion in making decisions about carcass disposal to protect public health. However, the exercise of police power does not shield governmental entities against nuisance actions if the proper precautions are not taken. In the case of rendering, private firms engaged in rendering could also face legal challenges.

The two main problems posed by rendering are pathogen residue in the rendered product and disease spread when the carcasses are transported. If these problems occur, they could trigger a nuisance claim or lawsuit. Sovereign immunity may not be a defense to such an action. Private firms that trigger the spread of disease may be subject to both civil and criminal actions.
Planning considerations

Plan to coordinate with the managers of the rendering plants and make all the necessary arrangements such as the transportation and delivery of carcasses to the plant. The managers of the facilities under consideration must be willing to stop all other operations to render the “infected” carcasses. Table 1 lists the Web sites and contact information for seven rendering plants in the United States.

Consider the issues related to handling, packing, storing and conveying the carcasses to the rendering plant as described in the Transportation section of the “General Considerations” chapter of this guide.

Although most rendering companies will charge a fee for pickup, plan to use their services for transporting large amounts of animal carcasses. Consider that a mass mortality event may require multiple trips between the farm and the rendering facility. If the rendering company does not offer pickup service, or the farm is out of the range of the pickup service, alternatives must be considered.

Determine in advance whether the local rendering plants will accept infected or noninfected carcasses and, if so, the volume accepted per day.


The fallen or condemned animals (high-risk materials) must be rendered under close
Table 1. Some of the U.S. rendering plants with greater acceptance of carcasses.*

<table>
<thead>
<tr>
<th>Company</th>
<th>Contact information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baker Commodities</td>
<td>James Andreoli&lt;br&gt;323-268-2801&lt;br&gt;<a href="mailto:jandreoli@bakercommodities.com">jandreoli@bakercommodities.com</a></td>
</tr>
<tr>
<td>Los Angeles, CA</td>
<td></td>
</tr>
<tr>
<td>Darling International</td>
<td>Ross Hamilton&lt;br&gt;972-281-4461&lt;br&gt;<a href="mailto:rhamilton@darlingii.com">rhamilton@darlingii.com</a></td>
</tr>
<tr>
<td>Irving, TX</td>
<td></td>
</tr>
<tr>
<td>Griffin Industries</td>
<td>Robert Griffin&lt;br&gt;859-781-2010&lt;br&gt;<a href="mailto:Rgriffin@griffinind.com">Rgriffin@griffinind.com</a></td>
</tr>
<tr>
<td>Cold Spring, KY</td>
<td></td>
</tr>
<tr>
<td>Pascal Enterprises</td>
<td>Mel Roshanraven&lt;br&gt;214-871-0300&lt;br&gt;<a href="mailto:melr@pascalenterprises.com">melr@pascalenterprises.com</a></td>
</tr>
<tr>
<td>Dallas, TX</td>
<td></td>
</tr>
<tr>
<td>Sacramento Rendering</td>
<td>Michael Koewler&lt;br&gt;916-363-4821&lt;br&gt;<a href="mailto:michaelkoewler@aol.com">michaelkoewler@aol.com</a></td>
</tr>
<tr>
<td>Sacramento, CA</td>
<td></td>
</tr>
<tr>
<td>Anamax Corp.</td>
<td>Bob Pfeil&lt;br&gt;920-494-5233&lt;br&gt;<a href="mailto:bpfeil@anamax.com">bpfeil@anamax.com</a></td>
</tr>
<tr>
<td>Green Bay, WI</td>
<td></td>
</tr>
<tr>
<td>Valley Proteins</td>
<td>J.J. Smith&lt;br&gt;540-877-2590&lt;br&gt;<a href="mailto:jjsmith@valleyproteins.com">jjsmith@valleyproteins.com</a></td>
</tr>
<tr>
<td>Winchester, VA</td>
<td></td>
</tr>
</tbody>
</table>

veterinary supervision and surveillance.

Plan to minimize the risk of contamination from carcass materials entering and of finished products exiting the processing plant by careful and precise inspection, an on-site chemical control program, proper housekeeping and sanitation of the facility/equipment, and inspection and decontamination of the load-out and transport trucks, cars, vessels and containers.

Each carcass rendering plant should participate in the Animal Protein Producers Industry (APPI) program to test for *Salmonella* (pathogenic bacteria) in the meat and bone meal and have at least one person on site who has received training by the APPI or a certified trainer from an equivalent program.

All of the equipment of rendering plants that comes into contact with carcasses and their derivatives should be easily cleanable and washable.

Plan to control the harmful compounds, such as nitrogen and sulfur compounds, that may leach from wastewater of the rendering plant to groundwater.

Rendering 1 ton of carcass materials produces 1.5 to 2 tons of wastewater. Additional wastewater may result from the cleaning processes. To decrease organic loads, mechanically aerate and oxidize the wastewater. Rendering plants have on-site wastewater treatment systems.

