

# Utilization of by-products and food waste in livestock production systems: a Canadian perspective

Kim Ominski,<sup>†</sup> Tim McAllister,<sup>‡</sup> Kim Stanford,<sup>||</sup> Genet Mengistu,<sup>†</sup> E. G. Kebebe,<sup>†</sup> Faith Omonijo,<sup>†</sup> Marcos Cordeiro,<sup>†</sup> Getahun Legesse,<sup>§</sup> and Karin Wittenberg<sup>†</sup>

<sup>†</sup>Department of Animal Science, University of Manitoba and the National Centre for Livestock and the Environment, Winnipeg, MB, Canada

<sup>‡</sup>Agriculture and Agri-Food Canada, Lethbridge, AB, Canada

<sup>||</sup>Department of Biological Sciences, University of Lethbridge, Lethbridge, AB, Canada

<sup>§</sup>Manitoba Agriculture and Resource Development, Winnipeg, MB, Canada

## Implications

- Food waste produced across the supply chain poses negative environmental, social, and economic consequences.
- Livestock can play a key role in using food waste and by-products by converting low-value materials into high-quality products.
- Challenges regarding utilization of food waste include regulatory restrictions, safety concerns, and logistics associated with collection, transport, and handling.
- Addressing these challenges ensures improved stability and resiliency of Canada's food supply chain, which will be increasingly threatened by global political unrest and climate change.

**Key words:** food waste, by-product utilization, livestock

## Introduction

Increasing demand for food coupled with higher environmental standards is shaping agricultural activities toward ecologically sustainable and efficient systems (McGuire, 2015). However, food waste remains a global dilemma, with negative environmental, social, and economic consequences (Spang et al., 2019) associated with estimated annual losses of approximately one-third of all edible food (1.3 billion metric tonnes, MMT) across the supply chain (FAO, 2011). More recently, the FAO (2019) has defined food waste using two indices: food lost in production or in the supply chain before it reaches the retail

level (Food Loss Index) or food that is subsequently wasted by consumers or retailers (Food Waste Index). Fourteen percent of the world's food is lost before it reaches the retail level, but the contribution associated with the Food Waste Index is still being explored (FAO, 2019). In the United States alone, food loss streams have been estimated at 35.9 MMT from production/processing of vegetables, fruit, and meat/poultry/fish, whereas total retail and consumer waste are estimated at 19.5 MMT and 40.8 MMT, respectively (Dou et al., 2016). In Canada, total annual loss and waste along the food value chain equates to 35.5 MMT, of which 11.2 MMT (32%) is avoidable, valued at \$49.5 billion, and representing 51.8% of the food dollars spent in retail stores in 2016 (Gooch et al., 2019).

As described above, food loss is typically associated with loss of quality or low-quality by-products during the production, processing, and distribution stages of the supply chain, whereas food waste or surplus food is defined as food that is not consumed at the retail, food service, and consumer stages of the food supply chain and is related to consumer behavior (Dou et al., 2016). By-products include a wide range of feed-stuffs obtained from 1) cereal grain and oilseed cleaning, milling or extraction; 2) brewery, distillery, or ethanol production; 3) vegetable, fruit, and sugar processing, and 4) livestock processing. Often, a collective term, "food loss and waste," refers to both indices (Gooch et al., 2019). The term surplus, although perhaps more socially acceptable, was purposefully avoided as it implies that producers and the associated food supply chain are using land and resources in excess of demand. Furthermore, it mitigates the shared responsibility to address loss and waste across the supply chain, from the producer to the consumer.

Estimates of food loss and waste are dictated by methodology, with potential overestimates because 1) food redirected for less productive uses, such as fertilizer and animal feed, is deemed as lost; 2) farm losses are monetized at retail-level prices (Bellemare et al., 2017); and/or 3) an inability to accurately determine consumer waste, which can be impacted by many factors including consumer affluence (van den Bos Verma et al., 2020).

© Ominski, McAllister, Stanford, Mengistu, Gunte, Omonijo, Cordeiro, Legesse, Wittenberg

This Open Access article contains public sector information licensed under the Open Government Licence v3.0 (<http://www.nationalarchives.gov.uk/doc/open-government-licence/version/3/>).

doi: 10.1093/af/vfab004

Minimizing food loss is an important avenue to improve global food security and improve management of land, water, and energy resources in food production systems. Indeed, it has become a global priority formalized by the United Nations (UN) 2030 goal to “...halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses” (UN, 2015).

Options to reduce food loss and waste have been described using a “hierarchy of recovery” (Figure 1) which include 1) reduction at source, 2) recovery/redistribution to address hunger, including utilization in animal diets, 3) recycling into pharmaceuticals, cosmetics, fertilizers/compost, as well as biodiesel or natural gas production through anaerobic digestion, and finally, 4) disposal in landfills or via incineration (ECCC, 2019). These options, however, vary broadly by country according to technological development, regulations restricting rendering of animal products into animal feed, as well as consumption. Although countries with higher per capita consumption have higher food waste production (van den Bos Verma et al., 2020), many also have efficient livestock production systems based on emissions per unit of commodity (Gerber et al., 2011). Canada, for example, has highly efficient livestock production systems, but produced 961 kg of waste per capita in 2014 at a cost of \$85/capita for nonhazardous waste management (Richter et al., 2018). Many Canadian communities utilize landfills for disposal as a consequence of the availability of significant tracts of undeveloped land (Bruce et al., 2016).

