

# Upstream Food Loss Across the Beef and Dairy Supply Chains

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This white paper was prepared for ReFED as part of a collaborative effort with WWF to analyze and reduce upstream food loss and waste in the U.S. beef and dairy supply chains.

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## 1.0 Executive Summary

Food losses occur at every upstream stage of the beef and dairy supply chains. This research looks at the major causes, quantities, and destinations of beef, dairy, and milk loss on farm, in transport, and during pre-processing. While focused on U.S. beef and dairy supply chains the paper also incorporates international literature to fill critical data gaps and contextualize findings where domestic sources are limited or absent. It integrates findings from a structured review of 91 U.S. and international dairy and beef food loss and waste peer-reviewed scientific papers, technical reports, and 14-primary interviews across the beef and dairy supply chains to provide one of the most comprehensive assessments to date of early-stage food loss in United States livestock systems.

Together, the broader literature and industry interview insights confirm that upstream food loss in beef and dairy systems represents a meaningful but under-measured loss of nutritional value and embedded greenhouse gas emissions. Previous research states that by reducing upstream food loss through targeted interventions can significantly lower emissions intensity losses occurring on farm, during transport, and prior to processing reduce total edible output while intensifying emissions per unit of product delivered.

A major challenge in the research came from the lack of detailed loss accounting and reporting, and non-standardization of what is considered “loss” upstream in the beef and dairy industry. While the classification of pre-harvest animal losses as “food loss” is not universally accepted, given that living animals are not legally defined as food until harvest, this analysis adopts a food-system perspective that treats these events as upstream food loss because they remove edible protein from its intended human food pathway after substantial production inputs have already been incurred.

Across both literature and stakeholder interviews, the strongest and most consistent drivers of upstream loss include animal health challenges, environmental stress, delayed culling decisions, improper handling, transport conditions, infrastructure constraints, and gaps in communication across supply chain partners. Available evidence suggests that a meaningful share of loss occurs prior to processing, with on-farm mortality and milk discard typically accounting for 0.3–1.0% of dairy milk production and 2–6% of cattle removals annually through mortality or involuntary culling, depending on system and management context. Transport-related losses, while lower in frequency, are highly consequential: dead-on-arrival events and condemnations together account for roughly 0.8–1.2% of harvest weight, and bruising affects 40–65% of carcasses, resulting in trim losses that are rarely quantified by mass. Pre-processing losses, including rejected milk loads and off-spec products, are sporadic but can represent millions of pounds annually at individual facilities. Destinations of lost material vary widely ranging from rendering, composting, and anaerobic digestion, to manure systems and land application. But systematic, mass-based tracking remains limited, leaving major data gaps around both the volumes lost at each stage and their ultimate fates.

Within this context, the two priority solutions evaluated were 1) mastitis prevention and early detection at the farm level, and 2) improved live animal transport management through fitness-for-transport training, and both emerge as practical, high-impact entry points. Together, these interventions target large and preventable upstream loss categories while simultaneously strengthening data collection, feedback mechanisms, and stakeholder engagement, thereby laying the groundwork for broader, system-level transformation in beef and dairy supply chains.

1. Priority solution 1: Mastitis Prevention- Implementing mastitis prevention and early detection technologies could reduce on-farm milk loss by 15–30% in typical herds (up to 50% in high-SCC herds), potentially preventing hundreds of millions of pounds of milk discard annually and delivering farm-level returns of approximately \$6,800, which corresponds to roughly \$65–\$85 per cow annually based on a representative 80–100 cow herd, with total savings scaling proportionally with herd size, and payback periods under two years (subject to herd size, milk price, and baseline SCC levels).

- Priority solution 2: Live Animal Transport Management- Improved live animal transport (referred to as “transport” for the duration of the paper) management through fitness-for-transport training could reduce dead on arrival (DOA) and condemnation losses by 15–30%, preventing approximately 20-40 million pounds of beef loss annually and delivering national economic benefits of \$35-\$70 million per year against a one-time training investment of \$24 million. The above losses are prevalent, highly manageable, and influenced by day-to-day management decisions rather than fixed biological constraints, and they occur at points in the supply chain where relatively modest changes in practices, training, or monitoring can generate outsized reductions in food loss, economic inefficiency, and embedded environmental impacts, making them strong candidates for targeted economic analysis and scalable intervention.

**Table#1 Upstream Beef & Dairy Food Loss by Supply Chain Stage**

Supply Chain Stage	Loss Types	Key Causes	Destinations	Solutions
<b>On-Farm</b>	<ul style="list-style-type: none"> <li>• Cow &amp; calf mortality</li> <li>• Involuntary culling</li> <li>• Mastitis-related milk discard</li> <li>• Milk withheld from sale</li> </ul>	<ul style="list-style-type: none"> <li>• Disease (pneumonia, scours, mastitis)</li> <li>• Weather stress (heat, mud, cold rains)</li> <li>• Reproductive failure</li> <li>• Labor shortages, overcrowding</li> <li>• Equipment failures</li> <li>• Delayed culling decisions</li> </ul>	<ul style="list-style-type: none"> <li>• Carcasses to rendering, composting, or burial</li> <li>• Discarded milk to calves, lagoons, manure systems, sewer or field application</li> </ul>	<ul style="list-style-type: none"> <li>• Improved calf care, bedding, drainage</li> <li>• Mastitis prevention &amp; early SCC detection</li> <li>• Heat abatement &amp; ventilation upgrades</li> <li>• Selective breeding for health</li> <li>• More timely culling</li> <li>• Enhanced recordkeeping/herd software</li> </ul>
<b>Transport (Animals &amp; Milk)</b>	<ul style="list-style-type: none"> <li>• Dead-on-arrival (DOA) animals</li> <li>• Injuries &amp; bruising</li> <li>• Shrink (weight loss)</li> <li>• Organ condemnation linked to stress</li> <li>• Rejected milk tanker loads</li> </ul>	<ul style="list-style-type: none"> <li>• Rough loading/handling</li> <li>• Overcrowding &amp; poor grouping</li> <li>• Heat/cold stress &amp; long journeys</li> <li>• Shipping compromised animals</li> <li>• Milk contamination, seal failures, temperature abuse</li> </ul>	<ul style="list-style-type: none"> <li>• DOAs to rendering, compost, or landfill</li> <li>• Bruised trim rendered</li> <li>• Rejected milk to land application, lagoons, sewer, or diversion companies (feed/digestion)</li> </ul>	<ul style="list-style-type: none"> <li>• Low-stress handling &amp; loading training</li> <li>• Fitness-for-transport screening</li> <li>• Improved trailer flooring, partitions, ventilation</li> <li>• Journey planning (avoid extreme weather, limit fasting)</li> <li>• Strict milk intake/seal protocols</li> </ul>
<b>Harvest/ Abattoir</b>	<ul style="list-style-type: none"> <li>• Ante-mortem rejections</li> <li>• DOAs/dead in pen</li> <li>• Carcass condemnations</li> <li>• Bruising &amp; trim loss</li> <li>• Organ condemnation</li> </ul>	<ul style="list-style-type: none"> <li>• Transport stress &amp; rough handling</li> <li>• Disease (lymphoma, pneumonia, sepsis)</li> <li>• Foreign materials (buckshot, wire, needles, and non-metal materials)</li> <li>• Poor arrival condition (late culling)</li> </ul>	<ul style="list-style-type: none"> <li>• Trim &amp; organs to rendering (pet food, feed, fuel)</li> <li>• Some DOAs &amp; SRMs to landfill or composting</li> </ul>	<ul style="list-style-type: none"> <li>• Earlier culling &amp; better herd health</li> <li>• Improved transport &amp; handling practices</li> <li>• Foreign-material prevention on farms</li> <li>• Carcass-data feedback loops to farms &amp; haulers</li> </ul>
<b>Pre-Processing, Milk Plants, Upcycling, Rendering</b>	<ul style="list-style-type: none"> <li>• Rejected milk loads</li> <li>• Off-spec dairy products</li> <li>• Solids lost in processing</li> <li>• Carcasses/tissue removed pre-fabrication</li> </ul>	<ul style="list-style-type: none"> <li>• Failed microbial, butterfat, or antibiotic tests</li> <li>• Temperature abuse</li> <li>• Seal/sanitation failures</li> <li>• Equipment malfunctions</li> <li>• Plant bottlenecks or shutdowns</li> </ul>	<ul style="list-style-type: none"> <li>• Rejected milk to land application, wastewater, lagoons, feed drying, or digestion</li> <li>• Condemned tissue to rendering, pet food, biofuel, or landfill</li> </ul>	<ul style="list-style-type: none"> <li>• Improved CIP &amp; sanitation protocols</li> <li>• Better cooling &amp; tank management</li> <li>• Processor–co-op communication on quality issues</li> <li>• Partnerships with diversion/upcycling firms</li> <li>• Facility-level tracking of rejected volumes &amp; destinations</li> </ul>

Together, the broader literature and industry interview insights confirm that upstream food loss in beef and dairy systems represents a meaningful but under-measured loss of nutritional value and embedded greenhouse gas emissions. Losses occurring on farm, during transport, and prior to processing reduce total edible output while intensifying emissions per unit of product delivered. Based on both the strength of available evidence and stakeholder readiness, the full set of priority strategies and next steps include:

- Scaling mastitis prevention and early detection technologies and strategies at the farm level (priority strategy 1).
- Increasing and enhancing animal handling and fitness-for-transport training and protocols at scale for producers on farm, haulers during transport, and auction facilities during handling to reduce bruising, dead-on-arrival events, and downstream condemnations (priority strategy 2).
- Improving mass-based measurement of upstream losses, and quantifying pounds of meat trimmed, animals lost, and gallons of milk discarded to enable more accurate food loss and waste and emissions modeling.
- Strengthening feedback loops between processors and upstream actors, including systematic reporting of bruising patterns, condemnations, and rejected loads to inform management decisions and accountability.
- Piloting traceability systems for early-stage loss events, such as digital logs or radio-frequency identification (RFID)-enabled tracking, linking loss causes, volumes, and destinations across farm, transport, harvest, and loss of diversion pathways.
- Promoting policy to prioritize inclusion of upstream livestock losses in national food loss inventories, recognition of mastitis prevention and transport improvements, and incorporation of embedded emissions into greenhouse gas reporting and life-cycle assessment methodologies.

## **2.0 Introduction and Methodology**

### ***2.1 Project Scope and Structure***

This project provided a landscape review aimed to better understand upstream food loss in the U.S. beef and dairy supply chains by identifying where losses occur, why they happen, and which interventions offer the greatest potential for reduction. This project identified and quantified causes and solutions to reduce upstream food loss in U.S. beef and dairy supply chains, spanning on-farm production, livestock and fluid milk transport, harvest, and pre-processing stages. The research progressed through three milestones: Milestone I established supply chain mapping and literature synthesis; Milestone II addressed data gaps through primary stakeholder interviews; and Milestone III evaluated practical, scalable interventions. This report synthesizes findings from all stages, providing an industry-facing analysis of upstream loss patterns and targeted solutions.

### ***2.2 Collaborative Framework***

WWF led loss characterization, literature review, stakeholder interviews, field synthesis, and solutions analysis across all project phases. Wageningen University & Research (WUR) provided methodological guidance, including the food-loss flow framework (Milestone I), loss quantification refinement (Milestone II), and diversion-potential assessment methodology (Milestone III). ReFED defined data and modeling requirements, advised on solution selection, and ensured integration with national FLW modeling tools. Stakeholders played a central role in shaping this work beyond simply responding to interview questions. Their input helped validate and refine our understanding of loss types, surfaced operational constraints not well documented in the literature, and directly informed the selection and design of modeled solutions. Rather than prescribing interventions, we used stakeholder perspectives to ground-truth feasibility, identify gaps in current practices, and co-develop practical strategies that reflect real-world conditions.