Add appropriate chemical flocculants, such as aluminum sulfate, to the wastewater to reduce the available phosphorus to permissible levels so the wastewater can be directly discharged or land-applied. This process converts the soluble phosphorus to insoluble phosphorus that can be removed by a settling process.
Procedures

Keep unauthorized personnel and uninfected carcasses out of the plant area used for processing infected carcasses.

Perform rendering processes within 24 to 48 hours of an animal’s death unless it is stored at a proper temperature (at least 40 °F, or 4.4 °C). It is easier to remove hides, hair and paunch from fresher carcasses than from those that are highly decomposed and have reduced quality of fat and protein.

To ensure that the carcass materials are not processed too quickly, control and record the input rate relative to the size of the rendering vessel and control the temperatures in different locations in the vessel.

Properly maintain the carcass-receiving and finished-product sections as “dirty” and “clean” areas of the rendering plant, and keep them separated from each other. Prevent workers from moving from the receiving area to the finished-product area unless they have taken cleaning and disinfection measures. Restrict equipment movement to keep contamination from the receiving area from moving to the finished-product area.

To produce rendered products with low levels of microorganisms, routinely sanitize the equipment and maintain the tools used on the processing lines and in the facilities. “Dirty” areas and all processing equipment should be sanitized with steam or suitable chemicals (see the EPA list of approved disinfectants in the “General Considerations” chapter) that produce sterilized animal meal and fat.

Prevent the drainage of liquids from dirty to clean areas to avoid contamination of finished products and their transportation system. Direct the airflow within the plant from the finished-product area to the receiving area.
Ensure that the rendering plant has a deodorization system (including a condenser, chemical scrubber, gas burner and biofilter) and implements procedures to monitor odors and investigate and resolve odor-related complaints.

Perform all of the prescribed rendering guidelines for cooking time and carcass temperature to produce high-quality tallow, meat and bone meal that is free of pathogens. Monitor the cooking process periodically. A good indication of cooking is a slight grittiness in and fibrous nature of the cooked carcasses (cracklings). Slippery cracklings indicate under-cooking; a lack of fiber indicates overcooking.

Ensure that the rendered products are tested for disease agents, and document that the rendering process has produced a safe product. If a disease agent has been identified in a finished product, dispose of it using an appropriate carcass disposal method.
### Table 2. Personal protective equipment guidelines for rendering.

<table>
<thead>
<tr>
<th>Nature of work</th>
<th>Mask/Respirator&lt;sup&gt;a,b&lt;/sup&gt;</th>
<th>Protective clothing&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Eye/hearing protection&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Gloves&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Head/foot protection</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Zoonotic Agent</td>
<td>Non-zoonotic Agent</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Direct handling of contaminated material</td>
<td>Disposable particulate respirator (N95, N99 or N100); half or full facepiece</td>
<td>None recommended unless for foot-and-mouth disease</td>
<td>Impermeable to liquids; consider based on heat situation</td>
<td><strong>Eyes</strong>: Full facepiece respirator or indirectly vented goggles; contact lenses should not be worn under goggles or safety glasses; consider prescription safety goggles <strong>Hearing</strong>: Consider disposable ear plugs if necessary</td>
<td><strong>Gloves</strong>: Heavy duty (15–18 mil) chemical resistant gloves that can be disinfected or disposed</td>
</tr>
<tr>
<td>No direct handling of contaminated material</td>
<td>As directed by the facility safety officer</td>
<td>As directed by the facility safety officer</td>
<td>As directed by the facility safety officer</td>
<td>As directed by the facility safety officer</td>
<td>As directed by the facility safety officer</td>
</tr>
</tbody>
</table>

<sup>a</sup>See [www.safetyequipment.org](http://www.safetyequipment.org) for a list of vendors from OSHA

<sup>b</sup>For information on a full respiratory protection program, see [www.osha.gov/SLTC/respiratoryprotection/index](http://www.osha.gov/SLTC/respiratoryprotection/index).

<sup>c</sup>Regulations governing use of personal protective equipment in hazardous waste operations can be found at 29 CFR 1910.134 and 29 CFR 1910.156 and are summarized in the “General Considerations” chapter of this guide.
Diseases of concern

**Viruses and non-spore-forming bacteria:** Viruses and non-spore-forming bacteria are temperature susceptible. For viruses such as foot-and-mouth disease (FMD), precautions must be taken to prevent inhalation and transmission of airborne pathogens. Non-spore-forming bacteria will be deactivated at continuous rendering temperatures.