Therefore, diverting food loss and waste toward livestock and poultry feed is a logical solution to reduce use of landfills as a strategy for disposal. Numerous studies have addressed food loss and waste in terms of food security, food safety, public health, and the environment, but there are a limited number of North American reviews (Dou et al., 2018), examining conversion to feed for food-producing animals. Modeling efforts have demonstrated that if livestock were removed from the landscape in the United States,  $43.2 \times 10^9$  kg of human-inedible food and fiber by-products would no longer be converted into human-edible food, pet food, or industrial products (White and Hall, 2017), highlighting the importance of food loss and waste utilization as an ecosystem service associated with livestock production. Unusable by-products present a liability and their disposal has an associated environmental footprint.

### Food loss and waste streams available for inclusion in livestock diets

Utilizing food loss and waste in animal diets addresses waste management, food security, resource and environmental challenges. Livestock as “up-cyclers” play a critical role in the solution to reducing food loss and waste (Figure 2), with the potential to convert inedible foods into high-quality protein in the form of meat, eggs, and milk, while addressing waste management, food security, resource and environmental challenges (Dou et al., 2018). More specifically, the presence of a myriad of microorganisms in the rumen, and to a lesser extent, the

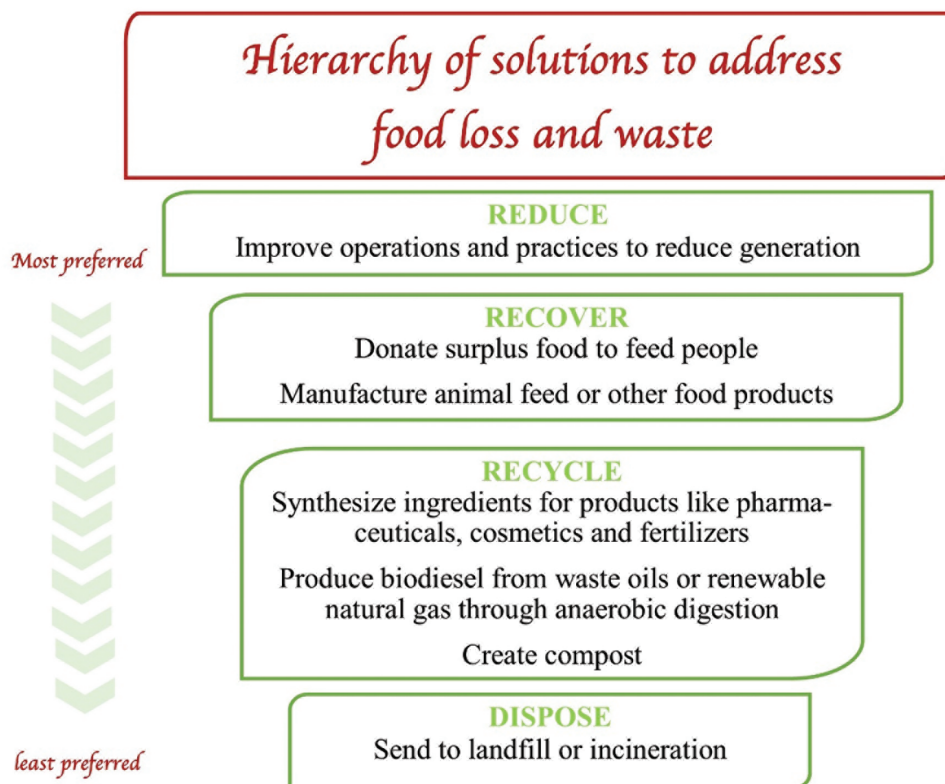
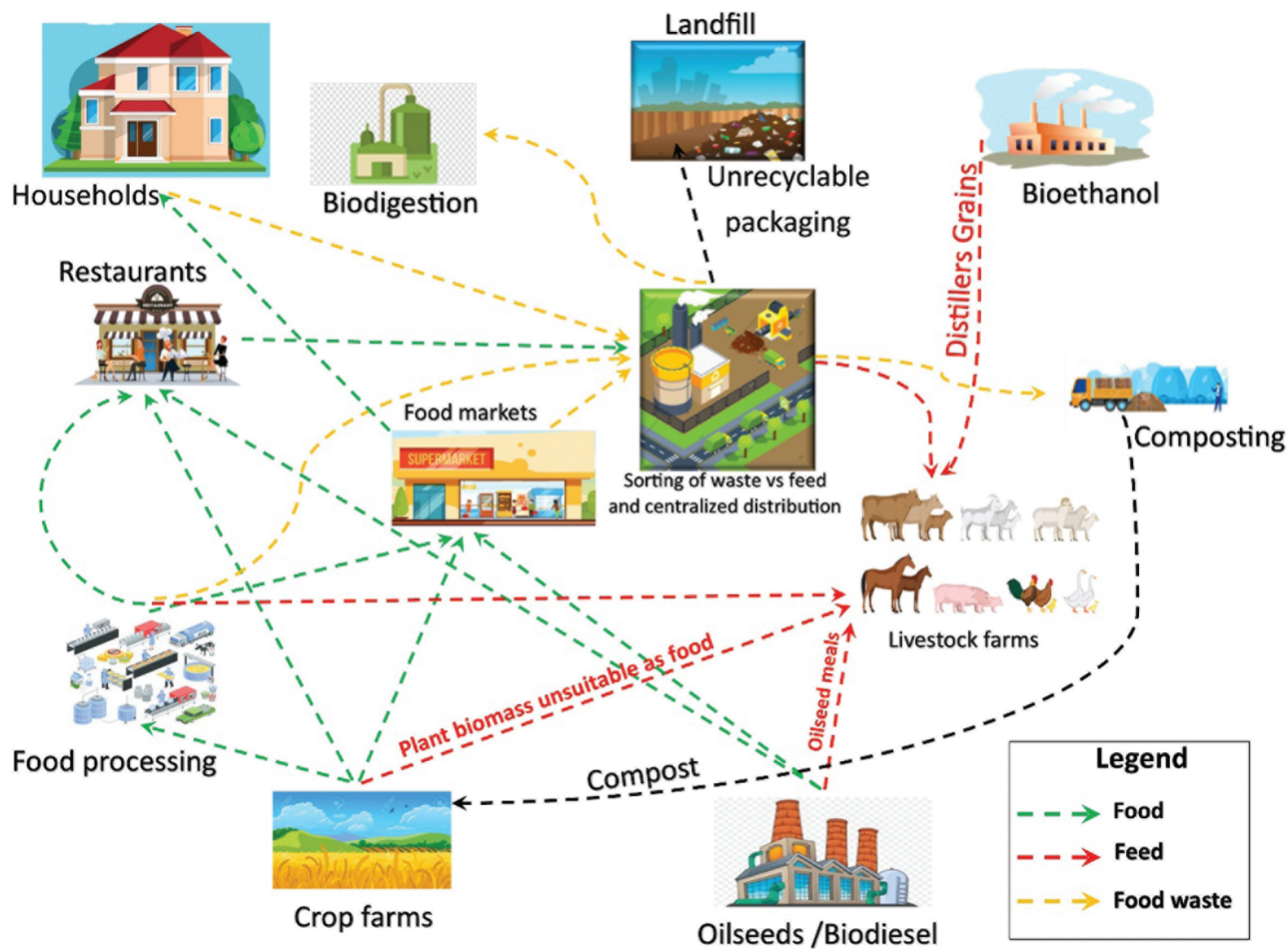