### ***2.3 Integrated Evidence Base***

The analysis combined two complementary evidence streams, beginning with a structured literature review synthesizing 91 sources (32 U.S.-based and 59 international) spanning beef and dairy systems in Europe (including the United Kingdom, Netherlands, Germany, Ireland, and Denmark), Oceania (Australia and New Zealand), Latin America (Brazil, Argentina, and Uruguay), and Canada, and covering a range of production systems from pasture-based and seasonal dairies to confined feeding operations and high-throughput processing systems which all examined loss types, causes, and destinations from farm through pre-processing. Secondly, primary data collection consisting of 14 semi-structured interviews with producers, haulers, processors, auction barns, and abattoirs, generating granular, practice-based insight into operational decision-making, structural constraints, and the mechanisms driving upstream food loss. Together, these streams established where losses occur, why they happen, and which intervention points offer greatest reduction potential.

### ***2.4 Literature Review Limitations***

While the existing literature provides important insights into where upstream losses occur, it reveals substantial limitations that constrain system-level analysis. Key gaps include the absence of integrated data across supply chain stages, inconsistent production terminology for loss, waste, and surplus that limits cross-study comparability, and a reliance on prevalence-based indicators rather than mass-based quantification of losses. In addition, few studies systematically track the ultimate destinations of lost material, obscuring whether products are rendered, land-applied, composted, or otherwise diverted. Visibility is particularly limited for transport and early processing stages, where losses associated with shrink, handling injuries, dead-on-arrival events, carcass trimming, and milk transport rejection are widely acknowledged but rarely quantified. As a result, the literature characterizes loss types but provides little evidence on volumes, destinations, or cumulative impacts across the supply chain.

### ***2.5 Primary Data Collection***

Stakeholder interviews helped address critical gaps identified in the literature by generating both quantitative and contextual evidence on upstream food loss. A total of fourteen semi-structured interviews were conducted with actors spanning the beef and dairy supply chains, including beef and dairy producers, livestock haulers, auction barn operators, harvest and processing facilities (referred to as abattoirs in this paper), rendering companies, and a dairy upcycling company. Interviewees represented a range of herd sizes, production systems, and geographic regions, enabling cross-system comparison of loss dynamics. Interviews followed a structured guide designed to elicit estimates of discarded milk, animal mortality and culling rates, carcass trim, dead-on-arrival events, and tanker rejections, alongside cause-level explanations linking losses to mastitis, reproductive failure, management constraints, environmental stress, and handling practices. Participants were asked to describe the destinations of lost material, including on-farm dumping (milk), calf feeding (milk), land application, rendering, composting, and diversion pathways, as well as operational constraints related to labor availability, monitoring capacity, facility limitations, and information sharing. Importantly, the cross-stage composition of interviewees enabled triangulation across supply chain nodes, revealing how upstream management decisions propagate downstream impacts at transport, harvest, and processing stages. The interviews further identified loss dynamics that remain poorly documented in existing studies, including volumes of milk withheld during antibiotic withdrawal periods, the role of delayed culling decisions in bruising and dead-on-arrival outcomes, and the absence of systematic feedback loops between producers, haulers, processors, and abattoirs.

### ***2.6 Loss Definitions and Classification Challenges***

A major challenge was that sources of loss do not classify loss the same way and often do not include definitions for how they are classifying the said loss. ReFED defines surplus food as edible food and food-associated inedible components (e.g., bones, peels, offal) that go unsold or unused across the supply chain, including food that is donated, diverted to animal feed, or otherwise repurposed. Food loss more

narrowly refers to surplus entering eight disposal pathways: composting, anaerobic digestion, landfill, combustion, wastewater, dumping, land application, or non-harvest. Recent updates classify even composting and land application as waste, reflecting embedded economic, environmental, and social costs of food grown but not consumed.

This fate-based definition of loss underscores the challenge of quantification, as data on the ultimate destinations of material are limited, fragmented, and inconsistently reported. Although many studies document the removal of cattle or milk from their intended human consumption pathways, they rarely specify whether these materials were subsequently recovered through donation, upcycling, animal feed, or other non-waste uses. As a result, it is often unclear how reporting entities operationalize the concept of “loss” relative to the ReFED framework, beyond indicating diversion from an intended market channel. This ambiguity constrains cross-study comparability and limits integration with standardized food loss accounting systems. Despite this uncertainty, evidence from the literature and interviews suggests that destination pathways differ by sector: upstream beef losses are predominantly diverted to rendering, while discarded milk in dairy systems is most commonly land-applied or managed through manure systems or sewer, rather than sent to landfill, composting, or digestion. Quantifying the volumes routed to rendering and other recovery pathways represents a critical priority for future research, both to improve mass-based accounting and to more accurately characterize environmental and economic outcomes.

### ***2.7 Data Gaps in Upstream Beef and Dairy Food Loss***

Although upstream food loss in beef and dairy systems is widely acknowledged, the evidence base remains fragmented and insufficient for robust system-level analysis. Across both the literature review and primary interviews, the most significant limitation is not identifying where losses occur, but quantifying how much is lost, why it is lost, and what ultimately happens to lost material.

The most persistent data gap is the absence of mass-based quantification of upstream losses, meaning that losses are rarely measured in physical units such as pounds of meat, gallons of milk, or number of animals lost, and are instead reported as percentages, rates, or frequencies. Existing studies predominantly report losses using prevalence indicators, such as the proportion of animals exhibiting bruising, the milk loads rejected, or the frequency of mortality events, rather than measuring losses in physical units such as pounds of meat trimmed, animals removed prior to harvest, or gallons of milk discarded. This reliance on prevalence metrics limits the ability to compare loss magnitudes across stages and systems and obscures the relative importance of different loss pathways.

A second critical gap is limited tracking of loss destinations. While interviews confirm that most upstream losses are diverted to rendering, land application, composting, digestion, or on-farm disposal rather than landfill, it identifies the volumes routed through each pathway are rarely measured or reported. Discarded milk, bruised meat, condemned organs, ante-mortem rejections, and pre-processing losses are often recorded only as regulatory or quality events, not as physical quantities linked to recovery or disposal pathways.

Transport-related losses represent a major blind spot in upstream food loss accounting. Live-weight shrink, bruising, stress-related organ damage, and dead-on-arrival events are widely acknowledged but inconsistently measured and rarely attributed to specific transport conditions or handling practices. A key contributing factor is fragmented ownership and financial responsibility during transport: animals and milk typically remain the property of producers or consignors until accepted by the next buyer, while haulers are responsible for logistics, but some do not bear the economic loss associated with mortality, shrink, or quality degradation. As a result, no single actor has both the incentive and the authority to systematically measure, attribute, intervene, and report transport-stage losses. For fluid milk, this challenge is compounded by the absence of national datasets quantifying transport-stage losses, despite

interview evidence that rejected tanker loads can represent millions of pounds of milk annually at individual processors.

Across all stages, event-level traceability and feedback loops are weak or absent. Losses are typically recorded at the point of detection rather than causation, preventing linkage between on-farm management, transport practices, and downstream outcomes. Haulers, abattoirs, and processors often collect relevant data internally, but systematic reporting back to upstream actors is rare, limiting learning and accountability.

Finally, conceptual and definitional inconsistencies further complicate the measurements. Living animals are not classified as food until harvest by the food industry. Until harvest, livestock are governed by animal welfare and veterinary regulations rather than food safety and quality laws. This legal and operational separation affects how losses, such as pre-harvest mortality or culling, are tracked, reported, and valued within the food loss and waste frameworks, representing an important consideration for future research and industry engagement.

These data gaps directly shaped this study’s design. The literature review established loss types but revealed limited quantification and traceability, necessitating primary interviews to provide operational context. However, interviews confirmed that current data systems are not structured for standardized food loss accounting. Addressing these data gaps is essential for improving the accuracy and credibility of national food loss modeling. These gaps also directly informed the selection of mastitis prevention and fitness-for-transport training as priority solutions, since both offer high loss-reduction potential while creating opportunities to strengthen upstream measurement, traceability, and feedback systems. An effective and economical way to reduce food loss is by ensuring animals remain healthy, well-cared for, and fit for transport throughout their lives.

**Table #2.** Key Data Gaps in Upstream Food Loss Accounting for Beef and Dairy Supply Chains

<b>Data Gap Category</b>	<b>Description</b>	<b>Implications for Food Loss Analysis</b>
Lack of mass-based quantification	Losses are rarely measured in physical units (e.g., pounds of meat, gallons of milk, number of animals) and are instead reported as rates or prevalence indicators.	Limits comparability across stages and systems; obscures the relative magnitude and priority of different loss pathways.
Incomplete tracking of loss destinations	Volumes routed to rendering, land application, composting, digestion, or on-farm disposal are rarely measured or reported.	Prevents assessment of recovery versus waste outcomes and weakens environmental and economic accounting.
Transport-stage measurement gaps	Shrink, bruising, organ damage, and DOA events are inconsistently measured and rarely linked to specific transport conditions or practices.	Creates a major blind spot in upstream loss attribution and mitigation targeting.
Fragmented ownership and incentives during transport	Producers retain ownership, haulers manage logistics, and processors detect losses—no single actor has incentive or authority to track losses systematically.	Discourages consistent data collection and accountability for transport-related losses.
Weak traceability and feedback loops	Losses are recorded at detection rather than causation, with limited reporting back to upstream actors.	Prevents learning, continuous improvement, and validation of loss-reduction interventions.
Conceptual and definitional inconsistencies	Pre-harvest animals are not legally classified as food, affecting how mortality and culling are recorded within FLW frameworks.	Complicates inclusion of upstream losses in national FLW and emissions models.

### 3.0 Literature Review and Primary Interview Results

The findings of the literature review and primary interviews are reported below by supply chain stage (On-Farm, Transport, Harvest, Pre-Processing) and include findings for both beef and dairy. For each supply chain stage, the research is organized by Loss Causes, Loss Destinations, and Solutions.

#### 3.1 On-Farm Stage Loss

##### 3.1.1 Loss Rate and Causes

On-farm losses stem from biological, environmental, and management factors resulting in premature animal loss or milk disposal. These losses carry substantial embedded resource inputs (feed, water, energy, labor, GHG emissions) without delivering nutritional or economic return, significantly inflating the resource demand and GHG intensity of products reaching market.

##### *Loss Causes for Beef On-Farm*

USDA data indicate annual adult cattle mortality of 2.2% and calf mortality of 6.2%, totaling approximately 3.9 million animals per year and \$3.87 billion in losses [8, 9]. Primary causes include respiratory problems (23.9% adults; 26.9% calves), calving complications (17.8% calves), digestive disorders (15.4% calves), old age (11.8% adults), and predator-related causes (2.4% adults; 11.1% calves) [8]. Reproductive inefficiencies contribute to pregnancy failure rates of 5–15% driven by poor nutrition, infectious disease, heat stress, or suboptimal breeding management [1].

**Table #3** Beef On-Farm Loss Rates and Primary Causes

Loss Category	Key Findings (Literature & Interviews)
Overall mortality	Adult cattle mortality: 2.2%; calf mortality: 6.2%, totaling ~3.9 million animals/year and \$3.87 billion in losses [8, 9].
Adult cow loss causes	Respiratory disease (23.9%), old age (11.8%), infertility, metabolic disorders, injury, and age-related decline [8]; interviews report 1–2% annual cow mortality across systems.
Calf loss causes	Respiratory disease (26.9%), calving complications (17.8%), digestive disorders (15.4%), predator-related causes (11.1%), dystocia, pneumonia, scours, and weather stress [8].
Reproductive losses	Pregnancy failure rates of 5–15%, driven by nutrition deficits, infectious disease, heat stress, and suboptimal breeding management [1].
Management & system drivers	Loss rates more strongly associated with management intensity and monitoring capacity than geography alone. Eastern operations reported disease pressure linked to fragmented land and muddy calving environments; Western extensive systems reported higher losses due to limited daily observation across large pastures (interviews).
Environmental stressors	Prolonged cold/wet conditions, heat waves, and excessive mud consistently cited as contributors to calf morbidity and mortality (interviews).