Diseases for which rendering is an appropriate disposal option include African swine fever, highly pathogenic avian influenza, contagious bovine pleuropneumonia, brucellosis (*B. melitensis, B. abortus, B. suis and B. canis*), FMD, glanders, Japanese encephalitis, Q fever, Rift Valley fever, rinderpest, classical swine fever, tularemia and vesicular stomatitis.

**Spore-forming bacteria:** Spore-forming bacteria are temperature susceptible. Those that are not destroyed can persist in the environment for long periods.

If it is not possible to render these carcasses immediately, they must remain intact to keep the spores from spreading to the external environment. The spore-forming bacteria will be deactivated and controlled if the uncut carcasses are properly rendered using the continuous method.

Diseases of concern include anthrax.

**Prions:** Prions (TSEs) are temperature resistant. Extremely high temperatures (more than 1,830 °F or 1,000 °C) for at least 15 minutes are needed to destroy prion-infected carcasses. The best method for destroying prion-infected animal carcasses is fixed-facility burning or alkaline hydrolysis. **Rendering is not an appropriate method of deactivation for prion-infected animal carcasses.**

Diseases include bovine spongiform encephalopathy, chronic wasting disease and scrapie.

**Note:** Samples of materials must be sent to the National Veterinary Services Laboratories.
(NVSL) or other laboratory approved by the Veterinary Services deputy administrator for laboratory testing to confirm that all potentially hazardous agents have been deactivated.

Verification by the NVSL could take several days, and waiting for results may require that you slow or suspend the rendering operations.

Notes on safety

Heat stress: See the guidelines on heat stress in the Safety section of the “General Considerations” chapter of this guide.

First aid: First aid should be available to employees at all times.

Safety observers: Moving heavy equipment is dangerous. Use a safety observer with the authority to stop and correct unsafe conditions or operations.

Physical hazards: Grinders, crushers and cookers are used in rendering operations. Use care when near this dangerous equipment. Watch for loose or dangling clothing, equipment or hair when working around this equipment; use a safety observer.

Ventilation: Although rendering equipment uses enclosed pressure vessels, the area surrounding the vessel should be adequately ventilated.
The facility or facilities accepting contaminated materials may be fixed-site facilities located on heavily trafficked public or private property; they will probably be on secondary streets next to major highways. The movement of animal materials contaminated with non-zoonotic organisms (those that do not transmit diseases from vertebrate animals to people) onto these sites should be planned very carefully.

Although moving carcasses contaminated with non-zoonotic materials does not present a health hazard to the public, a significant effort must go into public awareness and public relations activities well before any carcasses are moved to the site.

A rendering plant should process 60 to 70 tons of carcasses per day, assuming 20 working hours per day to justify the processing costs. Do not use such facilities to dispose of large volumes of carcasses contaminated with zoonotic agents; do not use them at all for destroying TSE-contaminated carcasses.

When handling infected animal materials, the rendering facility must discontinue all other operations in order to treat only the carcasses infected with hazardous agents. Continuous rendering rather than batch rendering should be used for the entire shipment of animal carcasses. This will prevent the vapors and materials generated during the rendering process from becoming airborne and spreading to the environment.

The rendering facility should have security measures in place to monitor and exclude animals and unauthorized personnel.

USDA guidelines dictate that the receiving side of a rendering facility be separated completely from the finishing side. Allow no one to move between the two areas without
Biosecurity

thorough cleaning and disinfection. Do not allow equipment to move between the sides.

The air flowing through the plant must be directed from the finished side through to the receiving side.

Trucks being used to haul away the finished product may not come into contact with the receiving side or any vehicles containing hazardous materials. Vehicles and personnel must be decontaminated before the vehicles leave the disposal site.
Groundwater pollution

Although discharge of effluent into a public sewer system and not into groundwater is anticipated, close coordination with state and local health and public works authorities is essential before any effluent can be released into a public sewer system.

Soil pollution

Continuously operating rendering facilities are nearly always fixed on site and will have coordinated with local health and public works authorities concerning releases. Before any discharge, confirm with the facility officials that all of the necessary permits are in place.

Soil pollution is not a concern unless the carcasses are allowed to accumulate on the surrounding grounds faster than the facility’s processing rate. Unprotected decomposing carcasses are a source of disease for people and animals and can pollute soil and surface water.

Do not allow the carcasses to accumulate at a rate faster than that which the facility can process. Piled carcasses outside the facility create a public awareness issue and can create human and animal health problems from disease vectors drawn to the carcasses. Decomposing carcasses also create an air quality issue.
Some onsite workers may need personal protective equipment to minimize their exposure to airborne or aerosolized agents. For more information, see the Safety section of this chapter.

**Air pollution**

Air emissions containing chemicals with unpleasant odors should be controlled at levels well below the odor threshold for chemicals of concern. Rendering facilities should have air emissions programs in place that comply with all federal, state and local regulations. Therefore, air emissions from the rendering process should be of minimal concern to outside personnel managing recovery operations from a catastrophic event.

