Sustainable Uses for Animal Hides and Byproducts Report

Empowering Local and Regional Meat Processing in the Upper Midwest Region

auri
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1.0 Introduction

In September 2021, the Agricultural Utilization Research Institute (AURI) and the United States Department of Agriculture, Agricultural Marketing Service (USDA-AMS) signed a multi-year cooperative agreement focused on the Upper Midwest's small meat and poultry processors. For this agreement's purposes, the Upper Midwest is defined as the following five states: Iowa, Minnesota, North Dakota, South Dakota, and Wisconsin. The 5-state project explored opportunities to strengthen industry resiliency and create solutions to position the meat and poultry processors for success. The project was entitled Empowering Local and Regional Meat Processing in the Upper Midwest and was designed as a regional pilot that could be emulated in other regions across the country.

A regional advisory taskforce provided guidance related to the pilot's main pillars of work, which included understanding the financial barriers facing small meat and poultry processors, conducting a needs assessment to guide technical assistance and business development support, and developing multiple solutions to assist the industry in overcoming barriers. The task force included industry representatives across the five-state region and convened quarterly during the pilot to advise AURI and USDA-AMS staff. Deliverables were completed in 2022 and 2023. Reporting was completed in early 2024.

This report explores alternative applications for animal hides and byproducts. A needs assessment of the regional and local meat industry indicated adding value to animal hides and byproducts was a critical factor impacting industry resilience. As such, AURI issued a request for proposals to conduct a wide-range technology scouting exercise to complement the organization's knowledge in this space.

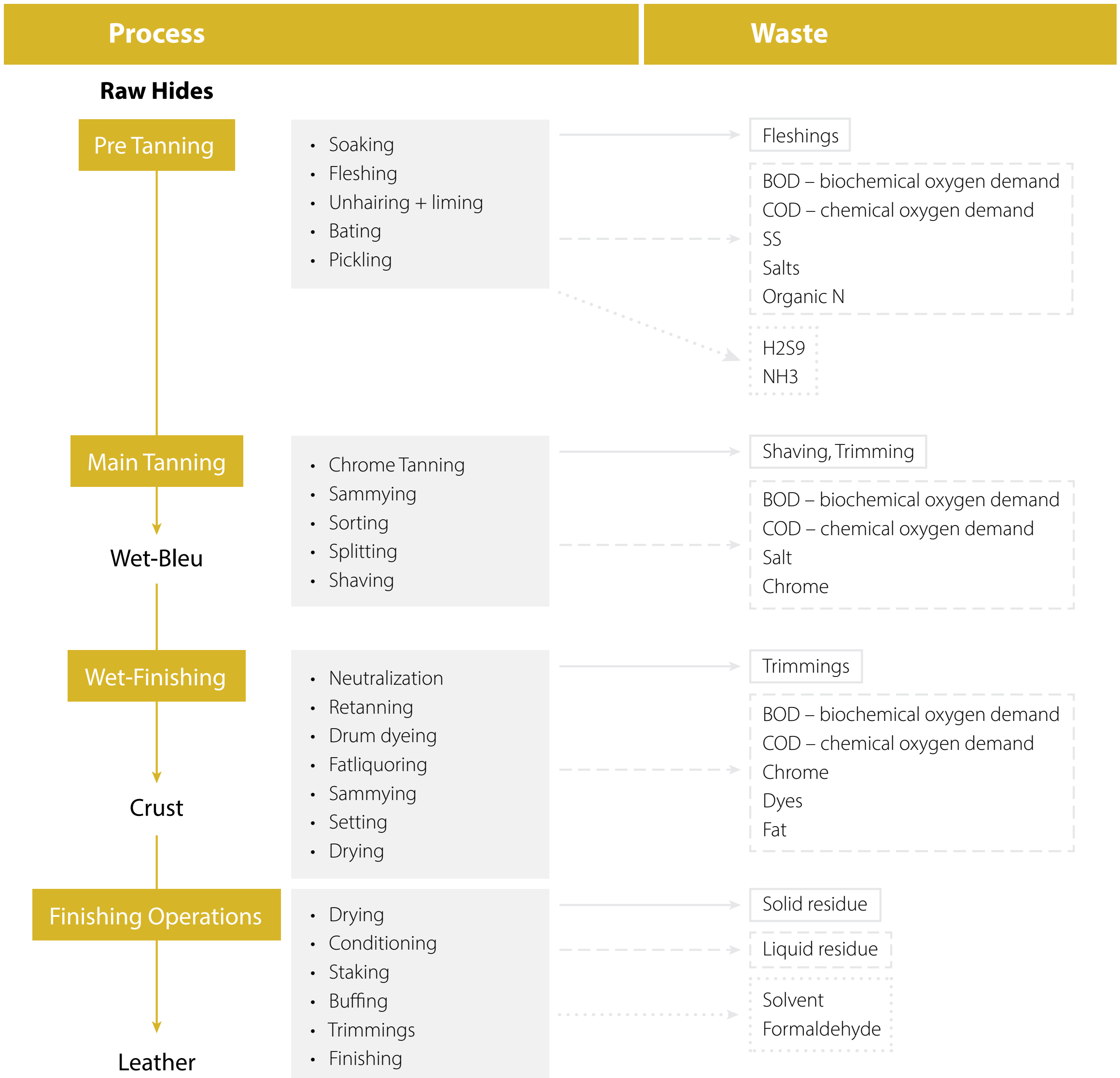
As a final note of introduction, AURI has a long history of supporting the meat industry to drive innovation forward. In addition to maintaining a USDA-inspected meat laboratory available for client use, AURI's meat science team offers resources and assistance related to food safety and Hazard Analysis and Critical Control Points (HACCP) planning, scale-up, product formulation and validation, packaging guidance, and troubleshooting. In 2022, the organization was named a technical assistance provider through the USDA-AMS Meat and Poultry Processing Technical Assistance Network (MPPTA).

2.0 Project Overview

Traditionally, hides have been an important source of income for the meat industry. According to Leather International, hides averaged nearly 54% of the drop in credit value (the value of byproducts) of a beef animal between 1980 and 2011. This represented 8 to 10% of the total value of the animal. Fast-forward to 2020, and hides represented a mere 1% of the animal's total value.

Reduced demand for leather, and therefore fewer hide off-take options, have resulted in hides becoming a cost center rather than a profit center due to the cost of disposal. Demand for animal hides has been declining for several reasons including the shift in consumer demand, economic factors, and waste management challenges. With the rise of fast-fashion, demand favors synthetic materials (vegan leather or plastic) over their natural counterparts. And, even as a natural product, demand for hides can be challenging due to little tolerance for off-spec products, such as imperfections from exposure to the elements, and branding marks. Altogether, this has resulted in downward pressure on the value of animal hides. Other economic factors include the rising costs of processing. For example, the added step of tanning hides makes it less profitable for processors to handle the hides and sell them directly to customers.

There are multiple grades of animal hides. The Leather and Hide Council of America have Uniform U.S. Industry Standards. According to the Leather Hide Council of America, in 2020 the United States processed 33 million head of cattle, resulting in a total of 33 million cattle hides. Of the 33 million hides, 28.2 million were used to make leather, while the remaining 4.8 million hides (14.5%) went to waste (burned or ended up in landfills). Traditionally, the leather is converted into a tanned good, that is an item made from the animal hide or skin that has undergone the tanning process. The process of tanning is the treatment of the raw animal hide to transform into a durable, flexible and usable material. Various techniques are used to prevent hides from decaying. Common types of tanned goods are leather, suede, or nubuck.



Source: https://www.fao.org/3/X6114E/x6114e05.htm

Figure 1. Description of the tanning-process. Credit: [3. TANNERIES (fao.org)]

Leftover pieces after tanning are referred to as rawhide trimmings. The trimmings can come from various parts of the hides including the edges, irregular shapes or scraps. Rawhide trimmings can be further treated to produce hide glue, animal feedstuff, biogas, thermal and landfill applications, and keratin-rich materials derived from hair and wool.

Figure 2 provides an overview of the applications identified through the secondary source review for animal hides and other materials extracted from animal byproduct waste. Eleven core applications were identified, followed by nine sub-applications derived from animal waste.

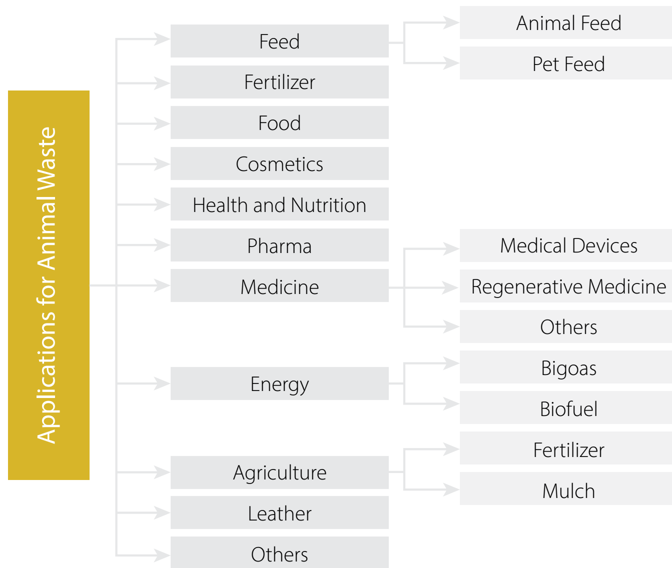


Figure 2. Applications Identified. Credit: Evalueserve

Very small and small processors indicated the cost associated with removing hides from their establishments and utilization of the hides and byproducts are bottlenecks. This project aims to identify alternative and innovative applications and solutions for very small and small meat processors, either individually or cooperatively, as well as the rendering industry. Note: the rendering industry is included in this scope as they are, and will continue to be, a critical component of the meat value chain.

3.0 Methodology

Researchers followed a multi-pronged approach to identify sustainable solutions and innovative uses of animal hides and byproducts. To be included in the search, the solutions must have a Technology Readiness Level (TRL) of at least four (i.e., validated at lab-scale). While completing the scouting process, solutions and applications related to leather sustainability were out of scope. The following key business questions were addressed:

1. What are the sustainable solutions and innovative uses of animal hides?
2. Which products are manufactured using these solutions?
3. What are the different application areas of these products?
4. Who are the key players developing these solutions?
5. What is technological maturity?
6. What are the activities of key plays in terms of mergers, collaboration, or acquisition?

The global search conducted had an emphasis on applications and solutions in the United States and the Upper Midwest Region (Iowa, Minnesota, North Dakota, South Dakota, and Wisconsin). Parameters were defined for the secondary data sources. Secondary data sources included patents, scientific literature, news, press releases, conference literature, and company directories (Figure 3). Timeline parameters for patents and research publications lasted the last five years (2018-2023).

Figure 3. Research Data Sources

The researchers approach for identifying applications was comprised of six categories:

1. Patent findings related to animal hides - Questel Orbit, Google Patents, Derwent Innovation;
2. Academic Journals - Ebscohost, SciDirect, MDPI, ResearchGate, PubMed;
3. Company Directories – Crunchbase, ZoomInfo, LinkedIn;
4. Trade journals, Associations, Societies - Ebscohost, Google;
5. Conferences and Expos - ResearchGate, Conference series, Google; and
6. News - Factiva, Google, and YouTube.

For the purpose of this study, solutions were categorized into three tiers. Tier I is most applicable to very small and small scale meat and poultry processors as relatively low-tech and low-cost applications. Tiers II and III include high-cost and high-volume applications. Tier II includes solutions such as medical and pharmaceutical products, while Tier III includes waste-to-energy solutions (Figure 4).