Interviewed beef producers represented a wide range of production scales and geographies, from small Eastern cow–calf operations managing 80 to 150-head, to large Western organic ranches with herds exceeding 4,000-head. The eastern operations reported land fragmentation and limited paddock space, resulting in muddy, high-pathogen calving environments that increased the incidence of neonatal scours, pneumonia, and crushing injuries. In contrast, the Western ranch described structural constraints associated with extensive grazing systems, where large pasture size and terrain limited the feasibility of daily animal monitoring. These differences suggest that calf loss rates are driven more by practicality and tradeoffs of management intensity and monitoring capacity than by geography alone. While Eastern operations often face land fragmentation and high-pathogen calving environments that elevate disease risk, the Western system experienced higher losses primarily due to limited daily observation across large

pastures. As a result, loss patterns are more strongly associated with operation size and management structure than with regional location.

Across systems, interviewed producers reported cow mortality generally at 1–2%; this was attributed primarily to infertility, metabolic disorders, injury, and age-related decline. Producers consistently identified pneumonia, scours, dystocia, and weather-related stressors, including prolonged cold and wet conditions, heat waves, and excessive mud, as the dominant drivers of calf loss.

#### *Loss Causes for Dairy On-Farm*

According to the literature review, in U.S. dairy herds (2006–2010), annual mortality averaged 6.4%, accounting for 19.4% of all herd removals, exceeding reproductive failure (14.6%), injury (14.0%), low production (12.3%), and mastitis culling (10.5%) [7]. Heat stress disrupts fertility and feed intake, particularly in high-producing dairy breeds [21].

The dairy operations interviewed spanned a broad range of production systems and scales, from 100-cow, grass-fed seasonal herds to a large Holstein operation milking approximately 3,700 cows on rotary parlors. Across systems, producers reported annual cow mortality rates generally below 4% and calf mortality rates ranging from 1 to 4%. Despite differences in scale and management intensity, similar structural factors shaped loss outcomes. Labor shortages were consistently identified as a key constraint, limiting capacity for close calf monitoring, milking hygiene, and early disease detection, thereby increasing the risk of preventable losses.

This section synthesizes findings from both the literature review and primary stakeholder interviews. The use of past tense reflects reported conditions and management decisions observed in prior studies and described retrospectively by interviewed producers, rather than a time-bounded historic period.

The literature review suggests that tight operating margins exacerbate loss risk by encouraging delayed culling of compromised cows and overstretched labor capacity, both of which increase exposure to health-related losses. The literature review showed that market conditions also influence herd management decisions; during periods of low dairy bull calf value interviewed producers reported shifting breeding strategies toward beef semen to reduce surplus calf losses. Across interviews, annual culling rates were reported at approximately 3–6%, driven primarily by reproductive failure, chronic mastitis, and low milk production. Mortality was most commonly associated with fresh-cow metabolic disorders, digestive complications, severe mastitis, and injuries, while calf losses were attributed predominantly to pneumonia, scours, dystocia, and weather-related stressors.

Mastitis and mandatory antibiotic withdrawal periods consistently emerged as the dominant cause of on-farm milk loss in both literature and interviews. The mandatory antibiotic withdrawal period for mastitis-treated cows requires milk to be withheld from sale for 24 to 96 hours to ensure it is free of antibiotic residues. While milk discarded due to mandatory antibiotic withdrawal represents a temporary loss, it is a necessary and acceptable component of responsible herd management which ensures animal health through treatment and protecting food safety by complying with residue regulations. This type of loss reflects prudent intervention rather than inefficiency and is an inherent part of managing live animal systems. Mastitis elevates somatic cell count which triggers automatic on-farm milk diversion. U.S. Grade A standards prohibit antibiotic residues, requiring strict withdrawal periods where all treated milk must be withheld [21, 27]. Interviewed producers reported variable discard volumes: tie-stall farms discarded approximately 1% of production; a robotic farm routinely dumped 100–200 lb./day when detecting residues or high somatic cell count (SCC); a grass-based farm discarded less than 500 lb./year; and a large dairy sent approximately 30,000 lb/year to manure pits while withholding approximately 535,000 lb/year for calf feeding. Although these losses generally represented less than 1% of annual milk volume at the farm level, they correspond to tens to hundreds of thousands of pounds of human-grade

milk removed from the food supply, underscoring the material significance of even small percentage losses in high-throughput dairy systems. These losses reflect deliberate public-health safeguards embedded in U.S. Grade A standards, which require zero tolerance for antibiotic residues and enforce SCC thresholds to protect consumer safety, product quality, and processing integrity, leaving little discretion once milk falls outside acceptable limits.

Heat stress compounds the above losses, reducing both yield and quality. Literature estimates annual economic losses of \$670 million, potentially reaching \$2.2 billion under future climate scenarios [21]. Interviewed producers described summer heat as a key period for elevated SCC, mastitis flare-ups, and equipment strain, with farms lacking adequate ventilation, cooling, or bedding management experiencing more frequent discard and quality problems than upgraded operations. Additional milk losses stem from equipment failures (cooling system malfunctions), power outages, or capacity mismatches at processing facilities, though these incidents are underrepresented in food loss and waste literature [21, 27].

**Table #4 Dairy On-Farm Loss Rates, Drivers, and Milk Discard Pathways (Literature and Interviews)**

<b>Loss Category</b>	<b>Key Findings</b>
Overall cow mortality (literature)	Annual mortality 6.4% (2006–2010), accounting for 19.4% of herd removals, exceeding reproductive failure (14.6%), injury (14.0%), low production (12.3%), and mastitis culling (10.5%) [7].
Cow & calf mortality (interviews)	Cow mortality generally <4% annually; calf mortality 1–4%, across diverse herd sizes and production systems (interviews).
Primary cow loss drivers	Fresh-cow metabolic disorders, digestive complications, severe mastitis, injuries, infertility, and age-related decline (literature and interviews).
Primary calf loss drivers	Pneumonia, scours, dystocia, and weather-related stressors (cold, heat, mud) (literature and interviews).
Culling rates	Annual culling ~3–6%, driven primarily by reproductive failure, chronic mastitis, and low milk production (interviews).
Structural & management constraints	Labor shortages limit calf monitoring, milking hygiene, and early disease detection, increasing preventable loss risk (interviews).
Economic pressures	Tight margins encourage delayed culling and overstretched labor; low dairy bull calf value incentivizes beef semen use to reduce surplus calves (literature and interviews).
Mastitis & milk discard	Mastitis and antibiotic withdrawal identified as dominant causes of on-farm milk loss; elevated SCC triggers automatic diversion under Grade A standards [21, 27].
Reported milk discard volumes (interviews)	Tie-stall: ~1% of production; robotic farm: 100–200 lb/day; grass-based farm: <500 lb/year; large dairy: ~30,000 lb/year to manure pits plus ~535,000 lb/year withheld for calf feeding.
Heat stress impacts	Reduces yield and quality; estimated \$670M/year in losses, potentially \$2.2B under future climate scenarios [21]; interviews report summer spikes in SCC, mastitis, and equipment strain.
Additional milk loss causes	Equipment failures, cooling malfunctions, power outages, and processing capacity mismatches, rarely quantified in FLW literature [21, 27].

*Economic Pressures and Late Culling (Loss Causes for Both Sectors)*

During droughts or spikes in feed-costs, producers may cull animals prematurely at reduced weights, limiting productivity and increasing downgrade risk [10, 17, 23]. While at other times, high cull-cow prices and tight margins incentivize holding compromised animals longer to capture additional milk, increasing risk of on-farm death, poor-condition arrival at auction or harvest, or condemnation post-harvest. Interviewees noted this creates a cycle where potential saleable food product shifts into loss.

### *3.1.2 Destinations*

#### *Destinations for Beef On-Farm*

Carcasses may be rendered, buried, composted, or incinerated depending on state regulations, available infrastructure, and the cause of death; although nationally consistent data on disposal pathways remain limited [3, 6, 9, 24]. Interviewed producers reported using a combination of rendering, composting, and burial, with composting increasingly serving as the default option where land availability and regulatory frameworks permit. Herd size was largely constrained by land and forage availability, underscoring the role of environmental and spatial limitations as central drivers of both herd management decisions and loss outcomes.

#### *Destinations for Dairy On-Farm*

The literature indicates that discarded milk may be repurposed as calf feed or disposed of through various on-farm pathways; however, these destinations are rarely quantified or systematically reported [21, 27]. Interview findings corroborated with this pattern, indicating that withheld or discarded milk is most commonly fed to calves, discharged to manure lagoons, or applied to fields, with limited formal documentation of volumes or final use. Several producers reported deliberately avoiding the feeding of treated milk to calves due to concerns regarding antibiotic exposure, antimicrobial resistance, and the masking of early disease symptoms. Carcasses of dairy cattle follow disposal pathways similar to those in beef systems, including rendering, composting, burial, or other approved methods, depending on regulatory and infrastructural constraints.

### *3.1.3 Data Gaps*

Despite the magnitude of upstream losses, substantial data gaps persist at the farm level across both beef and dairy systems. Mortality data are rarely tracked beyond the point of death, limiting understanding of downstream destinations and recovery pathways [6, 8, 9]. A significant share of adult cattle deaths, approximately 14%, is reported as having an unknown cause, reflecting gaps in diagnostic resolution and recordkeeping [9]. Many studies rely heavily on self-reported producer data collected without standardized definitions or measurement protocols, constraining comparability across operations and regions [9, 19]. Losses are typically reported as annual averages, with limited geographic or seasonal resolution, masking episodic drivers such as extreme weather events or disease outbreaks [7, 24]. In dairy systems, both the volume and fate of discarded or withheld milk are inconsistently documented and estimates of heat-stress impacts are largely model-based. These estimates primarily reflect reductions in milk yield per cow rather than discrete quantities of milk physically discarded or diverted, making it unclear whether, and to what extent, heat-stress-related production losses should be treated as food loss versus unrealized production potential [21, 27].

### *3.1.4 Potential Solutions.*

In summary, mastitis drives the largest on-farm milk loss in dairy systems. Prevention and early-detection strategies include improved milking hygiene, improved bedding/stall management, enhanced ventilation, early-warning sensors, robotic/automated systems with inline SCC detection, and selective breeding for udder health. Robust prevention and early detection can reduce discarded milk by 15–30% in typical herds, up to 50% in high-SCC herds. A detailed economic analysis of this solution is provided in Section 4.1.

## **3.2 Transport Stage Loss**

Transport represents a critical but under-characterized stage of upstream food loss in beef and dairy supply chains, linking on-farm management decisions with harvest and milk processing outcomes. Losses

during transport arise from animal stress, handling practices, journey conditions, and equipment design; and manifest as live-weight shrink, bruising, injuries, dead-on-arrival events, organ condemnation, and rejected milk loads. The following section synthesizes literature and interview findings to characterize transport-related loss rates, causes, destinations, and key data gaps across both livestock and fluid milk transport.