Depending on the pathogen involved, there may be a stigma attached to the rendered products that makes them unacceptable for further use.
The costs of rendering follow the general specifications in the Cost section of the “General Considerations” chapter. Figure 3 shows the components of the direct and indirect costs of rendering.

Table 3 lists direct variable costs for rendering carcasses. For indirect cost items, see the “General Considerations” chapter of this guide.

**Figure 3.** Components of direct and indirect costs for rendering operations.
Table 3. Estimates of direct variable cost items for rendering animal carcasses.

<table>
<thead>
<tr>
<th>Estimated average variable cost per carcass</th>
<th>Cattle</th>
<th>Calves</th>
<th>Weaned hogs</th>
<th>Preweaned hogs</th>
<th>Others (sheep, lambs, goats)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Labor</td>
<td>$11.38</td>
<td>$4.04</td>
<td>$2.02</td>
<td>$0.09</td>
<td>$1.17</td>
</tr>
<tr>
<td>Equipment</td>
<td>$27.28</td>
<td>$9.68</td>
<td>$9.49</td>
<td>$0.61</td>
<td>$8.44</td>
</tr>
<tr>
<td>Landfill cost of disposing of residual</td>
<td>$2.69</td>
<td>$0.95</td>
<td>$0.48</td>
<td>$0.02</td>
<td>$0.28</td>
</tr>
<tr>
<td>Permitting</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Transportation</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Average variable cost per mortality</td>
<td>$41.35</td>
<td>$14.67</td>
<td>$11.99</td>
<td>$0.72</td>
<td>$9.89</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Estimated average cost per ton</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Labor</td>
<td>$30.35</td>
<td>$30.35</td>
<td>$30.35</td>
<td>$30.35</td>
<td>$30.35</td>
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<tr>
<td>Equipment</td>
<td>$72.75</td>
<td>$72.75</td>
<td>$142.32</td>
<td>$204.15</td>
<td>$219.33</td>
</tr>
<tr>
<td>Landfill cost of disposing of residual</td>
<td>$7.16</td>
<td>$7.16</td>
<td>$7.16</td>
<td>$7.16</td>
<td>$7.16</td>
</tr>
<tr>
<td>Permitting</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Transportation</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Average variable cost per ton</td>
<td>$110.26</td>
<td>$110.26</td>
<td>$179.83</td>
<td>$241.66</td>
<td>$256.84</td>
</tr>
</tbody>
</table>

Figure 4. Formulas to estimate the direct variable cost relating to rendering.

If the hourly labor and equipment costs are $10 and $25, respectively, use these formulas to estimate the **direct variable cost (DVC)**:

- **By number of carcasses:**
  \[
  DVC = 41.35Q_{\text{cattle}} + 14.67Q_{\text{calves}} + 11.99Q_{\text{weaned hogs}} + 0.72Q_{\text{preweaned hogs}} + 9.89Q_{\text{others}}
  \]
  Where \(Q_i\) is the total number of carcasses in animal category \(i\).

- **By weight:**
  \[
  DVC = 110.26W_{\text{cattle}} + 110.26W_{\text{calves}} + 179.83W_{\text{weaned hogs}} + 241.66W_{\text{preweaned hogs}} + 256.84W_{\text{others}}
  \]
  Where \(W_i\) is the total weight in tons of animal category \(i\).

(Figure continued on next page)
If the hourly labor and equipment costs are $C_L$ and $C_E$, rather than $10$ and $35$ respectively, use these formulas to estimate the direct variable cost (DVC):

- **By number of carcasses:**
  \[
  DVC = (1.14C_L + 0.78C_E + 2.69)Q_{\text{cattle}} + (0.40C_L + 0.28C_E + 0.95)Q_{\text{calves}} + (0.20C_L + 0.27C_E + 0.48)Q_{\text{weaned hogs}} + (0.01C_L + 0.02C_E + 0.02)Q_{\text{preweaned hogs}} + (0.12C_L + 0.24C_E + 0.28)Q_{\text{others}}
  \]
  
  Where $Q_i$ is the total number of carcasses in animal category $i$.

- **By weight:**
  \[
  DVC = (3.04C_L + 2.08C_E + 7.16)W_{\text{cattle}} + (3.04C_L + 2.08C_E + 7.16)W_{\text{calves}} + (3.04C_L + 4.07C_E + 7.16)W_{\text{weaned hogs}} + (3.04C_L + 5.83C_E + 7.16)W_{\text{preweaned hogs}} + (3.04C_L + 6.27C_E + 7.16)W_{\text{others}}
  \]
  
  Where $W_i$ is the total weight in tons of animal category $i$.

Besides the labor, equipment and land-fill costs of disposing residuals, the variable disposal cost includes transportation costs and permitting fees.