Figure 4. Animal Hide and Byproduct Utilization Tiers

Tier I

Easy Implementation

Applications and solutions that can be implemented by small and medium scaled processors for better utilization of animal hides and byproduct waste, such as pet chews or composting.

Tier II

High Capital Applications

More applicable or accessible to large-scale players. In some cases, there are barriers to entry into Tier II based on existing collaborations in this application space. Tier II includes manufacturing collagen use in bio-medical and pharmaceutical applications.

Tier III

Community/Municipal Application

Likely multi-organization collaboration opportunities, such as at the community or municipal level. Applications include waste-to-energy and gasification.

4.0 Tier I Applications for Hide Utilization and Other Meat Byproducts

4.1 Animal Hide Product Application Solutions for Small Processors

Applications included in this tier have a low degree of technical complexity and capital investment. They can be implemented within small-scale organizations. Three applications are highlighted below that convert an animal hide into an innovative byproduct. These include pet chews, beef rinds, bone broth, casings and parchment.

There is increasing demand for locally sourced pet chews. The product is made from dried animal skins. Although already fully commercialized, this application strategy can be explored by small processors.

Pet Chews	
Raw Material	Rawhide Trimmings
Product	Rawhide chews made from dried animal skin
Description	Pet owners purchase pet chews for numerous reasons including mental stimulation and dental health.
Estimated Technology Readiness Level (TRL)	Fully commercialized TRL 9
Data Sources	Company websites, products, news

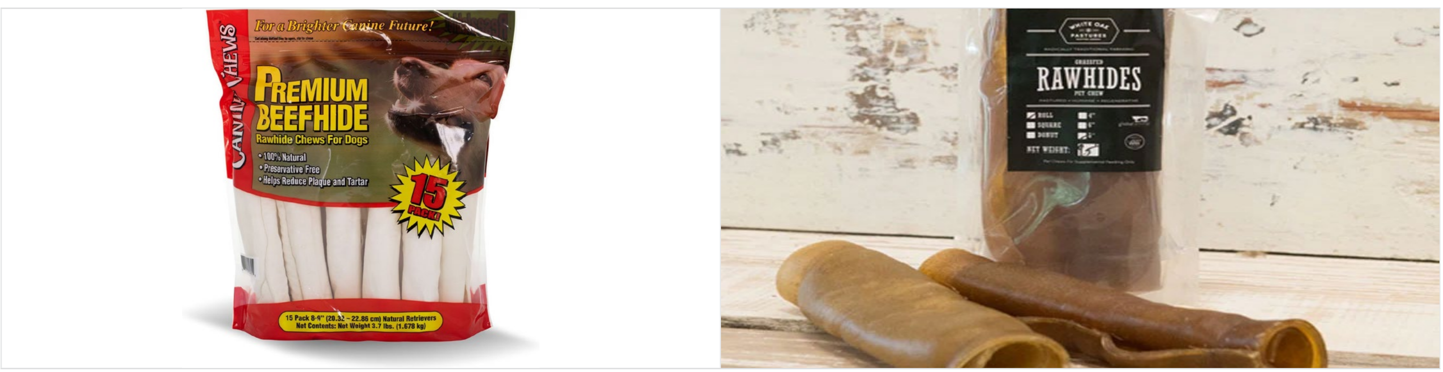


Figure 5. Raw hide product examples

Beef skin, or beef rinds, are processed from cattle rawhide that is cleaned, trimmed, and prepared for processing. After further processing, the rawhide is boiled to render any fat under the skin, cooled, and then excess fat scraped away, resulting in just the outer layer of the skin. Finally, the skin is cut into strips or smaller pieces for consumption.

Beef Rinds	
Raw Material	Hide
Product	Nutrient-dense snack as an alternative to pork rinds
Description	The meat snack category has continued to expand, not only with new flavors but with new formats. One of the latest evolutions introduced a new competitor to the traditional pork rind.
Estimated Technology Readiness Level	Development TRL 6-7 (product trial stage)
Data Sources	News, company websites

Figure 6. Beef rind product example

Parchment membrane is a leather-like material that can be used to produce lampshades, chandeliers, wall hangings, tabletops, footwear, handbags, purses, wallets, etc. It's advantages include reduced environmental impact and value-added products. (Sastry et al., 2005).

Parchment	
Raw Material	Hide
Product	Parchment made from dry rawhide that is untanned product
Description	Parchment can be made from the hides and skin of sheep, goats, cattle, pigs, and buffalo. The skin is dried without tanning. The material is dried, greased, and smoothed during the production process. After drying in a drying frame, it is sanded with pumice stone. While the parchment is still wet, the product can be formed more easily and has more tension. After drying, the hide is rigid and no longer malleable.
Estimated Technology Readiness Level	Fully commercialized TRL9
Data Sources	Company websites and articles

Figure 7. Examples of animal hide parchment products

Another Tier I application is producing collagen-rich bone broth. The process is simple and cost-effective. It involves steeping animal bones containing the nutrient-rich marrow from the hollow central core of bone, along with remains of meat and cartilage still attached.

Bone Broth	
Raw Material	Animal marrow bones (femur, shank, tibia)
Product	Bone broth
Description	Bone broth can be made from the bones of sheep, goats, cattle, pigs, and buffalo.
Estimated Technology Readiness Level	Fully commercialized
Data Sources	Company websites, articles

Figure 8. Bone broth product example. Credit: https://www.takingstockfoods.com/

Small processors that already process meat into value-added products, like sausage, can easily incorporate the byproduct of pig intestines for casings. The application produces a natural casing and may be of particular interest to developing clean-label products.

Sausage Casings	
Raw Material	Pig intestines
Product	Sausage casings for smoked meat products
Description	For several hours, casings are soaked in heavily salted water to make them more pliable and remove any impurities. The small intestine is then detached and unraveled. Afterwards it is cut into smaller sections and rinsed thoroughly with a hose.
Estimated Technology Readiness Level	Fully commercialized
Data Sources	Articles

Figure 9 and 10. Examples of pig intestine casings. Credits: https://www.tompress.co.uk/A-10002777-how-to-prepare-intestines-for-sausages.aspx and https://premiumpackind.md/en/kishka.html

4.2 Animal Hide Preservation Methods

Proteins are the main constituent of hides and skins and are prone to bacteria and autolysis (action of enzymes in hides). To maintain value and account for the variable demand of leather and other applications, it is important that hides and skins are preserved to halt the degradation process.

- **Tanning.** Tanning is necessary for the hide to be processed into different finished applications/products. Before tanning, there is the preparation of the leather. Hides are dehaired and any excess meat, fat, and connective tissue is removed.
- **Salt Curing.** The most popular curing technique worldwide due to ease, cost-efficiency, and the quality of the finished leather produced. Typically, salt brine is used for storing hides for leather manufacturing. Hides can be preserved for up to six months using this method, but they generate many effluents in the form of total dissolved solids (TDS) and chlorides.

Figure 11. Salt curing preservation method. Credit: www.vermontnaturalsheepskins.com

- **Wet Blue.** Wet blue is a preservation method used to describe the blue-tinged color the chemical agents chrome salts (chromium sulfate) leave on the hides. Once the leather is tanned, the hide is not dried or dyed but treated with chrome salts which are blue in color. This method allows for the hide to be stored for up to six months. The advantages of this method include its low cost and its simplicity in that it does not require specialized equipment. The salt content in wet blue prevents bacterial growth and can be stored for extended periods of time without significant deterioration. Challenges in using this method include high salt use that can impact the environment, as this treatment generates large quantities of saline wastewater. Moreover, the method can impact the flexibility and texture of the hide, a consideration for the finished good.

Figure 12. Wet blue animal hide preservation method. Credit: Leather Hide Council of America

- **Freezing/Cooling.** Hides are typically preserved for three weeks if the temperature is reduced to two degrees Celsius (35.6 degrees F). An increasing number of tanneries in Europe are processing fresh hides by cooling/freezing due to growing environmental pressure. The advantage to using this method is that cooling to reduce the temperature slows down microbial activity, inhibiting the growth of microorganisms that cause decomposition. Furthermore, freezing does not require additional chemicals or salt. It maintains the natural properties of the hide's color, texture, and flexibility, and is suitable for short-term preservation to store or transport when immediate processing is not possible. Challenges include the high cost of proper storage space at the required low temperature. Furthermore, freezing temperatures can result in the formation of ice crystals that can affect the hide's quality. Thawing also poses a challenge as the process must be done carefully to prevent any damage impacting future functionality.
- **Drying.** The simplest and oldest preservation process is drying. Skins are stretched in dry air to allow air flow around the hide on all sides. Drying preserves hides for up to three months, like salt curing. Advantages of using this method include the reduction of microbial growth, zero reliance on the use of chemicals, and affordability. It also does not require specialized equipment. Unfortunately, drying alters the texture and flexibility of the hides, and excessive drying can lead to loss of strength in the hides. Furthermore, this method is very time-consuming.

Other techniques such as reducing salt with other agents such as silica gel, sodium metabisulfite, and boric acid have been investigated as an alternative to salt for curing hides. Salt-free curing is a technique that uses inorganic preservatives (potassium chloride, sodium sulfate, silicate, and ozone), organic preservatives (natural and synthetic preservatives) and other chemical antiseptics.

Another preservation technique is the Preservation Cum Unhairing of Hides (PCU). This technique has been validated at the pilot scale that uses the raw hide material. A single compound performs dual functions, specifically preservation and unhairing at natural pH and ambient conditions. The technique avoids using salt for preservation and sodium sulfide for unhairing. Treated hides or skins can be stored for six months in ambient conditions without dehydration.

4.3 Composting for the Management of Hide Waste and Other Animal Waste

A final Tier I application is composting. Composting is an efficient method for managing animal waste, especially animal hide waste. This procedure entails the breakdown of organic resources to provide a nutrient-rich soil amendment that can be used in agriculture and gardening. It is crucial to combine hide waste with other organic materials in a temperate and moist environment.

Composting	
Raw Material	Animal waste
Product	Soil amendment
Description	There are various types of composting, four of which are described below. Composting can be utilized in small—to large-scale meat processing establishments. • Aerated Static Pile Composting: This technique uses a sizable pile of organic materials, such as hides and other materials, and aerates the pile by employing a system of pipes or hoses to blow air through the material. The procedure expedites the breakdown of the hides and creates an excellent-grade compost. • Vermicomposting: Worms are used in the vermicomposting process to break down organic materials like hides. The worms consume the organic material and create a superior compost. • In-Vessel Composting: Composting in a closed container to break down animal skins and other organic materials, is known as "in-vessel composting." The procedure takes less time and generates compost of higher quality due to strict monitoring. • Open Window Composting: This technique entails building extensive piles of organic materials like animal hides and rotating the piles frequently to allow air to enter. Although it takes longer than other procedures, it yields a high-quality compost.
Estimated TRL	Fully commercialized
Data Sources	Articles

Figure 13. Examples of compost.

4.3.1 Types of Composting

Composting can be utilized in small to large-scale meat processing establishments. There are four different types of composting which are described below. Additional resources for composting in the U.S. and specifically the Midwest are included in section eight of this report.

- **Aerated Static Pile Composting:** This technique uses a sizable pile of organic materials, such as hides and other materials, and aerates the pile by employing a system of pipes or hoses to blow air through the material. The procedure expedites the breakdown of the hides and creates compost of excellent grade.
- **Vermicomposting:** Worms are used in the vermicomposting process to break down organic materials like hides. The worms consume the organic material and create a superior compost.
- **In-Vessel Composting:** Composting in a closed container to break down animal skins and other organic materials, is known as "in-vessel composting." The procedure takes less time and generates compost of higher quality due to strict monitoring.
- **Open Windrow Composting:** This technique entails building extensive piles of organic materials like animal hides and rotating the piles frequently to allow air to enter. Although it takes longer than other procedures, it yields a high-quality compost.