### *3.2.1 Loss Rates and Causes*

#### *Live Animal Transport*

Live animal transport-related losses are driven by dehydration, thermal stress, extended transit durations, overcrowding, and improper handling practices [2, 15, 18, 25]. Live-weight shrink, which is a result from excretion, reduced feed and water intake, and stress-induced metabolic changes, is widespread across production systems. Feeder cattle experience average shrink losses of approximately 7.9% of live weight, while fat cattle lose roughly 4.9% during transport [18]. Although these losses are rarely captured within food loss accounting frameworks, part of these directly reduce carcass yield at processing and increase greenhouse gas intensity per pound of beef delivered by lowering edible output without reducing upstream resource use.

Bruising is widespread and highly dependent on the animal type and age, affecting 64.1% of cow carcasses and 42.9% of bull carcasses, leading to tissue trimming that gets diverted to rendering or waste streams without consistent tracking [25]. Transport conditions such as loading time, compartment position, and mixing unfamiliar animals exacerbate bruising and stress-related injuries [25, 31]. Offal condemnation often links to transport stress: livers (44.6%), lungs (23.1%), hearts (22.3%) commonly removed due to trauma or disease evident at harvest [25].

Dead-on-arrival events, though less frequent, represent total food loss, as the animal yields no edible product for the human food supply. A commercial hauler who was interviewed (transporting approximately 35,000 head/year) estimated injury rates approximately 1 in 200 head and DOAs approximately 1 in 500, attributing most incidents to human factors: overloading compartments, inappropriate grouping, accepting unfit animals, rushed or inattentive loading/unloading. Auction staff similarly linked bruising, downer cows, and on-site mortalities to animals arriving in compromised condition and inconsistent low-stress handling. At auction barns, approximately 25% of arriving dairy cows were shipped too late due to delayed culling decisions, resulting in compromised conditions and elevated risk of non-ambulatory outcomes and on-site mortality. Rendering of on-site mortalities cost approximately \$150/head, charged to the consignor of the cattle.

Transport shrink affects approximately 4.2% of live animal mass [2]. Bruising and organ condemnation rates are acknowledged as high (greater than 60% carcasses show visible damage), but total trim weight for trimming and losses due to damaged organs and bruised meat remains unquantified nationally [25]. Some reports aggregate transport losses into harvest-stage data [30, 31] but it is essential to distinguish the occurrence stage to prevent double-counting.

#### *Milk Transport*

Unlike live-weight shrink which reflects a reduction in mass, which is indirectly implied in loss of edible product, milk losses during transport represent the direct loss of a ready-to-consume, resource-intensive food. These losses embody substantial upstream inputs, including feed, water, veterinary care, and milking energy, yet rejected or spoiled milk is typically excluded from both food loss inventories and environmental reporting frameworks. Despite the scale of these losses, no national datasets or peer-reviewed studies quantify fluid milk transport loss volumes in U.S. systems.

Fluid milk transport losses occur through spillage, agitation, contamination, and temperature deviations, particularly when tanker seals, sanitation protocols, or cooling systems fail. At plant intake, milk may be rejected due to quality control, elevated bacterial counts, antibiotic residues, butterfat deviations, or out-of-range temperatures [2, 21, 27]. One fluid milk processor interviewed reported rejecting approximately one tanker per week, which is out of 25 million pounds received weekly, which is equivalent to an estimated 3.9 million pounds of milk annually, or 0.3% annually. The ultimate nature of these rejected loads, including land application, upcycling, or disposal, was not systematically recorded. Interview-based estimates further suggest that transport-stage losses are of substance but largely invisible. While animal transport losses were reported at approximately 0.5% due to injuries and 0.2% due to dead-on-arrival events, milk transport losses at a single processor averaged roughly 75,000 pounds per week. Although this represents a relatively small proportion of total milk volume handled, the loss is economically and nutritionally significant in absolute terms, as it reflects tens of thousands of pounds of fully edible, human-grade milk removed from the food supply on a recurring basis. These losses also underscore the systematic exclusion of transport-stage dairy losses from formal food loss, waste, and sustainability accounting frameworks.

### *3.2.2 Destinations*

Transport-stage losses are directed to a limited set of destinations, though systematic tracking remains sparse. Animals that arrive dead are excluded from the food supply and are typically sent to rendering or landfill, depending on regulatory requirements and facility access. Bruised tissue identified at harvest is trimmed and diverted primarily to rendering or discarded, yet the specific destinations and quantities of this material are rarely recorded or reported [25]. In contrast, live-weight shrink represents a loss that is never physically recovered or redirected; the reduction in animal mass occurs prior to harvest and remains an unmeasured and unaccounted loss within food loss frameworks [15, 18].

Interview data further indicate that dead-on-arrival animals and pen deaths occurring at cattle auction facilities are most commonly rendered or composted either on-site or at the farm of origin. Rejected milk loads identified during transport or at plant intake may be diverted to land application, lagoons, or third-party diversion companies for animal feed or anaerobic digestion. However, these pathways are managed on a case-by-case basis, and aggregated data on volumes, destinations, and recovery outcomes are not consistently collected, limiting visibility into the ultimate fate of transport-stage losses.

### *3.2.3 Data Gaps*

Transport-related losses remain poorly characterized due to the absence of standardized, event-level tracking across supply chain actors. Live-weight shrink is routinely recorded as a net change in animal weight, yet its downstream implications for carcass yield, trim volume, and economic loss are rarely analyzed or attributed to specific transport conditions [18]. Similarly, bruised tissue and condemned organs are typically identified at harvest but are neither consistently weighed nor systematically linked back to transport variables such as journey duration, stocking density, compartment placement, or handling practices [25, 31]. In fluid milk systems, losses are detected at plant intake through load rejections, but volumes are not aggregated nationally or categorized by causal factors such as temperature deviation, contamination, or equipment failure.

These measurement gaps create a disconnect between transport-stage loss causation and national food loss, emissions, and economic accounting frameworks, limiting the ability to prioritize and evaluate mitigation strategies. Operational data silos further compound this challenge: haulers generally track performance metrics internally without standardized reporting; auction facilities rarely receive feedback from packers on carcass bruising or condemnation outcomes; and processors do not routinely report the volumes or destinations of rejected milk loads back to farms or haulers. The lack of cross-stage feedback

loops prevents upstream actors from identifying loss drivers, learning from transport outcomes, and implementing targeted improvements, underscoring the need for integrated data systems that link transport conditions to physical loss quantities and destinations.

#### *3.2.4 Potential Solutions*

In summary, bruising and DOAs are common but largely preventable losses. Transport management improvements include low-stress loading and unloading, fitness-for-transport screening, optimized stocking densities and or grouping, trailer upgrades (non-slip flooring, partitions, ventilation), and journey planning (reduced fasting, avoiding extreme weather, limiting multiple loadings). Reducing bruising through calmer handling, optimized density, deliberate grouping, and improved design could decrease bruising-related trim/organ condemnation by 20–40%. DOAs could reduce 30–60% with rigorous fitness screening, improved journey planning, and consistent low-stress handling. Electrolyte supplementation can reduce live-weight loss from 6.3% to 4.1% [15]. A detailed economic analysis of this solution for ‘Improved Live Animal Transport Management for Bruising and DOA Reduction’ is provided in Section 6.2.

### **3.3 Harvest Stage Loss**

The harvest stage represents a critical convergence point where upstream animal health, handling, and transport conditions materialize into observable food loss outcomes. Losses at this stage include whole-animal rejection at ante-mortem inspection, carcass trimming due to bruising or disease, organ condemnation, and carcass downgrades. These outcomes reduce edible yield despite the full investment of upstream resources, including feed, land, labor, and embedded emissions. While portions of removed material are recovered through rendering and other secondary uses, harvest-stage losses are still not consistently quantified or linked to upstream causes and remain largely absent from U.S. food loss inventories and life-cycle assessment frameworks. However, the packer stage presents a pivotal opportunity to redefine efficiency, enhance transparency, and close data gap, transforming the abattoir from a loss bottleneck into a catalyst for upstream food waste prevention and supply chain improvement

#### *3.3.1 Loss Rates and Causes*

Harvest-stage losses arise from a combination of biological conditions, management decisions, and animal welfare factors. Key loss pathways include whole-animal rejection during ante-mortem inspection, carcass trimming due to bruising or disease, organ condemnation linked to infection or trauma, and carcass downgrades associated with poor condition or stress. While some removed material is diverted to rendering, these losses are rarely measured on a mass basis and are not systematically linked to upstream drivers such as late culling, transport stress, or handling practices. Despite their scale and economic relevance, harvest-stage losses are inconsistently reported and remain largely absent from formal U.S. FLW accounting and environmental impact assessments, limiting visibility into both their magnitude and preventability.

Quantitative evidence at the harvest stage remains limited and highly fragmented. Standard dressing percentages indicate that more than 40% of live animal weight is not retained as edible carcass, although this figure largely reflects expected inedible components rather than avoidable loss [2]. In contrast, losses associated with disease and handling are substantial: nearly half of dairy cow livers and approximately 20–25% of major organs are routinely condemned due to infection, trauma, or abscesses [25]. Although the prevalence of condemnations and trim is well documented, few studies report mass-based estimates or systematically relate losses to animal type, transport conditions, or facility-level performance [14, 25, 30]. One national assessment suggests that 61% of total food loss tonnage in meat manufacturing occurs at or near the harvest stage, with roughly 19% attributed to water loss and 23% disposed rather than recovered [3]. However, these estimates do not clearly distinguish edible from inedible material or differentiate

recovery through rendering from true waste, limiting their usefulness for targeted intervention and life-cycle assessment.

A fundamental biological constraint at harvest is the dressing percentage (a proportion of a live animal's body weight that remains as the carcass after harvest), with approximately 58.5% of live animal weight converted into edible carcass material [2]. Building on this baseline, losses attributable to upstream farm- and transport-stage conditions manifest at the abattoir in the form of bruising, disease, and compromised animal condition. Bruising affects up to 64.1% of cow carcasses and necessitates tissue trimming that removes otherwise edible meat from the human food supply [25, 30, 31]. Organ condemnation further contributes to yield loss, with an average of 44.6% of dairy cow livers and more than 20% of lungs, hearts, and other viscera condemned due to infection, trauma, or abscessation [25]. In cull dairy cows, light muscling and non-visible bruising exacerbate yield reductions and increase carcass downgrades [25, 31]. Animals rejected during ante-mortem veterinary inspection because of systemic illness, injury, or compromised welfare are diverted to rendering, incineration, or landfill depending on regulatory requirements and condition, yet no centralized U.S. reporting system captures these losses. As a result, ante-mortem rejections represent a significant and under-documented food loss gap, as these animals embody the full suite of upstream resource inputs but never generate edible meat.

Interviewed meat packers (one processing approximately 1,000 head per day and another approximately 2,000 head per day) confirmed the literature review findings, reporting condemnation (the rejection of all or part of an animal's carcass at harvest because it is deemed unfit for human consumption due to disease, contamination, injury, or food safety concerns) and trim losses primarily associated with bruising, disease, and compromised animal condition, with overall condemnation rates of approximately 1% for cull cows and substantially lower rates for fed cattle. Our interviewed plants stated that smaller plants observed approximately 1% harvest-floor condemnation, plus approximately 0.5% condemned in pens and trailers and approximately 0.75% DOAs and dead-in-pen. The larger plant reported near-zero condemnation for fed beef but approximately 1% for cull cows (due mainly to lymphoma). Both highlighted bruising as widespread with the smaller facility estimating 40% of the carcasses requiring extra trim due to bruising and defects, with that material being diverted to rendering.

### *3.3.2 Destinations and Impacts*

Trimmed tissue and condemned organs typically are diverted to rendering (pet food, industrial applications, landfill), though specific volumes and end uses are not consistently tracked [3, 25]. Bruised meat is excluded from human consumption, often discarded without formal weighing and or reporting [30, 31]. Materials unsuitable for rendering may be incinerated, landfilled, or disposed of via wastewater [3].