Figure 1. Hierarchy of solutions to address food loss and waste (adapted from ECCC, 2019).



**Figure 2.** Food waste arises from food processors, restaurants, households, and food markets. Some food waste can go directly to livestock farms as feed, whereas others require secondary processing where they are separated from waste, subject to further processing. Streams that are suitable as feed are used on livestock farms, those designated as unsuitable may be directed toward composting or biodigestion. Unrecyclable packaging may be directed toward landfill. Plants that produce bioethanol and vegetable oils produce distillers grains and oilseed meals, which can be used directly by livestock as an important source of energy and protein.

large intestine, has the potential to effectively degrade fiber present in human-inedible plants and plant by-products to enable the ruminant host to generate high-quality protein including essential amino acids and fatty acids (Matthews et al., 2019). Animal protein is also an important source of B vitamins, with B12 obtained exclusively from animal sources, as well as A, D, and K2 (organ meats) and various minerals (i.e., zinc, selenium, iron) that are often more available in animal than plant-based foods (Leroy and Cofnas, 2020).

Currently, a large portion of the feed utilized in North American livestock production consists of grains, pulses, and oilseeds, as well as other commodities including potatoes that fail to reach the quality grade required for human consumption. This can be the result of harvest failures, crop pests, poor growing conditions due to early frosts, floods or drought, or excess production exceeding storage capacity. For example, in Canada, malt barley commands a price that is 51% greater than feed barley, but over 75% of malt barley fails to meet the criteria necessary for beer-making (Ribeiro and McAllister, 2016) due to factors including sprouting damage or low protein

content which interfere with the malting process. However, barley that is rejected for malt production is acceptable as livestock feed. Furthermore, cereal grains and pulses are cleaned of contaminants prior to shipping, generating “grain screenings” consisting of mixtures of broken grains, chaff, weed seeds, and dust. The chemical composition of grain screenings can vary substantially depending on the parental material from which they were derived and their origin during the cleaning process. Screenings that are captured in dust collection systems are often high in minerals and fiber, suitable only as a low-quality feed for ruminants. To improve nutrient consistency and quality, screenings are often blended and pelleted prior to feeding.