4.3.2 Compost from Animal Hair Waste

The use of bacterial species for degradation of animal hair waste, animal byproducts and organic waste is a process commercially available that processors could implement in their operation.

Degradation of Animal Hair Waste	
Process Input	Animal hair waste, animal byproduct waste, organic waste
Technology Details	• Approximately 50-70 kg of hair is produced from one ton of raw hides during pre-tanning operations. • The process has been developed for the preparation of composting using solid waste. • A suitable bacterial species has been identified for the degradation of hair Waste, followed by manufacturing of compost using keratin hydrolysate (product of hair degradation). • The whole process could be completed within 9-10 days.
Estimated Technology Readiness Level	Implemented commercially, TRL 9 (1 kg to 500 kg level)
Data Sources	Company website, articles, news
Company	CLRI, India

5.0 Tier II Applications for Hide Utilization and Other Meat Byproducts

Tier II applications are applicable or accessible to large-scale players. In some cases, there are barriers to entry into Tier II based on existing collaborations in this application space. This section describes applications including manufacturing collagen, collagen extraction used in the biomedical and pharmaceutical industry, and gelatin extraction technologies for hide and meat byproduct utilization.

5.1 Collagen Extraction of Useful Materials from Animal Hides and Meat Byproducts

Collagen is the main structural protein found in the connective tissues of animals, including mammals, fish, and birds. It is the most abundant protein in the human body and plays a crucial role in maintaining the strength and elasticity of various tissues, such as skin, bones, cartilage, tendons, and ligaments.

At least 28 types of collagens are known, but the majority of collagen can be categorized into the following types:

1. Type I Collagen: This type is the most abundant and found in various tissues, including skin, bones, tendons, and ligaments.
2. Type II Collagen: This type is found in cartilage, which provides cushioning and support to joints.
3. Type III Collagen: This type is found in skin, blood vessels, and internal organs, where it provides structural support and elasticity.
4. Type IV Collagen: This type is found in the basement membrane, a specialized layer of tissue that separates different body tissue types.
5. Type V Collagen: This type is found in placenta, hair, and on the surface of cells.

A unique molecular structure and function characterizes each collagen type, and different collagen types work together to give the body its structural framework. Because hides and skin are key slaughterhouse waste materials considered in this study, Type I collagen and its applications are key considerations. Besides collagen, other commonly used livestock waste-derived materials include calcium phosphate, hydroxyapatite (HAP), keratin, and hyaluronic acid (HA). Due to collagen's special characteristics, including a capacity to provide tissue structure, texture, and support, it is used in various applications in the food, cosmetic, and pharmaceutical industries.

Figure 14. Overview of Waste Materials Extraction Method for Protein in Meat and Food Applications. Credit: Evalueserve

Waste Material	Main Protein	Extraction	Functionality	Meat & Food Applications
Blood	Plasma proteins (albumin, fibrinogen, and globulin) and red blood cells (hemoglobin)	• Using evaporators for producing whole blood. • Blood can also be treated with anticoagulant agents and then separated into plasma proteins and red blood cells via centrifugation.	Emulsifying, stabilizer, clarifier, color additive, water and fat binder	Blood sausages, blood pudding, cured meat, biscuits, bread, and bio-medical,
Heart, liver, lungs, tongue, spleen, meat residues from canning	Myofibrillar proteins	• Using denaturing solutions containing urea, thiourea, reducing agents such as dithiothreitol and beta-mercaptoethanol, detergents such as sodium dodecyl sulfate, and salts. • Acid or alkaline solubilization followed by isoelectric precipitation method. • Surimi processing is based on washing the minced meat to remove the water-soluble proteins, enzymes, blood, and minerals that lead to higher concentrations of myofibrillar proteins. To increase the protein stability, the product is mixed with a cryoprotectant.	Viscosity and creaminess, mild water binding and good cooking yield, emulsifying and foaming	Braised, cooked in liquid, luncheon meat, patty, loaf
Feathers, hair, wools, horns and hoofs, nails	Keratin	• Chemical methods (oxidation, reduction, and hydrolysis), microbial and enzymatic treatment, supercritical water and steam explosion, and microwave irradiation are the main extraction methods for keratin.	Film forming ability, scaffolds and hydrogels, drug release application	Food industry, cosmetics, bio-medical application, textile, bio-fertilizing

5.1.1 Collagen Extraction Processes

The collagen extraction process from animal hides to obtain pure collagen protein involves various phases. The connective tissues of animals, such as bones, tendons, and hides are important collagen extraction feedstocks.

- Fleshing: Fleshing equipment removes the flesh and fat from animal hides. These devices scrape the hide and eliminate any leftover flesh, fat, or meat using revolving blades or drums. This procedure ensures the hide is clean and prepared for subsequent processing.
- Soaking: Hides are softened and prepared in soaking tanks. The hides are normally soaked in water or a chemical solution to rid any filth or blood and to loosen the fibers for simple handling. The soaking period may change depending on the type and state of the hides.
- Dehairing: Dehairing devices remove any leftover hair, epidermis, and other undesirable tissues from the hides. These machines use mechanical and chemical techniques to remove hair and other debris. While some dehairing devices spray chemicals onto the hides to destroy the hair, others tumble the hides in a spinning drum.

Image credit: https://www.fwi.co.uk/farm-life/photos-turning-beef-hide-leather

- Size reduction (shredder, crusher, and grinder): Grinding devices reduce the treated hides to manageable bits for the collagen extraction procedure. The ground-up hides are more manageable and process more quickly. Depending on size, different types of shredders, crushers, and grinding machines may be used, from small manual grinders to massive, automated ones.
    - Shredding - Shredder machines shatter particles instead of smashing them. These machines utilize one or more spinning shafts, each having a set of cutting discs or knives fixed closely together on the shaft(s), which sit in a chamber at the bottom of a feed hopper. The material is pulled downward through tiny gaps between the cutting knives and discs. Most shredders suck the material down and force the fragments out between the two shafts using a pair of counter-rotating shafts. Particles made by shredders have an elongated shape.
    - Crushing - Crushers are used to reduce size or alter form so that the finished product may be processed more quickly. Crushing devices hold the material between two parallel or tangent solid surfaces and use enough force to press the surfaces together, creating enough energy within the crushed material to cause the molecules to split from fracture or realign in response to deformation.
    - Grinding - Through a mixture of tensile, shear, and compressive pressures, grinders reduce the size of particles by continuously smashing them into smaller and smaller pieces. A hammermill serves as the primary pounding mechanism in almost all grinders, including tub and horizontal feed grinders. A rotor and drum that spin quickly together comprise a hammermill. The hammers have enough inertia to shred the material due to the high rotational speed (greater than 1,000 RPM) (Goldstein and Diaz, 2005). The material trapped inside the hammermill chamber is smashed by the quickly spinning hammers as the drum rotates until the fragments are tiny enough to pass through the discharge screen or grate. Although the hammers will eventually pulverize the material being ground, the end product must be hard and brittle to be effective.

- **Extraction:** Collagen is extracted from the ground hides using extraction tanks. The ground hides are placed in a tank with a chemical solution to dissolve the collagen. The solution is then drained and filtered to remove any contaminants.
- **Filtration:** After collagen extraction, filtration tools are employed to eliminate any contaminants from the collagen solution. The solution is repeatedly run through a filter to remove any particles or impurities remaining after the extraction process.
- **Drying:** The filtered collagen solution is dried into a powder or sheets using drying equipment. This step removes any remaining moisture and leaves a dry, powdery substance that can be packaged and sold.

5.2 Collagen Applications in Meat Processing and Food

Collagen is widely used in various applications for meat products, food, and beverages. Specifically, collagen is used in meat and poultry processing to improve texture, act as a binding agent, and to improve the appearance of processed meats.

Collagen Application in Meat Processing and Food	
Raw Material	Waste from cutting hides and trimmings
Product	Collagen, gelatin, collagen hydrolysate, collagen peptide
Application	**Meat Processing:** Used in meat processing to improve texture and appearance of processed meat (e.g., sausage, deli meat, etc.), and as a binding agent to hold the product shape during the cooking process. **Gelling Agent:** Used in a variety of foods (e.g., gummy bears, marshmallows, jelly desserts etc.) to provide a smooth texture and firmness to the product. **Emulsifier:** Used as an emulsifier in food (e.g., salad dressing, mayonnaise, ice cream etc.) to help stabilize and thicken the product, while also impacting its texture. **Nutritional Supplements:** Collagen is added to food and beverages to support joint health, skin health, and other aspects of health and wellness. **Flavor Enhancer:** Used as a flavor enhancer in savory foods (e.g., soups and stews). It provides a rich meat flavor and can enhance the overall umami taste.
Estimated Technology Readiness Level	Already commercialized (TRL 9)
Data Sources	Article, products

5.3 Collagen Applications in Cosmetics, Bio-Medical, 3D Printing, Wound Care, and ACL Implants

Collagen is a popular ingredient in cosmetic products due to its ability to improve skin elasticity and hydration.

Collagen Application in Cosmetics	
Raw Material	Waste from cutting hides
Product	Collagen, gelatin, collagen hydrolysate, collagen peptide

Application	**Anti-aging:** Collagen is known for its anti-aging formulation to reduce wrinkles and fine lines. Cosmetics that contain collagen plump the skin to reduce the appearance of aging. **Moisturizing:** Collagen is a natural humectant, meaning it attracts and retains moisture. It can help hydrate skin and improve overall texture. **Firming:** Collagen helps maintain the elasticity of the skin to help keep it firm. **Healing:** Collagen is known to have wound healing properties. It helps speed up the healing process of minor skin injuries (e.g., cuts, scrapes etc.). **Hair and Nail Health:** Cosmetics containing collagen can help improve the health and appearance of the structures of hair and nails.
Estimated Technology Readiness Level	TRL 9. Already commercialized
Data Sources	Article, products

Figure 15. Commercially Available Collagen Cosmetic Products. Credit: Evalueserve

Collagen Application in Medical and Bio-medical Devices	
Raw Material	Waste from cutting hides
Product	Native collagen
Application	• Regenerative Medicine and Tissue Engineering: Collagen is used as a scaffold material for cell growth and tissue repair. • Skin Replacement: Collagen is used as a vehicle for the transportation of cultured skin cells or as a drug carrier for skin replacement burn wounds. • Bone Substitutes: Due to its osteo-inductive activity, collagen has been used as a bone substitute. • Orthopedic Defects: Collagen combined with other polymers have been used for orthopedic defect repair. • Drug Delivery Systems: Collagen sponges and films have been identified as effective for slow-release drug delivery and treatment of tissue infections. • Barrier Membranes: Collagen films are used as a barrier membrane for various applications.
Estimated Technology Readiness Level	Fully commercialized (TRL 9)
Data Sources	Article, products
Companies	Collagen Solutions, Rousselot, Advanced Biomatric, Botiss, BBI Solutions, Symatese, Miach Orthopaedics

Collagen Application in 3D Printing	
Raw Material	Waste from cutting hides
Product	Native collagen
Application	**Bio-ink:** Bio-ink is a material used to print 3D structures in a layer-by-layer fashion. Bio-ink is a mixture of collagen and other materials (e.g., hyaluronic acid, alginate, or gelatin, that process structural support and improve printability. **Scaffold:** Used to create scaffolds for tissue engineering applications. The scaffold is designed to mimic the structure and mechanical properties of natural tissue and seeded with cells to promote tissue regeneration. **Tissue Engineering:** Used to print 3D structures for tissue engineering applications (e.g., skin, bone, cartilage). The printed structures can be customized to match the size and shape of the defect or industry and seeded with cells to promote tissue regeneration. **Drug Delivery:** The drug is incorporated into the collagen bio-ink or scaffold and is released over time as the collagen degrades. **Organ Printing:** Collagen is being investigated for use in organ printing to create the scaffold for the organ and seeded with cells to promote organ regeneration. The technology aims to create functional organs for transplants.
Estimated Technology Readiness Level	Technology Development Stage (TRL 6-8)
Data Sources	Article, products
Companies	Collagen Solutions, Rousselot, Advanced Biomatric, Botiss, BBI Solutions, Symatese, Miach Orthopaedics

Figure 16. Sample 3D printing technology. Image Credit: https://www.pioneeringminds.com/fresh-collagen-3d-printing-fix-broken-hearts/

For wound care, applications of reconstituted collagen sheet derived from the waste of cutting a hide, tannery solid wastes, or fish scales has been validated in India at a laboratory scale (500 samples/day (10 x 10 cm).