Inedible products (bones, hides, blood, offal, diseased tissue trimmings) can serve economic and or environmental functions when properly managed, including rendering into feed ingredients, pet food, biofuels, fertilizers, industrial products, medical applications (bovine pericardium in surgical implants, fetal bovine serum for cell culture, collagen and gelatin for pharmaceuticals), and enzymes for research. Interviewed plant staff sent most inedible and condemned material to rendering (trim and blood for poultry feed, pet food, renewable fuel); specified risk materials and some downer (a non-ambulatory animal unable to stand or walk) or DOA animals are occasionally sent to landfill and or composting when rendering is not feasible.

### *3.3.3 Data Gaps*

One challenge in quantifying harvest-stage loss is overlap with transport-related causes (bruising, stress,

injury) often only observed and recorded at harvest. Carcass defects caused by transit are dealt with on the kill floor, making it difficult to allocate losses to either stage with precision [25, 30, 31].

Substantial traceability and quantification gaps persist at the harvest stage. Pre-harvest rejections, despite their significant environmental and economic implications, are not systematically recorded on a mass basis [22]. These rejections typically occur during ante-mortem veterinary inspection and are driven by observable indicators of compromised animal health or welfare, including severe lameness or non-ambulatory status, advanced emaciation, systemic illness (e.g., septicemia, pneumonia, lymphoma), traumatic injury, or evidence of drug residues or treatment violations. Animals rejected at this stage embody the full upstream investment of feed, land, water, labor, and emissions, yet are diverted to rendering or disposal pathways without entering the human food supply. Trimmed and condemned tissues are rarely weighed or tracked beyond their point of removal, limiting the ability to quantify loss magnitude or assess recovery pathways [25, 30]. Downstream destinations of removed material are inconsistently documented, and national audits and USDA reporting frameworks do not integrate harvest-stage losses into broader food loss or life-cycle assessment inventories [22, 25]. As a result, the environmental impacts associated with these losses, including methane emissions from landfill or other disposal pathways, are seldom incorporated into greenhouse gas accounting [4]. The absence of event-level, mass-based data constrains the ability to link specific causes to outcomes, evaluate intervention effectiveness, or design targeted mitigation strategies. Interviews with abattoirs further highlighted weak feedback loops, as detailed carcass information on bruising, trim, and condemnations is typically retained internally or shared informally, leaving producers, haulers, and auction barns with limited systematic insight into how upstream practices translate into harvest-stage losses.

#### *3.3.4 Potential Solutions*

Literature and interviews point toward several promising interventions such as earlier culling to prevent animals from deteriorating to non-ambulatory or condemnable condition, improved fitness-for-transport assessments preventing shipment of weak or compromised animals (detailed analysis in Section 6.2), better handling throughout the chain reducing stress-related bruising and organ damage, and intentional carcass-data feedback systems where abattoirs routinely report bruising patterns, trim estimates, and condemnation summaries to upstream haulers and producers, enabling continuous improvement. However, these solutions remain underutilized until loss measurement and incentive structures more clearly recognize and reward harvest-stage loss reduction.

### **3.4 Pre-Processing Stage Loss**

Pre-processing losses represent a distinct but underexamined stage of upstream food loss in beef and dairy supply chains. These losses occur after animals or raw milk arrive at processing facilities but before full fabrication or product transformation, affecting products that have already incurred substantial on-farm and transport-related resource inputs. Losses arise primarily from quality rejections, spoilage, equipment and sanitation failures, capacity constraints, and systemic disruptions. Despite their economic and environmental significance, pre-processing losses are inconsistently measured, rarely quantified on a mass basis, and infrequently linked to downstream destinations, limiting their visibility in food loss, waste, and life-cycle assessment frameworks.

#### *3.4.1 Loss Rates and Causes*

At this stage, otherwise edible or recoverable products may be removed from the human food supply due to microbial failures, antibiotic residues, temperature deviations, formulation errors, equipment malfunctions, or processing bottlenecks. Because these losses occur after products have met initial intake thresholds, they represent high-input, resource-intensive losses. However, physical quantities are rarely

recorded, and losses are often documented only as quality or regulatory events rather than as measurable volumes linked to specific causes or destinations.

#### *Pre-Processing Losses for Beef*

Animals arriving at processing facilities may be rejected during ante-mortem inspection or experience substantial value loss due to carcass bruising, disease, or failure to meet quality specifications. Within plants, mechanical breakdowns, sanitation lapses, contamination events, and kill-floor delays can result in carcass spoilage or partial condemnation prior to fabrication. These outcomes highlight how pre-processing bottlenecks can translate upstream operational constraints directly into irreversible food loss [13].

#### *Pre-Processing Losses for Dairy*

Milk may be rejected prior to the processing line due to elevated bacterial counts, antibiotic residues, temperature deviations, or sensory defects such as off-odors [12]. Even milk that meets quality specifications at intake can be lost through equipment malfunctions, batch formulation errors, or improper Cleaning-in-Place management [20]. Additional losses occur through leaks, transfer spillage, and partial tanker offloading when processing capacity is constrained. During periods of supply chain disruption or seasonal oversupply, emergency milk dumping has been reported, particularly during peak production periods, further contributing to upstream food loss [32]. While this paper focuses on upstream loss prior to processing, it is important to note that dairy processors who represent approximately 76% of U.S. milk production, have reported an average 94% waste diversion rate in recent years, highlighting strong recovery performance further downstream in the supply chain.[61]

An interviewed fluid milk processor receiving approximately 25 million pounds of milk per week reported that nearly all pre-processing losses were attributable to tanker rejections, averaging approximately one rejected load per week (~75,000 pounds, which is the same loss number reported in section 3.2.1.). This corresponds to an estimated annual loss of 3.9 million pounds, or roughly 0.3% of the approximately 1.3 billion pounds of milk received annually. Rejections were primarily driven by butterfat deviations, microbiological failures, temperature noncompliance, missing or compromised seals, and tanker sanitation issues, most of which originated upstream of the processing facility. Once accepted into the plant, milk losses were minimal and largely limited to residual washout associated with routine cleaning. The processor did not systematically track the treatment of rejected loads, as these volumes never entered the plant's internal accounting or production systems.

An interviewed dairy upcycling company handling approximately 150–250 tons of dairy material per week reported diverting fluid milk and semi-solid dairy products away from landfill toward animal feed production or anaerobic digestion. The majority of dairy material entering the system originated from retail expiration, packaging damage, or off-specification product batches, with smaller contributions from farm- or processor-level losses associated with plant rejections or logistics disruptions. Most fluid milk was dried and incorporated into animal feed, while high-sugar dairy products were preferentially directed to anaerobic digestion due to processing equipment constraints. Key barriers to scaling these diversion pathways included fragmented regulatory requirements, highly variable supply volumes, and limited awareness among producers and cooperatives of available diversion and recovery options.

Quantifying pre-processing losses remains challenging due to the absence of standardized, mass-based reporting. In dairy processing, even small efficiency gains can translate into substantial savings. For example, a 1% reduction in solids loss at a facility processing 1 million pounds of milk per day could yield approximately \$400,000 in annual savings, underscoring the scale of unmeasured waste [20]. Although spoilage-related losses are frequently captured in operational accounting through write-offs, disposal costs, or diversion revenue, the associated physical volumes are rarely measured or reported,

particularly when material is redirected to animal feed, anaerobic digestion, or other secondary pathways rather than classified as waste [12]. Emergency milk dumping events are frequently discussed in policy and environmental contexts yet are seldom linked to specific gallon or tonnage estimates, limiting their integration into food loss and waste inventories [32]. Available plant-level figures, including approximately 0.3% of milk rejected annually at a single processor and 150–250 tons of dairy material managed weekly by an upcycling facility, illustrate the possible scale of pre-processing losses. However, such data remain siloed within individual companies and are not aggregated into national estimates.

#### *3.4.2 Destinations*

Condemned carcasses and tissues are most commonly diverted to rendering, where they are repurposed into pet food ingredients, biofuels, and other industrial products; however, when contamination or disease precludes rendering, material may be landfilled, incinerated, or otherwise disposed of in accordance with regulatory requirements [3, 25]. The proportional distribution and ultimate destinations of these pathways are seldom quantified or systematically reported within food loss frameworks, constraining insight into the balance between recovery and disposal outcomes. Similarly, rejected or spoiled milk is frequently discharged into wastewater systems or redirected to land application, lagoons, or composting, particularly when immediate diversion options are unavailable [20, 32]. During emergency or high-supply conditions, entire milk loads may be dumped without systematic volume reporting, and subsequent fates, such as uses for animal feed, bioenergy production, or disposal, are seldom documented in aggregated datasets [12].

Interview findings indicate an expanding but patchy role for specialized diversion companies that recover rejected or surplus dairy products from processors and retailers. These companies commonly dry fluid milk into animal feed and route residual streams to anaerobic digestion, while associated packaging is typically landfilled. Despite this emerging capacity, processors rarely track the final destinations of diverted material in a systematic way, and participation by cooperatives and farms remains constrained by limited awareness of diversion options, logistical challenges, and regulatory complexity.

Rendering companies play a critical role in recovering value from livestock mortalities, off-spec meat, condemned material, blood, offal, hides, bones, and fats, converting these streams into feed ingredients, biofuels, and other industrial products under strict biosecurity and regulatory controls that define acceptable inputs. While rendering generally offers a higher-value and more resource-efficient outlet than burial or composting, the access remains uneven. Many producers, particularly small or geographically remote operations, face declining rendering service coverage, long transport distances, and cost barriers that limit participation. Renderers further reported increasing competition from subsidized composting and anaerobic digestion platforms, a tightening supply of raw material linked to reduced cattle inventories and missed opportunities to improve recovery efficiency through earlier mortality reporting, proper carcass handling, and the development of regional aggregation points.

#### *3.4.3 Data Gaps*

Significant traceability and data gaps persist at the pre-processing stage. Existing studies predominantly emphasize financial impacts rather than physical loss volumes, limiting insight into the scale of material removed from the human food supply [12, 20]. Final destinations of lost material, including rendering, landfill, wastewater, and composting pathways, are rarely reported in a systematic or comparable manner [3]. Animals culled prior to harvest due to facility constraints or processing backlogs are not consistently incorporated into national food loss or emissions inventories, despite their substantial embedded resource use [13]. Event-level traceability is also minimal, with losses arising from equipment failures, microbial rejections, or systemic disruptions seldom linked to quantified product volumes or downstream outcomes. As a result, current food loss and life-cycle assessment models do not capture the increase in emissions intensity associated with pre-processing losses, even though upstream production emissions are fully incurred. Interview findings further indicate that rejected milk and off-spec dairy products are frequently

managed through ad hoc arrangements, with limited reporting of volumes or destinations beyond regulatory requirements and weak alignment between facility-level operational records and broader food loss measurement and mitigation frameworks.

#### *3.4.4 Potential Solutions*

Addressing pre-processing losses will require a coordinated set of interventions that strengthen measurement, traceability, and integration with existing sustainability frameworks. Priority actions include facility-level collection of mass-based data on rejected and lost materials, standardized protocols for tracking destinations such as sewer discharge, rendering, landfill, and other diversion pathways, and systematic incorporation of these data into food loss inventories and life-cycle assessments. Improved modeling of emissions intensity increases associated with the removal of edible products prior to fabrication is also needed to accurately reflect the environmental consequences of pre-processing losses.