In addition to on-farm or near farm losses, as much as 30% of global agriculture production results in biomass waste (Ajila et al., 2012) from food and industrial processing, including alcohol and biofuel production, oilseed processing, fruit and vegetable processing, sugar production, root and tuber processing, and herb, spice and tree processing (Salami et al., 2019). Increased production of biofuels in Canada (approximately 1.8 billion liters in 2019; GAIN, 2019a) has generated

dried distillers grains, which are rich in energy, protein, and minerals. This by-product can constitute up to 50% of the diet dry matter (DM) for confined cattle (Leupp et al., 2009) and up to 15% and 10% of the diet dry matter for pigs (Beltranena and Zijlstra, 2011) and poultry (Salim et al., 2010), respectively.

Expansion of oilseed production in Canada has also resulted in increased availability of oilseed meals. Canola (19 MMT annually) and soybean (6 MMT annually) were the principal oilseeds produced in Canada in 2019 (GAIN, 2019b). Soybean and canola meal are the principal protein sources used in livestock diets, with the fiber being higher and protein content lower in canola than soybean meal. Sunflower, flax, corn, and safflower are also sources of oilseed meals in Canada, but account for less than 1% of meal production.

A number of feed sources resulting from the regional processing of crops are often substituted for a portion of the cereal grain in animal diets, many of which have been characterized by Lardy et al. (2015). Milling of wheat to flour produces bran and germ or a mixture of by-products that can be offered to livestock as wheat middlings. Similarly, the hulls of primary crops such as oats, soybeans, and sunflowers may be removed during processing and are frequently used as a fiber source in ruminant diets. Processing by-products of fruits and vegetables including potatoes are also available for utilization in livestock diets. However, their high moisture necessitates immediate use or further treatment (e.g., ensiling) to prevent spoilage. As fractionation of commodities for inclusion in foodstuffs expands due to increased demand for novel products including meat substitutes, the diversity and volume of by-products in livestock diets is expected to increase. For example, pea processing in western Canada has expanded significantly to provide pea isolates used in dairy and meat substitutes (Acheson, 2016; <https://www.roquette.com/media-center/news/2020-09-29-roquette-world-largest-pea-protein-plant-portage-canada>).

Japan and South Korea have been leaders in recycling food waste into animal feed, where as much as 60% of daily municipal food waste is redirected to animal feed (Nguyen et al., 2017). An opportunity for further inclusion of food waste in livestock diets in Canada exists, given that of the 61.12 MMT consisting of dairy and eggs, field crops, produce, meat and poultry, marine, and sugar/syrup entering the Canadian food system in 2016, only 25.58 MMT (41.9%) were consumed, with 31.4% of the remainder deemed as avoidable food waste. The largest volume and value arose from manufacturing, followed by households, and the processing sector (Gooch et al., 2019).

## Challenges

Despite the abundance of by-products and food waste available, there are a number of challenges regarding their use in livestock production.

### *Economic viability*

Logistics associated with collection, transport, and handling of by-products and food waste may be too cost-prohibitive

for use in livestock diets, particularly when considering high-moisture by-products and food waste. In Canada, some food processing by-products, such as whey and waste vegetables, may be provided at little to no cost to livestock farms, provided that the farms pay transportation costs and ensure timely pick-up. For livestock farms located in close proximity to source, these by-products can reduce feed costs significantly. Even for more “main-stream” by-products such as distillers grains, reduced costs compared with cereal grains and protein supplements promote increased inclusion in livestock diets.

Several Canadian food producers (including Maple Leaf Foods, McCain Foods, Kraft Heinz Canada, Unilever Canada, General Mills, Nestlé and Kellogg's) have made public commitments to reduce food waste including diverting surplus food for human consumption or reusing food as livestock feed, compost, or to generate alternative energy (ECCC, 2019). Identifying industries with significant loss and waste sources along the food supply chain, quantifying food waste and by-product availability, as well as effective communication and coordination (Gooch et al., 2019), are necessary steps to leverage strategies for large-scale diversion of food loss and waste to livestock feed. To date, economic costs have limited the number of animal feed processors and distributors in Canada that have converted human-inedible food waste to animal feed (MacRae et al., 2016). Economic assessments of food waste recycling scenarios using indicators such as return-on-investment are needed to assess their economic feasibility at a commercial scale. Incentives are considered necessary to ensure the economic feasibility of recovering and recycling materials from food loss and waste, especially in the retailing, manufacturing, and processing sectors (Caldeira et al., 2020). Improving the economic efficiency of recycling by-products and food waste, combined with tax incentives, could create demand for these products within the animal feed industry.