Wound Care	
Raw Material	Waste from cutting hides, tannery solid wastes, fish scales
Product	Reconstituted collagen sheet
Application	Reconstituted collagen sheet (RCS) is a dry sheet that can be stored at room temperature and exhibits wound healing properties.

Estimated Technology Readiness Level	Lab scale validation (TRL 6)
Data Sources	Company website, patents
Company	CLRI, India

Bridge to ACL Restoration (BEAR)	
Raw Material	Hide
Product	The BEAR impact is a decellularized bovine-derived, type 1 collagen implant that resorbs within 8 weeks of implantation.
Technology Details	The application restores the native ACL as it bridges the gap between the ends of the torn ACL and is clinically effective for a majority of ACL tear types.
Estimated Technology Readiness Level	Clinical trials completed (TRL 7-8)
Data Sources	Company website, news
Company	Miach Orthopaedics

5.4 Gelatin Extraction Technology Available for Commercialization

The traditional gelatin extraction process from animal hides begins with dehairing the hide, then chemically treating it in a lime sulfide bath for about 40 days. Collagen is also broken down through either an acid pretreatment or alkaline treatment. After the pretreatment, hides are further processed to extract the gelatin.

Gelatin Extraction	
Raw Material	Waste from cutting hides, trim waste, fleshing
Product	Gelatin/Collagen hydrolysate and protein hydrolysate
Technology Details	• Complete utilization of trimming waste to make high value products within 48 hours. • Simple, innovative, and cost-effective technology. Holistic and a closed-looped processed for the extraction of gelatin. • Developed protein hydrolysate has multiple uses (e.g., leather, agriculture, and animal feed applications)
Estimated Technology Readiness Level	Already commercialized (TRL 9)
Data Sources	Company website, patents
Company	CLRI, India

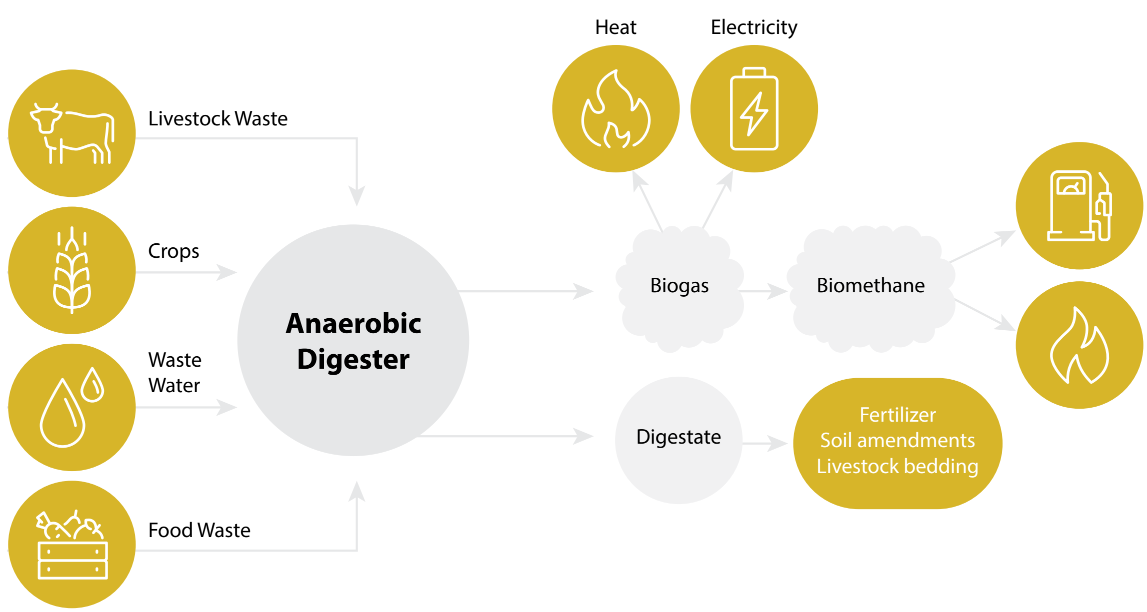
6.0 Tier III Applications for Hide Utilization and Other Meat Byproducts

Tier III applications are generally multi-organizational and offer collaboration opportunities, such as at the community or municipal level. This section describes applications including anerobic digestion, waste-to-energy, gasification, and thermal technologies for hide and meat byproduct utilization.

6.1 Anaerobic Digestion for the Management of Hide Waste and Other Meat Byproducts

Anaerobic digestion (AD) is a naturally occurring process by which bacteria break down organic matter without oxygen. Biogas, a mixture of methane and carbon dioxide with traces of other gases, results from the bacteria's metabolic activity and is the main product of AD. Industrial anaerobic digesters are engineered systems that harness the process under controlled conditions to harvest the biogas for beneficial use as a renewable energy source. Given its effectiveness in destroying organic contaminants in aqueous streams, AD has also found widespread application in wastewater treatment systems independently of its renewable energy generation capabilities.

While many digester configurations exist, some of which are discussed later, they are commonly mixed tank or plug flow reactors. The latter are horizontal tanks with the flow of the material being processed moving along the longitudinal axis. For large and relatively dilute waste streams, covered lagoons are also common. The residual from AD is typically a nutrient-rich substrate that can be applied as a fertilizer or soil amendment or may be further composted. AD is already commonly used in many meat processing plants as blood, waste grease, dissolved air floatation (DAF) sludge, and other hide-specific wastes such as fleshing are very digestible. Care, however, must be taken to avoid bones and excessive amounts of hair being introduced into a digester, as these are not digested. AD does not process chitin – the main component of hair – nor the carbonate minerals that make up bones. These undigestible solids, along with other non-organic solids, from dirt and sand to plastic packaging residues, may accumulate in the digesters and lead to unexpected system failure or premature maintenance needs. Furthermore, they may significantly reduce the opportunity for beneficial use of the digestate, forcing its disposal into a landfill. Similarly, the introduction of paunch in the AD system should be avoided in meat processing plants as this material is better suited for composting.



Anaerobic processes are distinguished by their operating temperature and are typically defined as mesophilic when operating around 95F or thermophilic when operating around 125F. Also, the AD system can be characterized as low solids (less than 10% suspended solids) and high solids (from 10 to 30% suspended solids). In principle, any of these systems are suitable for processing waste from meat plants and animal hide processing. However, specific design and operating choices will be dictated by various factors related to the amount of available waste, space, and final disposal of gas and digestate that need to be addressed case-by-case. Lastly, AD systems are relatively large, requiring several days of hydraulic residence times (HRT), HRT between 10 and 20 days being the most common. AD systems with a significant reduction in HRT exist (measured in hours rather than days). Although these high-rate systems can dramatically reduce the AD footprint, they are not generally applicable to all types of waste. For example, high-rate systems are not recommended for waste streams with a significant number of suspended solids. They have, however, found applications in the meat processing industry to process blood and emulsify fat waste streams.

6.1.1 Assessing the Suitability of an AD Project

When assessing if AD is suitable for a specific waste management problem, it is worthwhile to engage expert advice for the evaluation of the opportunity and to identify the best technical solutions. There are plenty of technical and business resources available to those interested in developing AD projects, and the American Biogas Council (www.americanbiogascouncil.com), the largest U.S. AD trade organization, is an excellent resource to identify competent experts in every aspect of anaerobic digestion.

The first step in assessing the opportunity for AD is a detailed characterization of the feedstock using representative samples from the process. A well done feedstock characterization allows an experienced system designer to accurately estimate an industrial scale digester and support reliable economic analysis of the proposed solution. Feedstock characterization is always recommended. This characterization encompasses the following steps:

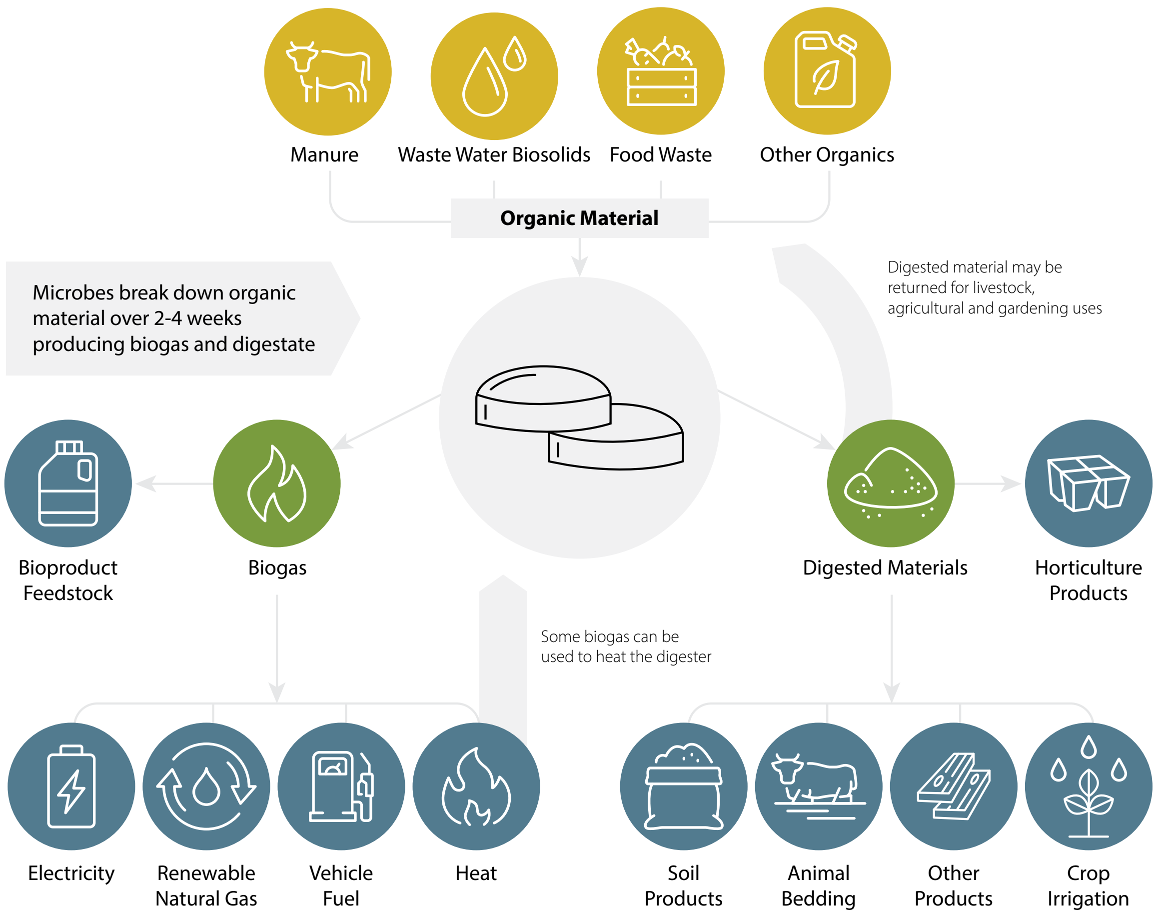
- Total solid (TS). Total solids indicate the weight percentage of solid material suspended or dissolved in the waste.
- Volatile solids (VS). VS are solids that can be volatilized—thus turned into gas—under certain standard conditions. They are expressed as a fraction of the TS. Regarding animal waste processing, bone fragments will be accounted for in the TS but not in the VS.
- Elemental composition. This analysis indicates the content as a carbon, oxygen, nitrogen, and sulfur weight percentage. Nitrogen is essential since the digestion process will not happen without adequate nitrogen. On the other hand, too much nitrogen may lead to the formation of ammonia, which may inhibit biological processes. A feedstock's carbon-to-nitrogen ratio (C:N) must be in the recommended range (40 to 20) for optimal digestion. Also, the presence of sulfur will indicate the possible presence and expected quantity of hydrogen sulfide (H2S) in the gas. H2S is a highly toxic gas with a characteristic rotten egg smell. The presence of moisture can lead to the formation of highly corrosive acids, which can rapidly damage pipes and equipment. Fortunately, once the possibility is determined, H2S presence in the gas can be easily mitigated by widely available and well-proven abatement technologies.
- Proximate analysis. This indicates the relative composition of the material by breaking it down into classes of compounds such as carbohydrates, lipids, etc. This determination is critical to help select the digester's optimal temperature and the compatibility of the feedstock for mixing with other waste material for co-processing.
- Chemical Oxygen Demand (COD) may be appropriate for waste where there is a small number of suspended solids and most waste material is dissolved. COD can be used for a quick estimation of the gas generation and energy content potential of the waste stream.
- Biomethane potential (BMP) directly measures a waste material's maximum methane generation potential. In BMP testing, a small material sample is digested under controlled circumstances. Gas is produced and collected over several days, creating a gas generation collection curve that indicates the gas produced by a specific amount of material over time. When the generation curve flattens, and no further gas is generated, the maximum gas generation rate has been reached, and the gas production to that point is expressed as the volume of gas per unit of waste processed (typically gr of methane per gram of VS) is the BMP. BMP represents a best-case scenario under ideal circumstances; in practical applications, HRT may be shorter, but in a large-scale system, both mixing and feeding policies will impact the actual gas generation. Those are considerations an experienced AD system engineer will consider to determine the expected performance of an industrial-scale system out of the BMP.