Interview evidence suggests that processors and emerging diversion enterprises already collect detailed operational data on rejected loads and diverted dairy products, yet these datasets remain siloed and are rarely applied to food loss analysis. The development of confidential, aggregated reporting frameworks that draw on existing facility records represents a practical and scalable first step toward closing pre-processing data gaps and better aligning economic and environmental incentives for loss reduction. In parallel, expanding access to diversion infrastructure, including mobile milk-drying equipment, regional aggregation points for rendering, and anaerobic digestion capacity, could substantially increase recovery of currently wasted material and shift pre-processing losses toward higher-value utilization pathways.

#### **3.5 Cross-Cutting Themes**

Across the dairy and beef supply chain stages several cross-cutting patterns consistently emerged. First, data fragmentation remains pervasive, with losses measured inconsistently or not at all and limited traceability linking loss events to their ultimate destinations. Second, feedback loops are weak, as producers, haulers, and auction facilities rarely receive systematic information from processors or abattoirs on how upstream practices translate into bruising, condemnations, rejected loads, or other downstream losses. Third, responsibility for loss prevention is distributed across multiple actors and stages, particularly in transport, harvest, and pre-processing, which dilutes accountability and reduces incentives for any single stakeholder to invest in mitigation. Fourth, capital and labor constraints continue to limit adoption of known loss-reduction practices and technologies, especially where upfront investment or additional staffing is required. Animal condition is a key predictor of loss across all stages, making early intervention and improved care of compromised animals a high-leverage strategy for preventing upstream food loss. Finally, incentives remain misaligned, with operational priorities often emphasizing speed, throughput, and short-term efficiency over loss reduction, animal welfare, or early intervention such as timely culling.

Within this context, the two priority solutions evaluated in Section 4.0 are 1) mastitis prevention and early detection at the farm level, and 2) improved live animal transport management through fitness-for-transport training. Both priority solutions emerge as practical, high-impact entry points. Together, these interventions target large and preventable upstream loss categories while simultaneously strengthening data collection, feedback mechanisms, and stakeholder engagement, thereby laying the groundwork for broader, system-level transformation in beef and dairy supply chains.

### **4.0 Economic Solutions Report**

This section evaluates two priority interventions selected for in-depth economic analysis through a structured screening process designed to identify upstream loss-reduction strategies that are both analytically manageable and scalable. Candidate solutions were first identified through the literature review and primary stakeholder interviews, then assessed against four selection criteria: (1) the magnitude and prevalence of the associated loss stream across U.S. beef and dairy systems; (2) the degree to which

losses are preventable through management or operational change rather than fixed biological constraints; (3) the availability of sufficient empirical or industry data to support credible economic and food loss modeling; and (4) relevance to decision-making by producers, haulers, processors, and policymakers.

Based on this screening, two interventions emerged as the most suitable for detailed economic evaluation: (1) mastitis prevention and early detection through somatic cell count monitoring in dairy systems, and (2) improved live animal transport management through fitness-for-transport training in beef and dairy supply chains. These solutions address loss mechanisms that are consistently identified in both literature and interviews, exhibit clear causal pathways linking management practices to food loss outcomes, and present realistic opportunities for adoption at scale. Together, they span distinct points in the supply chain, from on-farm production to animal transport, allowing comparison of farm-level versus system-level economic dynamics while illustrating how targeted management improvements can deliver substantial reductions in food loss, economic inefficiency, and embedded environmental impacts.

#### **4.1 Early Detection of Somatic Cell Count to Prevent Milk Loss**

Elevated somatic cell count (SCC) is a well-established indicator of udder health, milk quality, and mastitis risk, and is widely used in both research and regulatory contexts to assess intramammary infection and milk suitability for processing [16, 28, 33]. From both economic and food loss perspectives, elevated SCC is associated with reduced milk yield, impaired milk composition, processor quality penalties, and increased disposal or diversion of milk from the human food supply due to antibiotic withdrawal or quality non-compliance [20, 28, 34]. As a result, SCC monitoring represents a critical upstream intervention for preventing avoidable milk loss at the farm level [16, 28].

Over the past two decades, SCC detection technologies have evolved from basic handheld conductivity meters and periodic laboratory testing to fully integrated, inline sensors embedded in modern milking parlors and automated milking systems [26, 35, 41]. These technologies enable earlier identification of both clinical and subclinical mastitis, more timely treatment decisions, and improved herd-level health management through continuous, cow-level data streams [28, 39, 41]. When implemented effectively, SCC-based detection technologies have been shown to reduce milk discard, improve milk quality outcomes, lower mastitis-related culling rates, and enhance overall farm-level economic performance [28, 33, 34].

**Table #5** Different Types of SCC Sensors

<b>Device Type</b>	<b>Method</b>	<b>Cost Estimate</b>	<b>Best Fit Herd Size</b>	<b>Notes</b>
In-line SCC Sensors (e.g., SenseHub)	Automated sensor in parlor	Vendor quoted	Large herds	Real-time SCC per cow; data integration [117]
Optical SCC Analyzers (e.g., DeLaval Cell Counter)	Portable, test cassettes	~\$375 per 72 tests	Medium herds	Rapid screening; targeted testing [112, 116]
Multi-parameter Analyzers (e.g., Ekomilk Horizon)	SCC + fat, protein, lactose	~\$3,650	Small–medium herds	Broader milk quality profiling [118]
Conductivity Meters	Electrical conductivity	~\$160–\$215	Small herds	Low-cost, but limited accuracy [114]
SCC Test Strips (e.g., Bartovation)	Colorimetric	~\$1–2 per test	Very small herds	Basic mastitis detection; no automation [113]

SCC detection technologies currently fall into five primary categories (table 5 below), which vary in cost, accuracy, and operational suitability. Inline SCC sensors, such as SenseHub, provide automated, real-time per-cow SCC measurements and integrated data analytics and are best suited to large herds with modern parlor or robotic infrastructure [41]. Optical SCC analyzers, including the DeLaval Cell Counter, use portable test cassettes and offer rapid, targeted testing for medium-sized herds at an estimated cost of

approximately \$375 per 72 tests [35, 39]. Multi-parameter analyzers, such as the Ekomilk Horizon, measure SCC alongside fat, protein, and lactose content and are priced at approximately \$3,650, making them suitable for small to mid-sized herds seeking broader milk quality profiling [42]. Conductivity meters, which cost approximately \$160 to \$215, provide a low-cost option for small herds but exhibit limited specificity [37]. SCC test strips, such as Bartovation, rely on colorimetric detection at a cost of \$1 to \$2 per test and are primarily appropriate for very small operations requiring basic screening without automation [36]. Across these technologies, elevated SCC serves as a proxy for both clinical and subclinical mastitis, conditions associated with altered milk composition, reduced processability, and increased discard risk [16].

#### *4.1.1 Adoption Context*

Adoption of automated milking and advanced milk monitoring technologies remains limited but growing within U.S. dairy systems. Approximately 5% of U.S. dairy farms, or roughly 1,000 of 24,470 operations, have adopted robotic milking systems, with deployment concentrated in the Midwest and Northeast [52, 56]. These systems provide a key platform for integrating real-time SCC monitoring, electrical conductivity, milk yield, and cow health indicators. North America accounts for more than 12,000 installed automated milking systems, representing approximately 12.9% of the global market [53]. While 39 to 40% of U.S. dairy farms continue to use tie-stall or stanchion housing for lactating cows, limiting compatibility with fully automated systems [57], adoption of precision livestock technologies is increasing, particularly among larger operations [54]. Globally, more than 50,000 robotic milking systems are deployed, with nearly 28% of dairy farms utilizing robotic milking or automated monitoring technologies [53]. Although national data on standalone SCC sensor adoption outside of robotic systems are unavailable, the penetration of automated milking systems provides a useful proxy for advanced SCC monitoring adoption in the U.S. dairy sector [52, 55].

#### *4.1.2 Economic Impact Assessment*

Mastitis-related milk losses are economically significant, and early detection technologies have been shown to reduce both the duration and severity of infections [28]. Cost-benefit modeling for small herds, defined as 50 to 100 cows, suggests that mid-range or automated SCC detection systems generate monthly returns ranging from \$428 to \$743 by reducing production losses and enabling access to milk quality premiums [34]. Larger operations benefit further through labor efficiencies and integration with herd health decision-support platforms. Documented economic benefits include avoided disposal of contaminated milk [20], reduced culling associated with chronic mastitis [28, 33], improved processor bonuses for low-SCC milk [28], and labor savings attributable to automation.

To estimate farm-level economic potential, literature-based benchmarks were applied to primary producer data. Previous studies indicate that typical dairy herds can reduce milk loss by 15 to 30% through improved SCC monitoring and mastitis control, while herds with elevated baseline SCC or poor management practices may achieve reductions of up to 50% when implementing targeted interventions such as real-time detection and automated diversion [34, 37, 38]. A weighted average diversion reduction of 32% was applied for modeling purposes.

Primary survey data from two medium sized farms reporting annual milk production of approximately 4-million and 1.6-million pounds, respectively, with discard rates of 0.3 to 0.4%, yielded baseline discard volumes of approximately 10,585 pounds per farm per year. Under a 32% reduction scenario, this corresponds to an estimated recovery of 3,387 pounds annually per farm. Using an average milk price of \$0.1821 per pound [58], the recovered milk value equals approximately \$617 per farm per year. Producers also reported that SCC monitoring technologies reduced manual observation and testing by approximately eight hours per week. At a conservative labor valuation of \$15 per hour [59], labor savings amount to roughly \$6,200 annually per farm.

Capital investment requirements averaged approximately \$9,000 per farm, based on three sensors per operation. Total annual benefits of approximately \$6,800 per farm yield a payback period of less than two years under stable milk price and labor conditions.

**Table#6** Summary Table

Metric	Value / Assumption
Baseline milk discard rate	0.3–0.4% of annual milk production
Representative farm milk production	~2.8 million pounds/year (average of modeled farms)
Baseline milk discarded	~10,585 pounds/year
Modeled loss reduction via SCC monitoring	32% (literature-weighted average; 15–30% typical, up to 50% high-SCC herds)
Recovered milk volume	~3,387 pounds/year
Average milk price	\$0.182 per pound
Recovered milk value	~\$617 per farm per year
Labor savings from SCC monitoring	~8 hours/week
Labor cost assumption	\$15 per hour
Annual labor savings	~\$6,200 per farm per year
Total annual economic benefit (farm-level)	~\$6,800 per farm per year

#### *4.1.3 Strengths, Limitations, and Use Case Recommendations*

SCC and conductivity-based monitoring tools offer meaningful improvements in mastitis detection and milk loss prevention, though their effectiveness varies by technology type. Conductivity meters, while affordable, exhibit lower specificity and may be influenced by lactation stage or feed composition [26, 29]. Optical SCC analyzers and automated inline sensors provide greater precision but require higher capital investment and supporting infrastructure [28]. Key limitations include false positives and negatives associated with conductivity-based tools [29], cost barriers for smaller producers [20], and integration challenges for advanced sensor platforms.

Despite these limitations, automated systems enable continuous SCC monitoring and real-time alerts, supporting proactive mastitis management and improved long-term herd health. Use case recommendations vary by herd size. Small herds benefit most from test strips or conductivity meters as low-cost screening tools, with confirmatory testing as needed. Mid-sized herds are well served by portable SCC analyzers that balance cost, accuracy, and operational flexibility. Large herds derive the greatest value from inline SCC systems, particularly when integrated with digital herd management platforms.

#### *4.1.4 Implications for Food Loss Prevention*

SCC detection technologies provide a direct mechanism for preventing food loss at its source. By identifying subclinical mastitis before contamination of bulk tanks, producers can retain a greater share of milk within the human food supply, avoid quality penalties, and sustain herd productivity. Although automated systems offer the highest efficiency and reliability, even low-cost SCC detection tools contribute meaningfully to milk conservation when embedded within comprehensive herd health strategies. Combining SCC monitoring with selective dry cow therapy, herd-level data analytics, and genetic selection for mastitis resistance can further improve both economic and environmental performance. Policy and cooperative incentives that lower adoption barriers, particularly for smaller producers, could accelerate uptake and deliver industry-wide reductions in milk loss.