### *Collection and distribution logistics*

Efficient and cost-effective collection and distribution of consumer food waste is a global challenge, with disposal in landfills often deemed as the most economically viable option (Dou et al., 2018). In Canada, urban centers are widely dispersed, with rural areas characterized by small communities and isolated farmsteads (NZWC, 2018). Consequently, transportation of waste commodities over long distances creates logistical challenges. Although consumers prefer to purchase locally produced food, options to reduce food waste at a local scale may be limited with the exception of its use as a substrate for biogas or composting. A systematic approach to food waste accounting is essential to design efficient and effective policies that result in reduced food loss and waste along the food supply chain. Fortunately, estimating the volume of food loss generated by production and processing is easier compared with estimation for the household and food service sectors as a consequence of standardized practices that generate by-products of known quantity. Defining the myriad of food wastes that arise from households, retail, and food service sectors is far

more challenging due to the diversity of purchasing and consumption behaviors by consumers (Caldeira et al., 2019).

### **Regulatory restrictions**

Inclusion of by-products and food waste in animal diets is also limited by regulatory policy as feedstuffs must be included in the Feeds Act governed by the Canadian Food Inspection Agency (CFIA). The Feed Acts in Canada permits the use of several processing by-products and bakery wastes as feed (CFIA, 2015), but there are many low volume and novel by-products associated with new processing technologies and changes in consumer demand that are not currently included. For example, by-products resulting from the extraction of oil from hemp include meal (32% crude protein) and hulls, which are valuable protein and fiber resources, but are not currently included in the list of permitted feeds. Increased consumer demand for newer products, such as quinoa, have resulted in by-product and wastes that have suitable nutritional profiles to allow displacement of cereal grains, but often these are not approved for use in animal diets. In other cases, existing regulations prevent or restrict use. For example, the Enhanced Feed Ban is a stringent regulation, which restricts the recycling of meat and bone meal to prevent the introduction of prions responsible for bovine spongiform encephalopathy that may be present in specified risk materials into the food chain. An examination of regulatory policy supported by research has the potential to address economic viability and sustainability of food production through safe expansion of by-product use commensurate with expanded commodity production and availability of food loss and waste at the processing, retail, and consumer levels.

### **Feed safety**

Any effort to divert food that does not meet quality standards for humans or is recovered prior to disposal in landfills must ensure that animal, human, and environmental health is uncompromised. A wide range of potential contaminants can be found in by-products and food waste, such as mycotoxins, herbicides, fungicides, pesticide residues, pathogens, antinutritional factors (glycoalkaloids, tannins), and heavy metals (aluminum, arsenic, cadmium, and lead), as well as glass, metal, and plastic packaging (CFIA, 2019). The high-moisture content of many fruit and vegetable by-products and food waste creates an ideal environment for the growth of bacteria and fungi that may produce toxins during decomposition. It is important to note that sensitivity to feedstuffs containing antinutritional factors such as fungal metabolites differs between species. For example, cattle and poultry are less sensitive than pigs to vomitoxin, a fungal metabolite that may be found in *Fusarium*-infected cereals (Trenholm et al., 1985).

Commercial composting plants employ a variety of processes to remove plastic, glass, metal, and stone contaminants including density separation with water or air, vacuum, and manual removal (Levis et al., 2010). Therefore, to divert food waste to animal feed, labor, and advanced equipment are

required to separate usable food waste from packaging and foreign contaminants (Truong et al., 2019).

A number of preservation techniques: 1) heat sterilization, 2) heat sterilization plus drying to 80% to 95% DM, 3) ensiling alone or after heat treatment with or without addition of fermentation aides (bacteria, enzymes, or acids), and 4) enzymatic treatment have been employed to stabilize food wastes (Dou et al., 2018). However, these processes can add significant cost to their utilization (Sugiura et al., 2009) and typically occur at a centralized industrial scale, making it challenging for small stakeholders to undertake. In Japan, specialized plants have successfully manufactured feed from by-products and food waste utilizing processes ranging from drying to ensiling with lactic acid bacteria (Sugiura et al., 2009). For several high-moisture commodities, such as potatoes, ensiling is essential for preservation and to suppress pathogens causing diseases such as cysticercosis (Buttar et al., 2013). In the European Union, advanced low-cost low-energy processing technologies based on physicochemical and biotechnological processes (Petrusan et al., 2016) have been developed to treat fruit, vegetables, tubers, cereals, and dairy wastes to produce bulk feed, as well as specialized functional feed additives including 1) protein hydrolysates; 2) functional immune-stimulating protein hydrolysates; 3) fiber with prebiotic properties; and 4) antioxidants to enhance oxidative status. More recently, enzymatically treated wastes from supermarket food including fruit, vegetable, meat, and dairy products were fed to growing pigs in California (Jinno et al., 2018). These wastes provided a level of nutrition comparable to that of a standard corn-soybean diet, but the pigs gained less weight due to reduced intake as a consequence of the high water content of the feed. Consequently, to be adopted, these food wastes must be priced to ensure cost of gain remains comparable or lower than standard diets.