6.1.2 Use of Biogas

Biogas is a mixture of methane, the main component of natural gas, and carbon dioxide, with a few minor potential contaminants. On a volume basis, biogas typically contains between 55% and 60% methane and 45% to 40% carbon dioxide. The primary contaminants are ammonia and hydrogen sulfide (H2S), typically 1% or less. Also, the biogas is saturated with water as it emerges from the digester. Less common for waste from non-human sources is the presence of siloxanes.

The versatility of biogas as an energy source is remarkable, with its applications ranging from direct combustion for heating to sophisticated uses like power generation and upgrading to renewable natural gas (RNG). However, biogas must undergo several processing steps to harness its potential effectively, notably drying and removing contaminants.

How Biogas Systems Work



The first crucial step in biogas processing is the removal of contaminants. These contaminants include hydrogen sulfide (H2S), water vapor, siloxanes, and other trace elements. If not adequately addressed, their presence can cause corrosion, decrease efficiency, and lead to environmental and health hazards. Hydrogen sulfide, a common contaminant, is particularly harmful due to its corrosive nature and toxicity. It is typically removed through simple and inexpensive processes like iron sponge scrubbers, water scrubbing, or activated carbon filters. These methods, all commercially available by various vendors, effectively reduce the concentration of H2S and other contaminants, rendering the biogas safer and more efficient for downstream applications. When the amount of H2S is particularly high, biological desulfurization of biogas is an innovative and environmentally friendly approach to its removal. This method leverages the natural ability of certain microorganisms to convert hydrogen sulfide into elemental sulfur or sulfate. The gas is bubbled through a bioreactor where the process occurs, and as a result, a wet cake of elemental sulfur is recovered. Unlike conventional chemical scrubbing systems like iron sponges, whose coproduct is a chemical waste to be landfilled, the wet cake produced by a biological desulfurization system can be land applied as a beneficial soil amendment. Also, biological desulfurization, initially pioneered in the Netherlands, is available from multiple commercial vendors.

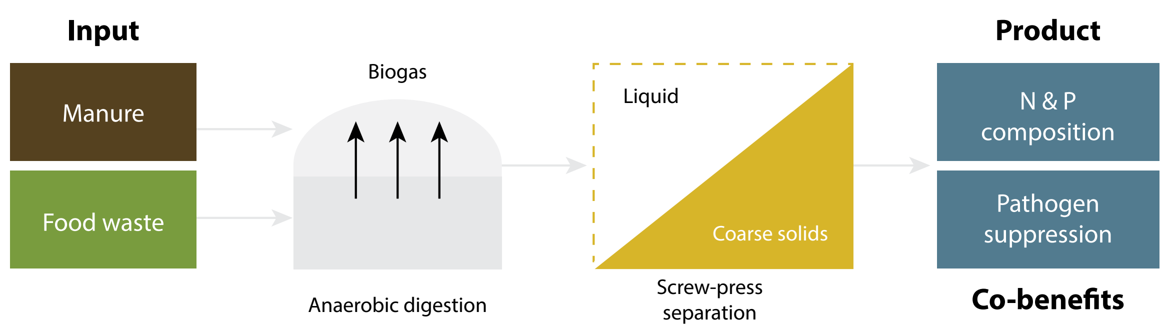
- Utilization in Combined Heat and Power (CHP) Systems. Once cleaned, biogas is an excellent fuel for CHP systems. CHP, also known as cogeneration, simultaneously produces electricity and thermal energy from a single fuel source, in this case, biogas. This dual production makes CHP one of the most efficient energy conversion methods, often reaching efficiencies greater than 80%. In a CHP plant, biogas is used to power a gas engine or turbine, which generates electricity. The heat produced in this process, which would otherwise be wasted, is captured and used for heating or industrial processes. Depending on the needs, CHP systems can be designed to produce hot water or steam, which can be used in the hide processing plant.
- Use for Thermal Energy. Apart from electricity generation, biogas can also be directly used for thermal applications. In its simplest form, this involves burning biogas in a boiler or heater, providing a renewable heat source for residential, commercial, or industrial uses. This direct use of biogas is particularly appealing due to its simplicity and cost-effectiveness since commercial

boilers and heaters can be used with simple modifications of the burners to account for the lower BTU gas. Often, thermal use of biogas can occur with a multifuel system allowing the use of biogas, natural gas, or propane for maximum versatility.

- Production of Renewable Natural Gas (RNG). To further elevate the value of biogas, it can be upgraded to RNG by removing carbon dioxide. This upgrading process involves several technologies, including water scrubbing, pressure swing adsorption, and membrane separation. The aim is to increase the methane content (the primary component of natural gas) well above 95%, making it comparable to conventional natural gas in terms of energy content and quality. The upgraded biogas, now RNG, can be injected into natural gas pipelines or used as a vehicle fuel. CO2 removal equipment is readily available from many commercial vendors, and the process technology is well-proven and reliable. Any CO2 removal process will require the gas to be pressurized to about 200 psi or higher. Since pipeline injection of use for automotive fuel also requires high pressure, the pressurization requirement of CO2 removal does not add extra costs. However, since local use of gas for thermal or CHP applications can be done without CO2 removal, the captive use of gas can offer considerable operating and capital cost savings. These trade-offs need to be considered when estimating the possible use of biogas.

6.1.3 Use of Digestate

The residuals from anaerobic digestion (AD), commonly known as digestate, are a valuable byproduct of the biogas production process. Digestate is a nutrient-rich substance that comprises undigested material, bacteria, and the remnants of organic matter that has been broken down. Its composition makes it an excellent resource for agricultural and landscaping applications, primarily as a soil amendment or fertilizer. However, digestate often requires specific treatments before its utilization to maximize its benefits and ensure safety.



First, the digestate is usually separated into solid and liquid fractions. The solid fraction is rich in organic matter and can be composted to stabilize the nutrients and reduce residual pathogens if applicable. This composting process enhances its value as a soil conditioner, improving soil structure, water retention, and microbial activity. On the other hand, the liquid fraction, rich in readily available nutrients like nitrogen and potassium, can be directly applied to crops as a liquid fertilizer, besides being recycled to the AD system or treated by conventional techniques to make it amenable for discharge into natural bodies of water. If used for irrigation, it is crucial to manage its application carefully to prevent nutrient run-off and groundwater contamination.

Occasionally, treatments such as pasteurization or sanitation may be necessary to reduce pathogen levels, mainly if the digestate is to be used on food crops. Pasteurization involves heating and holding the digestate at a specific temperature – minimum 165F for thirty minutes, although much lower retention time is needed when using higher temperatures to kill harmful bacteria, ensuring compliance with health and safety standards. Additionally, the nutrient content and pH levels of the digestate should be regularly monitored and adjusted to meet the specific requirements of the intended application.

Digestate from AD processes offers a sustainable way to recycle waste, return nutrients to the soil, and reduce the reliance on chemical fertilizers. However, appropriate treatments are essential to ensure its safe and effective use, particularly in agriculture. These treatments enhance the digestate's quality and play a critical role in environmental protection and sustainable agriculture practices.

6.1.4 Other Benefits of AD

There are other benefits of AD, namely odor reduction and pathogen destruction. The enclosed nature of the AD process and the chemical transformation occurring in the process ensure that typical odor-bearing compounds such as mercaptans and VOC are destroyed. H2S, while present in the AD process, will not be detectable in the vicinity of the process if properly handled and destroyed. The effluent from AD is typically free of noxious smells and possesses a musty, weak, organic smell, unlike compost. AD is also quite effective in pathogen destruction. While pasteurization steps may be needed for specific applications, the count of most typical pathogens, such as e-coli, is greatly reduced in most AD systems. The usual residence time in a digester system typically ensures decimation. It should be noted, however, that the proteins causing bovine spongiform encephalopathy (BSE) are not effectively destroyed in an AD system, and high-temperature incineration remains the only effective method to handle high specific BSE risk material.

6.1.5 Operating an AD System

Operating an anaerobic digester involves managing the complex interplay of biological, chemical, and mechanical processes. Effective management and continuous monitoring are crucial to maintaining optimal conditions for the breakdown of organic matter and biogas production. While this may appear complex, the operation of an AD is simple if monitoring key parameters is not ignored and sudden changes to the system are avoided. The key steps in operating and monitoring a digester are:

- **Feedstock Preparation:** The operation begins with preparing feedstock or the waste material or mix of wastes to be fed into the digester. While most feedstock requires minimal preparation, some pre-treatment may enhance biodegradability. Pre-treatment methods might include grinding, heating, or hydrating the material.
- **Feeding the Digester:** The prepared feedstock is fed into the digester. Consistent feeding schedules and maintaining the correct ratio of carbon to nitrogen (C:N ratio) are vital for efficient digestion and biogas production. When changing the digester feed, the change must be modulated slowly – often over several days – while critical digester health parameters are monitored.
- **Removing Digestate:** Digestate is removed from the digester and immediately dewatered, typically using mechanical means such as a filter press, belt press, or screw press. The liquid is then recycled to the digester or further processed for discharge as it may be required by relevant regulations and permits. If the dewatered digestate is still moist, but no standing water is present, it can be directly land-applied or thermally dried for palletization and used as solid fuel or compost.