## 4.2 Overview of Fitness-for-Transport Training Programs to Reduce Loss in the Beef and Dairy Supply Chain

Ensuring cattle fitness for transport at the point of loading represents a critical control point for reducing animal welfare risks, economic losses, and food loss across beef and dairy supply chains. Animals that are injured, ill, weak, or otherwise compromised face a substantially higher risk of becoming non-ambulatory or dying during transit, resulting in dead-on-arrival events, condemnations, and irreversible losses of edible protein [40, 43, 46]. Structured training programs, including those developed through the Beef Quality Assurance (BQA) program, the National Dairy FARM Program, the Meat Institute Animal Handling Guidelines and Audit, and veterinary and auditing bodies, support producers and haulers in assessing fitness for transport, handling cattle humanely, and making better-informed shipping decisions [40, 43, 44, 45]. These programs are designed as low-cost, high-impact interventions that target loss prevention at the point where transport-related risks are most effectively mitigated.

### 4.2.1 Adoption Context

Adoption of fitness-for-transport training within the beef sector is substantial but uneven. In 2019, more than 200,000 beef producers completed BQA certification, with recent industry estimates indicating that over 85% of U.S. beef production originates from operations with active BQA certification [50, 51]. Because BQA credentials expire every three years, reported figures reflect active rather than cumulative participation; production-weighted metrics (those that weight adoption by the share of total cattle marketed rather than by the number of operations) therefore provide a more meaningful indicator of system-level adoption, particularly among larger commercial operations [50]

Transport-specific training uptake is more limited but growing. Since its launch in 2017, the BQA Transportation program has enrolled more than 700 producers and haulers, demonstrating early adoption of transport-focused welfare and loss-reduction practices [48]. When compared with USDA NASS estimates of approximately 1.9 million U.S. cattle operations [49], current figures suggest that only about 10% of operations hold active BQA certification, indicating that participation is concentrated among higher-output farms while smaller operations remain underrepresented [49]. [60]

However, transport specific training progress is accelerating at the meat processor level. According to the Meat Institute’s 2025 Continuous Improvement Report, 89% of reporting establishments that handle live animals have or require animal welfare transport regulations or programs, and 92% pass third-party animal handling audits at least annually [60]. Additionally, 90% require suppliers to implement animal welfare programs, reflecting increased pressure across the supply chain to adopt standardized training and handling protocols [60]. These commitments represent a major opportunity to extend best practices for transport fitness and welfare back upstream, particularly if further paired with producer-facing training and certification programs.

Comparable adoption data for dairy producers are not available through BQA, as the program primarily targets beef systems. Adoption within dairy supply chains must therefore be assessed through dairy-specific frameworks such as the National Dairy FARM Program [44]. At the time of this analysis, no published studies directly link certification status to measured reductions in bruising or DOA rates at the herd or shipment level, representing an important evidence gap for future research.

**Table#7** Training Cost Estimates

<b>Training Format</b>	<b>Cost per Trainee</b>	<b>Duration</b>
BQA Online Certification	\$25–\$50	2–3 hours (self-paced)
In-Person Workshops	\$100–\$300	1 day
Internal SOP Refresher	Minimal; staff time only	Annual

#### 4.2.2 Economic Impact Assessment

Improper transport decisions contribute to quantifiable food loss and economic losses at harvest. Cattle that are unfit for transport due to illness, injury, lameness, or poor body condition may arrive dead, be condemned during ante-mortem inspection, or require extensive carcass trimming due to bruising and stress-related injuries, reducing edible yield, degrading meat quality, and diminishing economic returns [25, 30, 31].

Transport-related losses are both frequent and economically significant. Dead-on-arrival rates range from 0.2 to 0.5% of animals, with higher rates observed during long-haul journeys and periods of thermal stress [40, 43]. Bruising resulting from poor handling or overcrowding during transport leads to the loss of approximately 1.6 to 3.4% of carcass weight, as damaged tissue must be trimmed and discarded [46]. Cull cow condemnations exceed 1% in certain facilities, resulting in complete loss of carcass value [47].

The financial consequences of these losses are substantial but unevenly distributed across the supply chain. Each DOA animal represents an estimated loss of approximately \$720 per head, assuming a 1,200-pound cull cow valued at \$0.60 per pound [40, 43]. In most U.S. marketing channels, cattle remain the financial responsibility of the producer or consignor until accepted alive and deemed fit at the abattoir; as a result, DOA animals typically represent a direct and total economic loss to producers [40, 43]. Animals condemned during ante-mortem inspection are similarly uncompensated or only partially compensated, depending on packer policies [25, 47].

For animals that arrive alive but incur bruising, trim loss, or carcass quality downgrades, losses are more diffusely allocated. Reduced carcass yield and lost quality premiums are initially realized by processors, but these costs are frequently transmitted upstream through discounted grid pricing payments (consists of a base price with specified premiums and discounts for carcasses above and below a base or standard set of quality specifications), lower cull prices, or reduced settlement values rather than explicit penalties [25, 30, 31]. Consequently, producers experience the economic impact indirectly, often without clear attribution to specific transport or handling decisions.

Dead-on-arrival events generate immediate and visible losses for producers, with bruising, trim loss, and quality downgrades are rarely traced back to transport conditions or reported systematically to upstream actors [25, 30]. As a result, producers may underestimate both the preventability and economic significance of these losses, reducing the incentive to invest in transport and handling training [40, 43].

Although per-head loss estimates occur at the shipment or facility level, their cumulative impact is most appropriately evaluated at the national scale. Individual producers, haulers, or processors experience these losses episodically, limiting the ability to justify investments based on site-specific returns alone. Aggregated across the national cattle population, however, transport-related losses represent a substantial and largely preventable system-wide inefficiency [25, 30, 31].

Drawing on primary survey results, we estimate that approximately 1.1% of total harvest weight is lost annually due to DOA cattle (0.35%) and condemnations at processing facilities (0.75%). Applied to a national inventory of 78 million adult cattle with an average harvest weight of 1,447 pounds [5], and a representative live cattle price of approximately \$189.14 per hundredweight ( $\approx$  \$1.89 per pound) based on USDA market data [11], this represents roughly \$234.6 million in avoidable protein loss annually across U.S. beef and dairy supply chains.

Under conservative scenarios, structured training and improved transport management could reduce these losses by 15 to 30%, yielding annual national savings of approximately \$35.2 to \$70.4 million. Assuming nationwide training coverage for 646,000 beef and dairy producers at an average cost of \$37.50 per

participant, based on BQA certification cost ranges [40, 43], total implementation costs would be approximately \$24 million, implying a payback period of less than one year.

**Table#8** Summary Table

Metric	Value / Assumption
Total loss rate (DOA + condemned)	1.1% of total harvest weight (0.35% DOA + 0.75% condemned)
U.S. adult cattle population	78 million head
Average harvest weight	1,447 pounds per head
Total annual weight lost	124,153,000 pounds/year
Average beef price	\$1.89 per pound
Total economic loss (national)	\$234.6 million/year
Mitigation scenario	15–30% loss reduction via training
Estimated benefit (15% reduction)	\$35.2 million/year
Estimated benefit (30% reduction)	\$70.4 million/year

#### 4.2.3 Strengths, Limitations, and Use Case Recommendations

Fitness-for-transport training offers several strengths as a loss-reduction strategy. It is low-cost, scalable, and applicable across both beef and dairy supply chains, and it builds on existing standards established by BQA, the National Dairy FARM Program, PAACO, Meat Institute, and AABP [40, 43, 44, 45, 60]. Training also supports compliance with animal welfare audits and regulatory expectations [44, 45].

However, adoption remains uneven. Key limitations include required time investments by producers and haulers, uneven access to training in remote regions, and reliance on consistent implementation and follow-through. Because participation is not uniformly required or economically rewarded, uptake is lower among smaller or lower-output operations, despite these systems often facing higher relative loss risk [49].

There is scope for system-level policy and market interventions to address these barriers. Potential approaches include incorporating fitness-for-transport training as a prerequisite for participation in federally supported programs (e.g., conservation or climate-smart agriculture initiatives), industry education and voluntary use of animal handling training within processor procurement programs. Audit alignment across BQA, FARM, and processor animal handling programs could further reduce duplication and lower compliance costs.

Effective implementation also requires tailoring approaches to different actors. Dairy operations with routine cull cow management can adopt National Dairy FARM transport protocols alongside periodic staff refresher training, integrating mobility scoring and treatment record checks into routine workflows [44]. Beef producers shipping feeder or finished cattle can leverage BQA Learning Management System modules and formalize fitness-for-transport checks through internal standard operating procedures [40, 43]. Processors can accelerate adoption by requiring transport certification for contracted haulers and embedding training expectations into procurement and audit frameworks. Veterinarians and third-party auditors play a critical role in reinforcing standards and delivering hands-on training, supported by Meat Institute, AABP and PAACO guidance [44, 45, 60].

#### 4.2.4 Implications for Food Loss Prevention

Fitness-for-transport training addresses a key upstream loss point where compromised animals result in irreversible protein loss and wasted production inputs. By improving decision-making at the point of loading, training reduces DOA events, bruising, condemnations, and downstream quality losses while

advancing animal welfare objectives [25, 30, 31]. Although individual actors may experience losses sporadically, the aggregate national impact is substantial, supporting the case for coordinated, system-wide intervention.

Scaling adoption will require improved feedback mechanisms, clearer economic signals, and aligned incentives, such as cost-sharing, buyer mandates, or certification-linked requirements. Embedding standardized training and accountability at loading points offers a practical pathway to achieving measurement.

## **5.0 Recommendations for Next Steps and Conclusion**

Building on this research, future initiatives should deepen industry understanding of upstream food loss in the beef and dairy sector while advancing the testing of practical, scalable interventions.

### ***5.1 Quantify Losses with Mass-Based Precision***

Current assessments of upstream loss rely largely on prevalence indicators, such as the percentage of animals bruised or the share of milk discarded, rather than mass-based metrics such as pounds of meat trimmed or gallons of milk withheld. This limits the ability to model environmental impacts accurately and to prioritize interventions based on magnitude. Future research should quantify calf mortality, disease-related removals, reproductive failure, involuntary culling, and discarded milk in terms of scale, frequency, timing, and production context.

Priority efforts should focus on developing standardized protocols that measure losses in pounds or gallons, documenting seasonal peaks, geographic hotspots, and system-specific vulnerabilities, and assessing whether producers perceive these losses as unavoidable biological outcomes or as preventable inefficiencies. Linking quantified loss events to specific management practices will be essential for identifying high-leverage intervention points.

### ***5.2 Model Impacts and Integrate Emissions into FLW Frameworks***

Upstream losses embody substantial embedded emissions and resource use, yet these impacts remain largely invisible in existing accounting frameworks. While losses do not generate new emissions, they reduce edible output and thereby inflate greenhouse gas intensity per unit of product delivered. Underscoring the importance of efficiency gains in already highly productive systems, U.S. dairy and beef systems remain among the most efficient globally. Current EPA and ReFED frameworks rarely incorporate emissions associated with unproductive animals, discarded milk, or condemned products, which distorts sustainability metrics and undervalues the climate benefits of loss reduction.

Future work should model the consequences of early-stage loss for greenhouse gas intensity, feed and water use, land occupation, and overall production efficiency. This includes quantifying embedded emissions per pound of lost meat or gallon of discarded milk, comparing emissions profiles across disposal pathways such as rendering, composting, land application, and anaerobic digestion, and integrating these findings into USDA, EPA, and industry frameworks. Scenario modeling examining ten, twenty-five, and fifty percent loss reductions would provide actionable benchmarks for policy and investment decisions.