### **Assessment of nutrient quality**

The heterogeneity of by-products and food waste creates challenges as their nutrient composition may vary considerably within and between lots, making it difficult to balance diets to meet livestock requirements. Screenings, for example, are frequently marketed on the basis of bulk density, making it difficult to gage their nutritional value. Consequently, the nutrient composition of these products must be measured frequently and diets reformulated as necessary. One solution with on-farm application is the use of near-infrared spectroscopy (NIRS) for rapid assessment of feed value, and the detection of mycotoxins and pesticides in food waste (Shahin and Symons, 2011). However, prior to on-farm use, robust calibration equations must be developed for each by-product by comparing NIRS spectra to traditional laboratory evaluation of the feeds. Other rapid screening technologies, such as flow-injection mass spectrometry, could also be used to detect contaminants, but would only be suited to centralized food waste/by-product processing distribution centers due to operational complexity and equipment costs. Nonetheless, rapid and accurate assessment to determine the nutritional value of by-products and food waste is



For the past 10 yr in Alberta, Kasko Cattle Co. Ltd. has held contracts with both Cavendish Farms and Lamb Weston potato processors for by-products including peels, off-quality French fries, and potatoes that spoiled in storage. Potatoes are fed year-round, constituting 5%–15% of dietary dry matter, with peak inclusion occurring when overproduction of potatoes are seasonally cleared from storage facilities to ensure adequate storage for the new crop. Fresh potatoes are processed in a tub grinder, mixed with peels, and ensiled for 1 mo. The potatoes and peels are ensiled to kill eggs of *Taenia* spp, preventing cysticercosis and condemnation of cattle carcasses (Buttar et al., 2013). Although there are other challenges in feeding potato by-products (acidity of potatoes damages feed trucks and silage pits, high water content), this producer has found a way to ensure that the year-round supply of a relatively consistent product of high nutritive value outweighs the challenges.



Over the last decade, Canada Sheep and Lamb Farms Ltd have successfully included bread, beet pulp, pea, lentil, and dried bean screenings in formulated rations to 60,000 ewes. Use of by-products will continue as they expand their operation from Canada into Russia. Bakery products are being used successfully by some Canadian cattle and sheep farms. Bread packaged in plastic bags for retail sale is received by the feedlot where it is chopped, plastic removed by airflow and included in total mixed rations. The bread is an ideal substitute for cereal grains as it contains 16% crude protein and is high in energy.

essential if these products are to be utilized in precision feeding livestock operations (Dou et al., 2018).

### Environmental impact

Over the last decade, several life cycle assessments (LCAs) have been conducted to determine the environmental implications of traditional disposal streams for food loss and waste (anaerobic digestion, landfill, and composting) compared with their use as livestock feed. However, inclusion of end point affects without consideration of “up-stream” impacts along the food chain, including energy, fertilizer, water, and land use as well as greenhouse gas (GHG) and ammonia emissions, has been identified as one of the shortcomings associated with several of these assessments (Dou et al., 2018). Recently, Salemdeeb et al. (2017) conducted a hybridized LCA that used 14 environmental and health indicators associated with four food waste disposal strategies. Converting municipal waste to feed for pig production lowered the environmental impact compared with anaerobic digestion and composting, with wet-processing superior to dry processing for all environmental indicators. These evaluations often involve assessment of trade-offs in food waste management practices. For example, in South Korea, it requires energy to dry and process food waste in centralized facilities, but once produced it can be economically transported longer distances and is less likely to spoil due to its low water content. In contrast, wet food waste is much more expensive to transport and spoils rapidly, but if used locally does not produce the GHGs associated with drying and long distance transportation.

### Conclusions

Global and Canadian assessments of food loss and waste as a percentage of food grown are substantial, but there is no standardization as to how these assessments should be conducted. This hampers progress in our collective battle against food loss and waste by delaying public policy change and the creation of accountability metrics that can be applied across the food supply chain. Nonetheless, it is evident that redirection of food waste from landfills is necessary to improve global food security and resource sustainability issues. It is also logical that livestock, with their capacity to “up-cycle” relatively low-quality feedstuffs into high-quality protein, are an essential element of this solution. Canadian livestock producers are recognized globally for the animal care standards, milk, meat and egg quality and efficiency of production. Furthermore, Canadian farmers have demonstrated interest, ingenuity, and investment to replace traditional feeds with by-products and even food waste.

Today’s diversity of by-products and urban setting for much of our food waste requires a diversity of solutions. Disincentives to waste food will be influenced by food prices and costs for food disposal. Producer and processor incentives to recover more food and to redirect by-products away from landfill and nonfood recycling efforts will require investment to improve infrastructure, creating market

opportunities. Furthermore, revised policy and regulation are essential to fully implement the spectrum of solutions. Research to facilitate safe incorporation of by-products and food waste in animal feed is a critical step toward changes in policy and regulation.

Canada has some unique challenges. The large geographic area, with much of food processing and food waste occurring in large urban centers means that by-product and food waste sources are often large distances from the livestock and poultry farms. As a major food commodity exporter, Canada's food supply chain is heavily intertwined with multinational food processors and retailers affecting transportation costs. These companies will need incentives or regulation to shift current practices at the local or national level. As one of the world's most northerly food producers, Canada may have an advantage by using cold weather to reduce spoilage of by-products or food waste in storage for a part of the year to reduce storage and processing costs. Furthermore, comprehensive LCA-type assessments to examine environmental benefits of treatment options including replacement of feed grains with by-products or food waste will provide much-needed information regarding the impact on the environment including GHG and ammonia emissions as well as land and water. Finally, a coordinated approach requiring input from producers, feed suppliers, researchers, policy makers, and retailers is critical for the development of successful strategies for inclusion of food loss and waste in livestock diets.