An anaerobic digester is an engineered system that requires diligent and regular monitoring, although not extensive. That includes a variety of online measurements and regular sampling for tests. Those are typically carried out weekly unless other performance issues require detailed investigation or if the system is steered through operating changes. An example of the latter would be changing the feedstock type or feeding policy.

- **Temperature Control:** Digesters operate under mesophilic (around 95F) or thermophilic (around 125F) conditions. Temperature is critical to microbial activity and gas production and must be maintained consistently. In cold climates – especially in the winter – heating may be necessary, and adequately designed digesters include thermal control and insulation designed for their locations. A well-designed AD system has appropriate temperature control. Depending on the season and location, the system may need heating, typically done using some of the digester biogas or a waste heat source, such as the CHP system.
- **pH Balance:** The pH of the digester should be monitored and maintained around neutral (pH 6.8-7.2) for optimal microbial activity. Deviations can inhibit the digestion process. pH can be continuously monitored.
- **Biogas Composition Monitoring:** biogas composition (methane and carbon dioxide) is crucial. A sudden change in gas composition can indicate process imbalances. An inexpensive and reliable Near Infrared (NIR) analyzer allows this analysis to be carried out. Hand-held devices and panel-mounted stationary units can be used to offer readings as frequently as one-minute intervals and allow remote connectivity and continuous data recording.
- **Organic Loading Rate (OLR):** OLR is the amount of organic material per unit of digester volume per unit of time and represents the feed into the digester. It must be carefully controlled. Overloading can lead to process imbalances while underloading results in suboptimal gas production.
- **Hydraulic Retention Time (HRT)** refers to the time the feedstock remains in the digester. Ensuring the correct HRT is crucial for the complete digestion of the feedstock. HRT is controlled by monitoring and modifying inflow and outflow from the digester. Often, HRT and OLR are related.

- **Volatile Fatty Acids (VFAs):** VFAs are intermediate products of digestion. Monitoring VFA levels can indicate the health of the digestion process; high levels may suggest acidification and process imbalance. Monitoring VFA requires taking a sample from the digester liquid and carrying a simple chemical test, which can be automated using an automatic titrator. Automatic titrators are standard equipment in the wastewater industry.
- **Foam Formation:** Foam formation can cause operational issues. Foam is caused by the emulsification of dissolved proteins and some fat compounds. Monitoring and managing foam is essential to prevent blockages and ensure efficient gas release. Modifying the mixing regime and, in some circumstances, adding antifoaming agents to the feedstock are effective methods to control foam formation.
- **Digestate Quality:** The quality of the digestate, the material remaining after digestion, should be monitored.
- **Mixing:** The flow regime inside the digester must ensure no solids accumulation anywhere. Maintaining proper flow dynamics, whether via mixing or flow characteristics, is critical to ensure the long-term performance of the digester. On the other hand, mixing too aggressively may lead to foam formation.

The operation of an anaerobic digester is a finely tuned process requiring diligent monitoring and control. By keeping a close eye on key parameters like biogas composition, temperature, pH, OLR, HRT, VFAs, mixing, and digestate quality, operators can ensure the efficient and consistent production of biogas while producing high-quality digestate. This monitoring optimizes biogas yields and ensures the anaerobic digestion process's long-term sustainability and economic viability. While this type of monitoring is not highly time-consuming and can take advantage of opportunities for automation and remote sensing, it must be diligently carried out frequently and consistently.

Lastly, AD systems require moderate but effective maintenance to operate effectively. Typical maintenance procedures include steps familiar to anyone accustomed to managing and maintaining industrial processes and equipment such as those found in meat and meat coproducts processing plants:
- Regular inspections of tanks, pipes, valves, and pumps are essential. This includes checking for signs of wear, corrosion, leakage, or blockages with immediate repair or replacement of defective components.
- Over time, sediments and scum can accumulate in the digester, reducing its efficiency. Scheduled cleaning of the digester and associated components is necessary to prevent this. However, this process can be complex and may require the system to be shut down temporarily. Proper mixing and flow characteristics monitoring ensures that this type of maintenance may not be needed or only done once every several years.
- Biogas handling components, such as blowers, compressors, and storage vessels, should be regularly checked for leaks, corrosion, and mechanical integrity.
- Pumps, mixers, and other components with rotors and electric motors must be monitored for wear and tear, proper electric loading, and excessive vibration.

6.1.6 Funding and Incentives Available for AD Project Development

AD's potential for renewable energy production, greenhouse gas reduction and offsetting, improved nutrient recovery and reuse, and water quality enhancement has generated recent interest in AD and the arrival of public programs to incentivize the industry. While a detailed discussion of all the programs, some of which are local and often subject to change, is beyond the scope of this report, the trade resources such as the American Biogas Council (www.americanbiogascoucil.org) or the Coalition for Renewable Natural Gas (www.rngcoalition.com) can provide access to recent rulemaking, their interpretation, and expert advice on their applicability and eligibility requirements. The following agencies at the federal and state level can provide relevant information: Treasury Department, the Department of Energy, the Environmental Protection Agency, U.S. Department of Agriculture, as well as departments or agencies at the state level covering environmental, economic development, and agriculture areas.

Government grants, subsidies, and facilitated financing:

1. Capital incentives: Governments often provide capital grants or low-cost loans to cover some of the upfront costs of installing an AD system. They are crucial for reducing the initial financial burden on businesses or individual proprietors. Another form of capital incentive is loan guarantees, where a government agency becomes a guarantor for a privately held loan to a developer. Loan guarantees reduce the risk for the private lender and allow the developer to access cheaper and more abundant credit lines.

2. Operational subsidies: Some regions offer subsidies for the ongoing operation of AD systems, helping to make them more financially sustainable.

Tax incentives and credits:

1. Investment Tax Credits (ITC): These credits can be applied against the tax liability of a business, effectively reducing the net cost of installing an AD system. ITCs are often tradeable, thus allowing a new company with limited tax liability to benefit from them. ITCs are often subject to strict eligibility requirements, and their consideration always requires expert advice and consultation with the relevant government agencies.
2. Production Tax Credits (PTC): PTCs provide financial rewards based on the amount of energy produced by the AD system, encouraging efficient and continuous operation.

Feed-in tariffs:

1. Guaranteed pricing for energy: Governments or utilities may offer feed-in tariffs, guaranteeing the purchase of the electricity generated from AD at a fixed, often advantageous price. This ensures a stable income stream for operators.

Renewable Energy Certificates (RECs):

1. Certificates for renewable production**: RECs are tradable certificates representing producing a certain amount of renewable energy. AD operators can sell these certificates, providing an additional revenue stream.

Carbon credits and trading:

1. Emissions reduction incentives: By reducing greenhouse gas emissions, AD systems can qualify for carbon credits, which can be sold in carbon markets.
2. RNG pricing: In some markets, utilities and other natural gas buyers may be interested in buying RNG and pay a premium over the local natural gas price, which is tied to the RNG's carbon intensity (CI). By avoiding landfilling or decomposition in the environment, both sources of high greenhouse gas emissions, AD produces RNG with a considerable reduction in CI. Complex rules exist to calculate the CI of the AD system, and each project needs to be assessed individually. CI assessments are subject to audit and can change over time. RNG pricing, while typically very lucrative, is also subject to market and commodity risk, not unlike carbon pricing.

Green energy purchasing agreements:

1. Contracts with energy users: Some businesses or governments enter into purchasing agreements for the green energy produced by AD systems, offering a secure long-term market.

Research and development grants:

1. Funding for innovation: These grants support the development of new AD technologies or improve existing ones, encouraging innovation in the sector.

Community and cooperative programs:

1. Local incentives and support: Community-driven programs often provide support, both financial and logistical, for AD projects that benefit local communities, such as those converting community waste into energy.

Is anaerobic digestion an appropriate solution for an operation?

Waste from meat fabrication and ancillary processes is an excellent source of biogas. However, the quantity and yield of biogas can vary dramatically depending on local conditions, type of operations, and the size of the facility. Furthermore, the economic viability and value-added from biogas recovery are impacted by location, local demand for the gas or other energy products such as electricity, and the possibility of aggregating waste from meat fabrication with other organic wastes such as food waste, organic waste from other types of processors (e.g., breweries, agricultural commodity processing plants, etc.), and even integration with municipal wastewater treatment plants. Given the current incentives for biogas production and market demand for low-carbon intensity renewable natural gas obtained from the purification of biogas, even modest amounts of organic waste may become an attractive source of biogas when developed in the context of a larger biogas project using a variety of wastes. However, providing quantitative data that may satisfactorily guide across all possible circumstances encountered in the industry is not practical for the scope of this report. Anyone interested in anaerobic digestion should contact reputable professionals in the industry for a preliminary assessment of local feasibility and value opportunity. Trade organizations such as the American Biogas Council or government agencies such as the EPA can reliably help interested parties in identifying appropriate technical resources for such an evaluation.

Market development programs:

1. Support for developing market opportunities: These programs help develop markets for byproducts of AD, like digestate, enhancing the overall economic viability of AD operations.

6.2 Thermal Technologies for the Management of Hide Waste and Other Meat Byproducts

Pyrolysis and gasification are promising, but they are at a TRL 4-5 regarding the utilization of animal hides and other waste from slaughterhouses and have intrinsic operational complexity. Any thermal technology other than hydrothermal liquefaction is penalized by high moisture content, although heat recovery may help reduce the intrinsic thermal inefficiency associated with high moisture feedstock. Hydrothermal liquefaction is receiving a lot of interest because of the ability to produce bio-oils that could be further upgraded to bio-fuels, but for now has not been proven past the pilot stage. Combustion or incineration is well-proven but increasingly frowned upon as a waste management technique and may be complex to permit.

- **Pyrolysis:** Pyrolysis converts animal waste into bio-char, resulting in significant mass and volume reduction while retaining high nutrient value. The process also generates syngas, a combustible mixture of carbon dioxide, carbon monoxide, hydrogen and methane, and bio-oil. The syngas effluent is used to provide the heat needed for the process, while the bio-oil could be used as a fuel or as a chemical feedstock. Pyrolytic bio-oils are toxic and water soluble and may be fairly complex to handle requiring expensive metallurgy that may negate the capital cost benefit of a relatively compact system.
- **Gasification:** When heated in a low-oxygen environment, animal waste converts to syngas. Syngas could be used as fuel. It could also be upgraded catalytically to ethanol or other fuels, but the cost of such conversion is practical only for large amounts of syngas.
- **Hydrothermal Liquefaction:** Hydrothermal is a process to convert any organic material including cattle hides and other animal waste into a bio-char and liquid water-insoluble bio-oil. The process involves subjecting the feedstock to very high temperatures and pressure in the presence of water. The bio-oil can be used as a fuel or feedstock for manufacturing other bio-based products, including hydrogenation liquid fuels.