### ***5.3 Identify and Trace Underreported Loss Streams***

Several loss streams remain poorly documented or excluded from formal accounting, including surplus dairy bull calves, fetuses from pregnant cows at harvest, rejected edible offal, downgraded dairy products, transport shrink, and dead-on-arrival animals. Transportation and logistics represent particularly under-quantified nodes where losses accumulate across multiple handoffs.

Research priorities include quantifying surplus dairy calf volumes and disposition pathways, estimating the prevalence of fetuses at harvest, determining offal condemnation rates by organ and cause, and measuring transport shrink by journey type while quantifying associated foregone value. Emergency milk dumping events should also be documented, alongside an assessment of diversion feasibility. Partnerships with haulers, auction barns, processors, and cooperatives will be critical for accessing transport logs and loss records, linking bruising patterns to specific practices, and modeling greenhouse gas implications while distinguishing avoidable from inherent losses.

#### ***5.4 Strengthen Traceability and Data Infrastructure***

Existing systems lack event-level granularity that links loss causes to outcomes and final destinations. Haulers often track losses internally without sharing data, abattoirs rarely provide systematic feedback to suppliers, and processors do not consistently record the ultimate fate of rejected material.

Future traceability efforts should explore tools such as RFID or QR-based tracking from birth through harvest, automated logging through robotic milking systems that capture milk discard volumes and causes, and shared digital platforms that allow aggregated reporting while protecting confidentiality. Integrated feedback systems in which abattoirs report bruising patterns, trim estimates, and condemnation data back to upstream partners would significantly improve learning and accountability.

Infrastructure priorities include embedding food loss data fields into existing herd and logistics platforms, developing facility-level protocols to record rejected material by weight, cause, and destination, and creating centralized databases that link loss events to recovery or disposal pathways. Pilot projects should demonstrate return on investment through improved decision-making, quality premiums, and credible sustainability claims, while aligning with USDA NASS, EPA food loss inventories, and ReFED standards.

#### ***5.5 Test Practical Solutions Through Pilot Projects***

The next phase of work should move beyond characterization toward structured evaluation of interventions under real-world conditions. Pilot projects should prioritize solutions that address the largest loss categories and have demonstrated stakeholder support.

Top solutions:

- Mastitis prevention: Evaluate inline SCC sensors, robotic systems, improved bedding/ventilation, selective breeding across herd sizes
- Early culling tools: Test digital platforms integrating mobility scores, SCC trends, reproductive status, market prices
- Neonatal survival: Assess calving cameras, shelter upgrades, colostrum protocols, early disease intervention
- Transport protocols: Implement fitness-for-transport training, low-stress handling certification, trailer upgrades, journey planning
- Recovery strategies: Pilot collection infrastructure for rejected milk, surplus calves, downgraded offal, condemned carcasses

Each pilot should track baseline and post-intervention loss rates, conduct cost-benefit analyses, assess labor implications, and evaluate stakeholder satisfaction in order to identify which approaches deliver the greatest reduction in food loss per dollar invested.

#### ***5.6 Build Cross-Sector Collaboration***

No single stakeholder can address the fragmented data systems, diffuse responsibility, misaligned incentives, and capital constraints that characterize upstream loss. Progress will require coordinated engagement across government, industry, academia, and the private sector.

Key partnerships to facilitate cross-sector industry collaboration:

- USDA/FDA/EPA: Integrate loss metrics into NASS, FSIS reporting, climate-smart programs, and provide technical/financial support.
- Trade associations: Serve as a convening body for meat processors and packers, supporting alignment on data sharing and best practices for bruising, condemnations, and transport losses, and help integrate upstream food loss metrics into industry-led quality, welfare, transport and sustainability programs.
- Extension networks: Develop educational materials, on-farm assessments, peer learning; and leverage Land Grant infrastructure.
- Processors/packers: Establish supplier programs providing training, cost-sharing, performance incentives, and implement carcass-data feedback.
- Rendering/diversion: Expand service routes, develop regional aggregation, and reduce regulatory barriers.
- Academia: Conduct trials, economic analyses, LCAs, and support graduate research programs around food loss.
- Cooperatives/associations: Integrate FLW into quality assurance programs (BQA, FARM, PAACO), and create peer learning communities
- Multi-stakeholder Initiatives: Groups like the U.S. Roundtable for Sustainable Beef can include upstream loss metrics as part of their sustainability programs and support production level education and best practice sharing.
- Retailers/food service: Require transport certification, set condemnation thresholds, reward low-loss performance, co-invest in supplier pilot projects and support investments through long-term agreements.

### ***5.7 Disseminate Findings and Promote Policy Integration***

Findings should be disseminated through peer-reviewed publications, policy briefs, producer toolkits, industry webinars, and targeted media engagement. Policy integration should prioritize inclusion of upstream livestock losses in national food loss inventories, recognition of mastitis prevention and transport improvements, and incorporation of embedded emissions into greenhouse gas reporting and life-cycle assessment methodologies. Certification schemes and state-level programs should also be encouraged to incorporate upstream loss metrics and support infrastructure investments that reduce preventable loss.

### ***5.8 Moving Forward: An Integrated Approach***

Upstream losses in beef and dairy systems remain largely preventable, yet these losses are embedded in management practices, environmental stressors, and economic pressures. On farms, calf health challenges, reproductive inefficiencies, mastitis, and metabolic disorders initiate losses, while late culling and inadequate facilities increase risk. During transport and aggregation, haulers and auction barns often manage animals that are already compromised. At harvest, these upstream challenges manifest as bruising, trim, and condemnations, with cull dairy cows consistently identified as higher-risk. Milk processors overwhelmingly attribute rejected loads to upstream quality failures.

Stakeholders across the supply chain expressed strong interest in reducing loss and are already experimenting with solutions, including improved husbandry, infrastructure investments, monitoring technologies, and upcycling models. However, labor shortages, capital constraints, regulatory fragmentation, and weak feedback loops continue to limit progress. High-impact interventions will focus on earlier culling and fitness-for-transport assessment, improved calf health and early-life management, facility upgrades that reduce heat stress and disease pressure, transport training that embeds low-stress handling, and data systems that close feedback loops between farms, haulers, and processors.

The solutions evaluated in this research, particularly mastitis prevention technologies and fitness-for-transport training, represent practical, high-return entry points that address the largest preventable loss categories while laying the groundwork for broader system transformation. Together, these recommendations provide a strategic roadmap for strengthening measurement, testing interventions, aligning incentives, and accelerating adoption at scale.

## 6.0 Glossary of Terms

**Abattoir:** A facility where livestock are harvested for human consumption. Abattoir processes include ante-mortem inspection, stunning, exsanguination, carcass dressing, evisceration, carcass chilling, and post-mortem inspection. Food loss can occur at multiple stages, including condemnation, excessive trim, or failure to meet quality or safety standards.

**Ante-mortem Rejection:** The process by which animals are deemed unfit for harvest during pre-harvest inspection, typically due to visible illness, injury, or signs of disease. These animals are excluded from the food supply and typically diverted to rendering or landfill.

**CIP (Clean-in-Place):** An automated system used in dairy parlors and processing plants to clean interior surfaces of equipment (e.g., pipelines, tanks, milking units) without disassembly. Improper CIP procedures can lead to milk contamination and loss.

**Clinical / Subclinical Mastitis:** Clinical mastitis presents visible symptoms such as swelling, heat, or abnormal milk. Subclinical mastitis shows no external signs but is detectable through elevated somatic cell counts (SCC) or milk conductivity. Both reduce milk quality and can lead to milk being withheld or discarded.

**Colostrum:** The first form of milk produced after calving, rich in antibodies. It is generally not sold for human consumption and may be fed to calves or discarded depending on on-farm protocols.

**Condemnation:** The official designation of a carcass, organ, or part as unfit for human consumption following post-mortem inspection, often due to disease, contamination, or damage. Condemned material is excluded from the food supply and typically sent to rendering or landfill.

**Consignor:** The individual or business entity that owns and sends livestock to market, auction, or harvest. Often a producer or farm entity.

**Cooperative (Co-op):** A farmer-owned business entity that aggregates, markets, and may process products (e.g., milk) on behalf of its members. Co-ops often manage logistics, quality control, and payment systems.

**Culling (Involuntary):** The removal of an animal from the herd due to poor health, low productivity, or reproductive failure, as opposed to voluntary culling for strategic herd management. Involuntary culling can contribute to FLW when animals are unfit for transport or harvest.

**Dead on Arrival (DOA):** Livestock that die during transport and are non-salvageable upon arrival at the harvest facility. DOAs are a source of economic loss and protein waste and are typically sent to landfill or rendering.

**Fitness for Transport Training:** Training programs (e.g., through BQA or FARM) that teach producers and haulers how to assess animals for health, mobility, and welfare before loading. Aims to prevent transport of unfit animals and reduce DOA and condemnation rates.

**Harvest:** The stage at which livestock are slaughtered and converted into carcasses and by-products for food and non-food uses. In beef and dairy supply chains, “harvest” encompasses ante-mortem inspection, slaughter, dressing, and initial carcass processing, and marks the transition from animal welfare and veterinary oversight to food safety and meat inspection frameworks.

Lagoon: A large containment system used to store liquid manure and processing waste. Some FLW materials (e.g., rejected milk or blood) may be disposed of into lagoons, depending on regulatory and environmental considerations.

Mastitis: Inflammation of the mammary gland in dairy animals, usually due to infection. A leading cause of milk discard due to reduced quality and elevated SCC.

Milk Withheld from Sale: Milk that is produced but not sold due to contamination, poor quality, antibiotic residues, or regulatory restrictions. Common in cases of mastitis or during withdrawal periods after treatment.

Mortality: On-farm animal death due to illness, injury, birthing complications, or environmental stressors. Mortalities are excluded from the food system and typically managed through rendering or burial.

Off-Spec: Products that fail to meet specified quality, safety, or compositional standards and are therefore excluded from intended sale. Off-spec products may be diverted to lower-value markets or discarded.

Offal: The internal organs and entrails of a butchered animal, which may be sold for human consumption, pet food, or diverted to rendering depending on condition and market.

Rendering: A process that converts animal by-products and waste (e.g., offal, bones, condemned carcasses) into usable products like meat and bone meal, fats, pet food, and biofuels. Key destination for non-edible or inedible material.

Replacement Heifer: A young female cow raised to replace older or culled cows in a dairy herd. High mortality or failure to thrive in replacement heifers contributes to upstream FLW.

Rotary Parlor: A mechanized milking system where cows enter a rotating platform and are milked as the platform moves. Efficient for large herds and supports automated monitoring systems.

Shrink / Weight Loss: The reduction in animal body weight due to stress, fasting, and dehydration during transport. Shrink results in reduced carcass weight and economic loss.

Somatic Cell Count (SCC): A key indicator of milk quality and udder health. Elevated SCC suggests mastitis and is used to determine whether milk meets quality standards for sale.

Specified Risk Material (SRM): Tissues in ruminants that may contain prions and are restricted from human consumption due to risk of BSE (e.g., brain, spinal cord). SRMs are segregated and disposed of according to regulatory protocols.

Stanchion: A type of dairy barn where cows are confined to individual stalls for feeding and milking. Less commonly used than modern parlor systems.

Tie-Stall: A barn system in which each cow is tied in an individual stall. Milking occurs in-place, typically using portable milking units. Declining in use in favor of parlor and robotic systems.

Trim: Meat removed from a carcass due to bruising, contamination, or damage. Represents a loss of edible product and contributes to processing-stage FLW.

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