## Acknowledgments

This work was funded by the Beef Cattle Research Council and Agriculture and Agri-Food Canada through the Sustainable Beef and Forage Science Cluster (2018–23; ENV.15.17). The authors thank Mohammad Reza Marami Milani for support in developing the figures.

## Literature Cited

- Acheson, J. 2016. Health and wellness series. Pea protein isolate in food and beverage products. Ottawa (Canada): Agriculture and Agri-Food Canada. <https://www.agr.gc.ca/resources/prod/Internet-Internet/MISB-DGSIM/ATS-SEA/PDF/6780-eng.pdf> (Accessed 7 January 2021).
- Ajila, C. M., S. K. Brar, M. Verma, R. D. Tyagi, S. Godbout, and J. R. Valéro. 2012. Bio-processing of agro-byproducts to animal feed. *Crit. Rev. Biotechnol.* 32:382–400. doi:10.3109/07388551.2012.659172
- Bellemare, M. F., M. Çakir, H. H. Peterson, L. Novak, and J. Rudi. 2017. On the measurement of food waste. *Am. J. Agric. Econ.* 99:1148–1158. doi:10.1093/ajae/aax034
- Beltranena, E., and R. T. Zijlstra. 2011. Feeding value of western Canadian oilseed and biodiesel co-products. In: Proceedings of the 32nd Western Nutrition Conference; September 14 to 15, 2011; Edmonton (Canada); Western Nutrition Conference. p. 217–238.
- Bruce, N., A. Z. Asha, and K. T. W. Ng. 2016. Analysis of solid waste management systems in Alberta and British Columbia using provincial comparison. *Can. J. Civil Eng.* 43:351–360. doi:10.1139/cjce-2015-1414
- Buttar, B. S., M. L. Nelson, J. R. Busboom, D. D. Hancock, D. B. Walsh, and D. P. Jasmer. 2013. Effect of ensilation of potato on viability of

## About the Authors



**Kim Ominski** is a professor in the Department of Animal Science. Since joining the University of Manitoba, Kim has established a multidisciplinary research program improving the productivity and sustainability of forage-based beef production systems. She enjoys collaborating with researchers from across Canada, as well as sharing her research finding with producers and consumers. Kim also considers herself fortunate to teach in both the degree and diploma programs at the University of Manitoba. **Corresponding author:** [kim.ominski@umanitoba.ca](mailto:kim.ominski@umanitoba.ca)

**Tim McAllister** received a PhD in Microbiology and Nutrition from the University of Guelph in 1991. He has been a principal research scientist in microbiology and beef cattle production with Agriculture and Agri-Food Canada since 1996. He has been studying aspects of sustainable livestock production for over 20 years. His latest work has been on interactions between greenhouse gas emissions, biodiversity, and ecosystem services in beef production systems. Using food waste as feed for livestock is a key ecosystem service in a circular economy. Tim is an avid biker and dreams up many of his experiments while riding his bike.



**Kim Stanford** had a long career as a beef scientist for Alberta Agriculture and has recently transferred to the University of Lethbridge. After studying by-product feeds earlier in her career (Cheap Feed for Sheep), she has recently become interested in exploring by-product feeds for cattle. She tries to avoid food wastage at home, which is not always well received by her family.

- Taenia hydatigena* eggs. *Exp. Parasitol.* 133:483–486. doi:10.1016/j.exppara.2013.01.003
- Caldeira, C., V. De Laurentiis, S. Corrado, F. van Holsteijn, and S. Sala. 2019. Quantification of food waste per product group along the food supply chain in the European Union: a mass flow analysis. *Resour. Conserv. Recycl.* 149:479–488. doi:10.1016/j.resconrec.2019.06.011
- Caldeira, C., A. Vlysidis, G. Fiore, V. De Laurentiis, G. Vignali, and S. Sala. 2020. Sustainability of food waste biorefinery: a review on



**Genet Mengistu** is a postdoctoral fellow at the Department of Animal Science, University of Manitoba. She obtained a PhD degree in Animal Nutrition from Wageningen University, the Netherlands. Her previous research focused on nutritional manipulation in dairy cows to improve milk fatty acid profile, and the use of plant secondary metabolites as alternatives to reduce enteric methane. Currently, she is involved in research related to beef cattle nutrition, including the use of by-products and food waste in light of greenhouse gas mitigation.

**E. G. Kebebe** is a PhD student in the Department of Animal Science at the University of Manitoba. His current research strives to better understand the links between livestock production, environmental impacts, and the nutritional quality of animal products and to improve the sustainability of food choices. Prior to joining the University of Manitoba, he had a PhD from Wageningen University, the Netherlands. His previous research focused on modeling agricultural technology adoption and impact evaluation. He has published in both economic and animal systems journals.