Process	Advantages	Disadvantages
Incineration/ Combustion	• Easier handling because non-combustible material waste has already been extracted • The thermal energy obtained in the incineration process could be used for power recovery • Well-understood technology • Moderate capital cost	• Complex air emission control because of heavy metals, VOC's and particulates in the flue gas. • Ash handling and disposal
Pyrolysis	• Lower temperature than combustion • Compact equipment • Liquid product that can be stored and used as fuel or chemical precursor • Higher energy recovery rate	• High capital cost because of metallurgy requirements • High content of VOC's requires complex flue gas treatment with thermal oxidation • Scarce commercial uses of pyrolytic oil which are highly toxic and water soluble leading to possible high environmental risks
Gasification	• Production of syngas which can be used as fuel or as a chemical precursor	• Very high capital cost • Operational complexity
Hydrothermal Liquefaction	• Handles high moisture levels in the feedstock • Produces a stream of bio-char and a stream on non-water-soluble bio-oil hydrocarbons • Very compact	• High energy input • Waste water handling • Energy recovery requires the use of the bio-oil

Figure 17. Advantages and Disadvantages to Thermal Technologies of Hide Waste and Byproducts

6.2.1 Funding and Incentives Available for Thermal Technologies

- USDA Rural Energy for America Program (REAP): REAP provides grants and loan guarantees to agricultural producers and rural small businesses for the purchase and installation of renewable energy systems, including bio-energy projects such as pyrolysis, gasification, and hydrothermal liquefaction.
- DOE Bio-energy Technologies Office (BETO): BETO provides funding opportunities for research, development, and demonstration of advanced bioenergy technologies, including biomass conversion technologies such as pyrolysis, gasification, and hydrothermal liquefaction.
- National Science Foundation (NSF): The NSF offers funding opportunities for research and development of new technologies and processes related to the production of renewable energy from biomass, including hides and other animal waste.
- Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs: These programs provide funding opportunities for small businesses to develop and commercialize innovative technologies related to bio-energy and other fields.
- State and local government programs: Many states and local governments offer funding opportunities for renewable energy and bio-energy projects, including pyrolysis, gasification, and hydrothermal liquefaction.

7.0 Tier II and Tier III Animal Hide Applications in Development

Currently, there are four applications in development for the use of animal hides and byproducts. These include:

- Using animal hides as a source of high-quality proteins and fats;
- Leather waste as an insulation material;
- Animal fats and grease as a bio-fuel; and
- Gelatin use in packaging.

DeMythe® developed a technology that extracts high-quality proteins, fats, and oils from other animal waste (e.g.; pig skin, chicken skin, and animal organs) that is focused on extracting protein and fat in food applications. The company is also investigating opportunities in non-food applications (e.g., bio-coatings, surfactants, or chemical building blocks for bio-plastics).

In the United Kingdom, Nanoforce Technology developed a technology to break down leather waste into its constituent components (e.g., collagen, gelatin, and lump). The fibrous remnants of the hide have ideal insulation properties (soundproof, fire resistant, low thermal conductivity). Although this technology is in development, it has an advantage as a low-cost alternative.

The production of bio-fuels and bio-diesel are potentially high-demand applications for animal fats and grease. Currently, the dominant sources of bio-diesel are soybean oil (in the U.S.) and canola oil (in Europe). However, the number of plants utilizing mixed feedstock and animal fats and grease is increasing. There is an opportunity for direct utilization within renderers' own facilities.

Lastly, the use of gelatin in packaging is due to gelatin's mechanical and hydrophilic properties. Composites of gelatin with synthetic polymers like poly vinyl alcohol (PVA), poly lactic acid (PLA), and polyacrylamide, along with cross-linking can confer the required mechanical and water resistance in packaging.

8.0 Recommendations

Hides are versatile biomaterials that can be used in a range of applications. The applications vary from direct use and recycling/reuse applications like leather, parchment, pet chews, and snacks to applications utilizing materials extracted from hides such as collagen, keratin, elastin, etc. In addition, valuable products such as biogas, fertilizer, bio-char, and syngas can be generated from these materials using innovative waste management techniques such as composting, anaerobic digestion, pyrolysis, gasification, and hydrothermal liquefaction.

8.1 Animal Hides and Waste Management Reduction

The order of priority for waste management is Prevention > Reduction > Reuse / Recycling / Recovery > Disposal.

This allows for optimum and sustainable utilization of waste generated from slaughterhouses and rendering establishments. Some industry-wide strategies for the prevention and reduction of waste or hazardous waste generated from the process include:

- Increase share of native wastes while decreasing the share of chemically treated solid wastes. This is applicable for tanning for green fleshing and lime splitting. This decreases both the consumption and discharge of chemicals.
- Reduce the amount of non-usable waste by improving the efficiency of mechanical operations for hair removal and fleshing from hides such as splitting, shaving, and coating. Incorporate other techniques such as eco-friendly salt-free preservation and combined preservation and dehairing technologies.
- Avoid unnecessary contamination of solid wastes, which will allow a broader range of end uses and applications.
- Practice good housekeeping (i.e., stringent and prompt handling of all categories of solid waste).
- Institute proper classification, segregation, and handling of wastes not directly related to the manufacturing process (i.e., packaging, barrels, paper, etc.).

8.2 Challenges with Meat Processing Waste Management in the Midwest

Researchers analyzed harvesting, meat processing, and rendering establishments across five states in the Midwest (Iowa, Minnesota, North Dakota, South Dakota, and Wisconsin) and identified a few critical problem areas:

- **Shortage of rendering establishments** – There is severe shortage of rendering establishments in the Midwest, especially in North Dakota, South Dakota, and Wisconsin. North Dakota specifically has no rendering facilities and establishments and must rely on rendering establishments in other states. Often times, meat processors' only option is sending animal hides and waste to a landfill. As a solution, provide processors with more readily available access to rendering facilities and resources to alternative applications.
- **Lack of alternative waste disposal avenues** – while Wisconsin, Iowa, and Minnesota, ranking 5th, 6th, and 8th respectively in biogas production potential and have several anaerobic digestors on farm and in municipal water treatment facilities, there is an opportunity for more AD operations due to the extent of funding available. In addition, North Dakota and South Dakota lag behind significantly in this aspect, ranking 45th and 36th in the U.S. for biogas production potential (Source – American Biogas Council).
- **Logistics management** – The decreasing number of small, local rendering establishments coupled with consolidation by major players like Darling (takeover of Valley Proteins) led to small meat establishments having to pay renderers to take hides and other animal waste for further processing. The situation is more severe in North Dakota and South Dakota considering the points mentioned above. As a result, enabling optimized logistics for hide and animal waste collection from meat establishments would greatly alleviate issues regarding waste generated from these establishments.

8.3 Recommendations for AURI and Other Technical Assistance Providers

The Agricultural Utilization Research Institute (AURI) and other technical assistance providers, including those in the Meat & Poultry Processing Technical Assistance (MPPTA) Network, can further supplement local businesses with technical know-how related to the identification and implementation of new uses for animal hides and other waste. Recommendations include:

Research and Development:

- Conduct research and development to identify new uses for hides and other animal waste, such as further exploration of how to use these materials in the production of renewable energy, bio-based materials, or other value-added products.

Education and Outreach:

- Educate farmers and processors on the benefits of diverting hides from landfills.
- Work with industry associations to develop best practices for hide collection and storage and provide information on the economic and environmental benefits of hide recycling.
- Provide technical assistance to businesses and entrepreneurs to develop new products or processes using animal waste. This may include helping with product formulation, process optimization, or other technical aspects of product development. This could also involve setting up resources to access information, tutorials, and funding on waste disposal techniques like composting and anaerobic digestion.

Market Development:

- Identify markets for products made from animal waste. This may include creating linkages to potential customers, providing market research, or developing marketing strategies.

Collaboration:

- Collaborate with other organizations, such as tanners, leather goods manufacturers, and waste management companies, to develop new supply chains for hide recycling. By building partnerships across the value chain, technical assistance providers could help create a market for recycled hides and improve the economics of adding value to waste streams.

8.3.1 Potential Avenues for Research & Development

R&D activities that can be explored for the utilization of hides:

- **Processing and Tanning:** Leather remains the most dominant application area for hides and accounts for 50 – 80% of the total market for hides. R&D activities in this area can focus on developing new tanning methods or improving existing ones to produce higher-quality leather. For example, researchers could explore ways to reduce the use of toxic chemicals in the tanning process or develop new methods for producing specialty leathers with unique properties or textures.
- **Bio-based Materials:** Hides contain a variety of proteins and other natural compounds that can be used to develop bio-based materials, such as adhesives, coatings, or composites. R&D activities in this area can focus on identifying new applications for these materials or improving their performance properties. For example, researchers could explore ways to make these materials more durable or develop new formulations that are more environmentally friendly.
- **Renewable Energy:** Hides and other animal waste can be used as a feedstock to produce renewable energy, such as biogas or bio-fuels. R&D activities in this area can focus on developing new technologies for processing these materials or improving the efficiency of existing processes. For example, researchers could explore ways to increase the yield of biogas from cattle hides or develop new methods for converting animal fats into bio-diesel.
- **Health and Wellness:** Hides contain a variety of bio-active compounds that have potential health benefits, such as collagen and elastin. R&D activities in this area can focus on identifying new applications for these compounds or improving their effectiveness. For example, researchers could explore ways to incorporate these compounds into food or cosmetic products or develop new medical applications for them.

8.3.2 Bio-Based Materials

Animal hides contain a variety of natural compounds, including proteins, lipids, and other bio-polymers, that can be used to develop bio-based materials for various applications. Here are some examples of bio-based materials from cattle hides that can be used as adhesives, coatings, or composites:

1. **Collagen-Based Adhesives:** Collagen is a natural protein found in hides that can be used to develop strong and flexible adhesives. Collagen-based adhesives have good bio-compatibility and can be used in medical applications such as wound closure or tissue engineering. They can also be used in other industrial applications such as laminating or packaging.
2. **Gelatin-Based Coatings:** Gelatin is a protein derived from collagen and can be used to develop coatings for various applications such as food, pharmaceuticals, and textiles. Gelatin coatings can provide moisture and oxygen barriers, as well as improve the mechanical and sensory properties of the coated product. Cattle hide-derived gelatin can be used as a sustainable alternative to synthetic coatings.
3. **Chitosan-Based Composites:** Chitosan is a natural bio-polymer derived from chitin, which is found in the shells of crustaceans and insects. However, it can also be extracted from cattle hides. Chitosan can be used to develop composites by combining it with other natural or synthetic materials. Chitosan-based composites can have improved mechanical and barrier properties, making them suitable for packaging or structural applications.
4. **Keratin-Based Adhesives:** Keratin is a natural protein found in cattle hides that can be used to develop strong, water-resistant adhesives. Keratin-based adhesives can be used in applications such as wood adhesion or paper lamination. They can also be used as a sustainable alternative to synthetic adhesives.

These are just a few examples of the bio-based materials that can be developed from cattle hides and used as adhesives, coatings, or composites. By exploring these and other areas of research, it may be possible to create new sustainable materials and reduce waste in the livestock industry. For all these activities, the market for the end-product will need to be evaluated.

8.3.3 Renewable Energy

Hides and other animal waste can be processed into biogas and bio-fuel using the following commercial and pilot scale technologies.

1. **Anaerobic Digestion:** Anaerobic digestion is a well-established technology that can convert organic materials, including cattle hides and other animal waste, into biogas. The process involves specialized bacteria that break down organic matter without oxygen, producing biogas as a byproduct. Biogas can then be used as a renewable energy source or upgraded to bio-methane for use as a transportation fuel.
2. **Pyrolysis:** Pyrolysis is a thermal process that can convert hides and other animal waste into bio-oil, bio-char, and syngas. The process involves heating the feedstock without oxygen, causing it to break down into its constituent parts. Bio-oil can be used as a fuel or feedstock to produce other bio-based products, while bio-char can be used as a soil amendment or carbon sequestration agent.
3. **Gasification:** Gasification is a process that can convert hides and other animal waste into syngas, which can be used as a feedstock to produce bio-fuels. The process involves heating the feedstock with a controlled amount of oxygen and steam, producing a gas stream containing hydrogen, carbon monoxide, and other gases. The syngas can then be purified and used as a feedstock to produce bio-fuels such as ethanol or synthetic diesel.
4. **Hydrothermal Liquefaction:** Hydrothermal liquefaction is a process that can convert hides and other animal waste into a liquid bio-oil. The process involves heating the feedstock in the presence of water and a catalyst, causing it to break down into a liquid oil. Bio-oil can be used as a fuel or feedstock to produce other bio-based products.

8.3.4 Potential Avenues for Education and Outreach

In addition to undertaking research, here are some areas where technical assistance providers can further support the livestock and agricultural industry (specifically in the Midwest) with information, training, and resources for implementing new applications.

- **Composting:** Composting can be an effective strategy for handling small amounts of waste material and can be implemented with relative ease. There is also funding available for alternative waste disposal techniques like composting. AURI can provide training and information regarding funding to small players, so that this can be implemented fully. Many universities in the Midwest also currently provide resources and training for composting, including the University of Minnesota and the University of Wisconsin.

- **Anaerobic Digestion:** Anaerobic digestion has the potential to utilize manure and other co-digestion feedstocks such as hides, animal waste, and more from the agricultural and food sectors. The use of these alternative feedstocks, in addition to manure, can increase the biogas generation potential from anaerobic digestion. However, the process is complex and capital intensive, and in some cases (like hides) pre-treatment processes such as shredding and hydrolysis will be required to fully utilize these materials effectively. In addition, training is required for the operation of anaerobic digestors, as well as information on funding and market development for the coproducts and biogas generated. Organizations such as the American Biogas Council and EPA AgSTAR program offer several training materials and toolkits for the implementation of anaerobic digestion. AURI provides the following services related to AD:
    - Anaerobic Digestion project viability analysis
    - Feedstock and digestate characterization
    - Biomethane potential assessment and benchtop digestion
    - Supply chain and market development
    - Pilot digestion of complex feedstock
    - Two fully instrumented 1,200-gallon tank digesters
    - Digestate handling and characterization
    - Dewatering and drying characteristics
    - Further uses and nutrient recovery

Appendix A

Resources and Key Players for Meat Processors and Renderers

Section eight provides educational resources for meat and poultry processors and a list of major renderers in the five-state region.

Leather and Hide Education Materials

The following table provides processors access to a variety of reports, training materials, and studies relevant to leather, hides and meat.

Organization	Information Available
Leather Panel	Publications and learning modules related to hides, leather, and allied technologies
Food and Agriculture Organization of the UN (FAO)	Agriculture and livestock statistics, publications, and other media
Central Leather Research Institute (CLRI), India	Technologies for managing hides, leather industry waste, support, and consulting services
Eastern Regional Research Center (ERRC), Pennsylvania, USA	Research project on "Commercial Products from Lipids and Fibers" explores number of applications using fiber from hides, hair in combination with other biomaterials (chitosan, etc.)
Consejo Superior de Investigaciones Científicas (CSIC), Spain	Research Group for "sustainable processes and materials characterization" works on developing and implementing cleaner technologies to attain a more environmentally friendly leather industry
Leather Working Group	Global multi-stakeholder community committed to building a sustainable future with responsible leather.

Institute For Creative Leather Technologies (ICLT), University of North Hampon, UK	Supports the scientific and technological needs of the automotive, fashion, footwear, and allied leather industries.
Sustainable Leather Foundation	Supports players in the leather and allied industries in learning, implementation and audits related to sustainability issues including transparency, carbon footprint, etc.
United States Department of Agriculture (USDA)	Offers data on utilization of meat and meat coproducts, and conducts and commissions research on coproduct utilization
American Biogas Council	A national trade association championing the growth of the biogas industry by representing, informing, connecting, and training our members
United States Environmental Protection Agency (EPA) AgSTAR	AgSTAR promotes the use of biogas recovery systems to reduce methane emissions from livestock waste. Assists those who enable, purchase or implement anaerobic digesters by identifying project benefits, risks, options and opportunities.

Company Profiles of Key Players

The following provides an overview of the leading rendering operations located in the United States based on the scale of the operation. The table provides the company name, location of the headquarters and the products that are manufactured and specific industries the organization caters to.

Company Name	Headquarters	Products Manufactured / Industries Catered
Darling Ingredients (DI)	Irving, TX	Pet Food | Animal Feed | Edible Fats | Bio-fuels | Fertilizers | Pharma | Gelatins | Collagens
Valley Proteins (acquired by DI)	Valley Proteins (acquired by DI) Winchester, VA	Pet Food | Animal Feed | Bio-fuels | Fertilizers | Renewable Energy (via AD)
JBS US	Greeley, CO	Pet Food | Animal Feed | Bio-fuels | Fertilizers | Renewable Energy (via AD) | Tallow | Hide and Leather Products
Tyson Foods	Springdale, AR	Edible Fats | Pet Food | Animal Feed | Aquaculture Feed | Bio-fuels | Gelatin | Collagen Casings | Fertilizer
Smithfield Foods Inc	Smithfield, VA	Edible Fats | Pet Food | Animal Feed | Fertilizer | Gelatin | Other Proteins
West Coast Reduction Ltd	Vancouver, B.C., Canada	Edible Fats | Animal Feed | Bio-fuels | Fertilizer | Tallow – Soap, Candles & Cosmetics | Grease – Lubricants, Cutting Oils & Other Industrial Applications
Sanimax	Green Bay, WI	Pet Food | Animal Feed | Fertilizer | Bio-fuels | Glycerin – Industrial Chemical | Compost

National By-Products LLC	Minneapolis, MN (acquired by Darling) Ingredients) Irving, TX	Pet Food | Animal Feed | Bio-fuels | Fertilizers | Soil Amendments
Baker Commodities Inc	Vernon, CA	Animal Feed | Bio-fuels | Pet Food | Fertilizers | Tallow – Soap, Candles & Cosmetics
North State Rendering Co	Oroville, CA	Pet Food | Animal Feed | Bio-fuels

Rendering Organizations in Minnesota

Licensed Rendering Companies	City / County
Central Bi-Products Plant A	Long Prairie, Todd County
Central Bi-Products Plant B	Redwood Falls, Redwood County
D & J Rendering (offering services to South Dakota)	Luverne, Rock County
Darling International Plant A	Blue Earth, Faribault County
Darling International Plant B	Chatfield, Fillmore County
Klarenbeek and Son Rendering	Steen, Rock County
Sanimax	South St. Paul, Dakota County
T-N-T Rendering	Lyon County
Worthington Rendering Company	Worthington, Nobles County

Rendering Operations in Iowa

Licensed Rendering Companies	Location
Hoekstar Rendering	Rock Rapids
Kruse Rendering Service	Rock Rapids
Simonsen Rendering Service	Quimby
Akron Rendering Service	Akron
Sioux Valley Rendering Company (also service South Dakota)	Rock Valley
Cartall Inc	Walford
RUK Ltd	Pacific Junction
Crawfordsville Rendering Service	Crawfordsville
Nutrion LLC	Spencer
Proliant Inc	Ankeny
Darling International Inc	Alton | Ankeny | Belmond | Carroll | Clinton | Corning | Des Moines | Dubuque | Maquoketa | Muscatine | Oskaloosa | Sioux City | Tama | Waterloo

Rendering Operations in North Dakota

There were no licensed rendering companies identified in the state of North Dakota.

Rendering Operations in South Dakota

Licensed Rendering Companies	Location
Sioux Valley Rendering Company	Rock Valley

Rendering Operations in Wisconsin

Licensed Rendering Companies	Location
Sanimax	Green Bay
Anamax	Evansville
Buzzards Roost Airport-	Redgranite
Darling International Inc	Berlin | Eau Claire | Hazel Green | Milwaukee

Composting Resources

The following information provides available online resources for proper animal protein carcass disposal regulations, and information on composting guidelines. In addition, major composting operations located within the Upper Midwest region of IA, MN, ND, SD, and WI.

Organization with Resources / Trainings	Information Available	Details
University of Minnesota Extension	Tutorials and Information	Resources for implementing composting operation, horse composting video - Link
HPAI Carbon Sources for Composting – Minnesota	Organizations Supplying Carbon Sources	Details of carbon sources and their availability in MN counties along with contact information - Link
Iowa Department of Natural Resources	Guidelines for Dead Animal Disposal	Guidelines for dead animal disposal – Link
Iowa State University	Tutorials and Information	Composting Handbook Regulations, Training
Iowa Waste Exchange	Wood By-Products as Cover Material / Carbon Source	Carbon sources / cover material for composting - Link
North Dakota State University – Extension	Animal Disposal Options and Composting Tutorials	Options for disposal of animal carcasses discussed along with details of composting process - Link
South Dakota State University – Extension	Animal Disposal Options and Composting Tutorials	Options for disposal of animal carcasses discussed along with details of composting process - Link
South Dakota Animal Industry Board	Animal Disposal Options and Composting Resources	Animal carcass disposal options - Link

Wisconsin Department of Natural Resources	Animal Disposal Options and Composting Guidelines	Composting as an alternative disposal method for small farms - Link

Composting Operations in the Upper Midwest

Composting Organization / Contacts	County (Range)
Rigid Excavating LLC, MN	Becker (Up to 100 miles)
Dean Ouren Construction, MN	Otter Tail (Up to 50 miles)
Pat McCabe, MN	LeSueur (Up to 100 miles)
Bisland Swine Research Center, IA	Madrid (Tour Available, Range unclear)
Lauren Christian Swine Research & Demonstration Farm, IA	Atlantic (Tour Available, Range unclear)
University of Wisconsin-Extension Livestock Agent, WI	Dodge County (No range available)

Appendix B

Examples of Equipment Used and Major Suppliers

The following provides examples of equipment used and major suppliers of the equipment. From the generated list of equipment there are other variations of the equipment available depending on the specific requirements and scale of the operation.

Soaking Tanks:

- Lefebvre Industries (Fiberglass Soaking Tank)
- Mid-State Tank (Plastic Open Top Tank) – Sullivan, Illinois
- Midwest Imperial Steel Fabricators (Stainless Steel Tank) – Chicago, Illinois

Shredder:

- Doppstadt Single Shaft Shredder, Velbert, Germany
- MOCO Maschinen- und Apparatebau GmbH & Co. KG Viernheim, Germany
- Vecoplan LLC - High Point, North Carolina

Crushers:

- Berry Extreme Duty Carcass Crusher - Clermont, Georgia
- Haarslev Industries A/S - Søndersø, Denmark
- ANCO-EAGLIN Inc. - Greensboro, North Carolina
- The Dupps Company - Germantown, Ohio

Grinder:

- Buhler - Plymouth, Minnesota
- DuraTech Industries - Jamestown, North Dakota
- Diamond Z - Caldwell, Idaho
- KPI-JCI and Astec - Yankton, South Dakota
- MAVITEC - Heerhugowaard, The Netherlands

Extraction Tanks:

- Lee Industries (Stainless Steel Extraction Tank) – Philipsburg, Pennsylvania
- Highland Equipment (Plastic Extraction Tank) – Buffalo, New York
- Midwest Imperial Steel Fabricators (Fiberglass Extraction Tank) – Laen, Illinois

- Filtering Equipment:
- K-S Komline-Sanderson (Rotary Drum Filter) – Peapack, New Jersey
- FEECO International (Belt Filter Press) – Green Bay, Wisconsin
- BDP Industries (Screw Press) – Greenwich, New York

Drying Equipment:

- Carrier Vibrating Equipment (Fluidized Bed Dryer) – Louisville, Kentucky
- Bepex International (Spray Dryer) – Minneapolis, Minnesota
- Scott Equipment (Vacuum Dryer) – New Prague, Minnesota
- Wyssmont Company (Vacuum Dryer) – Fort Lee, New Jersey
- The Witte Company – Washington, New Jersey