**Faith Omonijo** obtained her MSc from the Department of Animal Science, University of Manitoba in 2018. She has been working as a biological technician with the Department of Animal Science, University of Manitoba since 2019. Her most recent work has focused on environmental footprint assessments, as well as identifying gaps in knowledge regarding environmental indicators. She is interested in improving animal health with best nutritional practices. While not at work, her hobbies are singing and playing the violin.



**Marcos Cordeiro** is assistant professor in sustainable food systems modeling at the Department of Animal Science of the University of Manitoba. He earned a PhD in Biosystems Engineering from the University of Manitoba and is registered as a Professional Engineer in that Province. His research focuses on the application of field monitoring and modeling tools at varying spatial scales to investigate current and emerging issues in crop and animal production systems.

**Getahun Legesse** received his PhD in Animal Science from the University of Hohenheim, Germany. For more than a decade, he has been involved in several research and knowledge transfer activities. Most of his research focused on comparing management practices and alternative systems for socially acceptable, environmentally sound, and economically viable production of ruminants. Currently, Getahun is a Livestock Research and Development Specialist with the Manitoba Government and an Adjunct Professor at the University of Manitoba, Canada.



**Karin Wittenberg** is Dean Emeritus, Faculty of Agricultural and Food Sciences, University of Manitoba. Dr. Wittenberg received her doctorate in Ruminant Nutrition from the University of Manitoba and was fortunate to remain there as an academic and professional agrologist. Her work addressed key issues facing animal agriculture relevant to environmental and economic sustainability. Wittenberg led initiatives to establish the National Centre for Livestock and the Environment and the Bruce D Campbell Farm and Food

Discovery Center. Collectively, these efforts have support student education, research, and public dialogue.

valorisation pathways, techno-economic constraints, and environmental assessment. *Bioresour. Technol.* 312:123575. doi:10.1016/j.biortech.2020.123575

CFIA. 2015. Approved feed ingredients. Available from <https://www.inspection.gc.ca/animal-health/livestock-feeds/approved-ingredients/eng/1322975007194/1322975281243> (Accessed 28 October 2020).

CFIA. 2019. Regulatory guidance. Available from <https://www.inspection.gc.ca/animal-health/livestock-feeds/regulatory-guidance/eng/1299871623634/1320602307623> (Accessed 10 November 2020).

Dou, Z., J. D. Ferguson, D. T. Galligan, A. M. Kelly, S. M. Finn, and R. Giegengack. 2016. Assessing US food wastage and opportunities for reduction. *Glob. Food Sec.* 8:19–6. doi:10.1016/j.gfs.2016.02.001

- Dou, Z., J. D. Toth, and M. L. Westendorf. 2018. Food waste for livestock feeding: feasibility, safety, and sustainability implications. *Glob. Food Sec.* 17:154–161. doi:10.1016/j.gfs.2017.12.003
- ECCC. 2019. Taking stock: reducing food loss and waste in Canada. Waste reduction and management division. Quebec (Canada): Environment and Climate Change Canada. Available from <https://www.canada.ca/content/dam/eccc/food-loss-and-waste/Taking%20Stock%20Report%20EN%20Final.pdf> (Accessed 4 November 2020).
- FAO. 2011. Global food losses and food waste – extent, causes and prevention. Rome (Italy): The Food and Agriculture Organization.
- FAO. 2019. The state of food and agriculture 2019. Rome (Italy): Moving forward on food loss and waste reduction.
- GAIN. 2019a. Global agricultural information network. Report no. CA19017. Available from [https://apps.fas.usda.gov/newgainapi/api/report/downloadreportbyfilename?filename=Biofuels%20Annual\\_Ottawa\\_Canada\\_8-9-2019.pdf](https://apps.fas.usda.gov/newgainapi/api/report/downloadreportbyfilename?filename=Biofuels%20Annual_Ottawa_Canada_8-9-2019.pdf).
- GAIN. 2019b. Global agricultural information network. Report no. CA2020-0031. Available from [https://apps.fas.usda.gov/newgainapi/api/Report/DownloadReportByFileName?fileName=Oilseeds%20and%20Products%20Annual\\_Ottawa\\_Canada\\_03-15-2020.pdf](https://apps.fas.usda.gov/newgainapi/api/Report/DownloadReportByFileName?fileName=Oilseeds%20and%20Products%20Annual_Ottawa_Canada_03-15-2020.pdf).
- Gerber, P., T. Vellinga, C. Opio, and H. Steinfeld. 2011. Productivity gains and greenhouse gas intensity in dairy systems. *Livest. Sci.* 139:100–108. doi:10.1016/j.livsci.2011.03.012
- Gooch, M., D. Bucknell, D. Laplain, B. Dent, P. Whitehead, A. Felfel, L. Nikkel, and M. Maguire. 2019. The avoidable crisis of food waste: technical report. Ontario (Canada): Value Chain Management International and Second Harvest.
- Jinno, C., Y. He, D. Morash, E. Mcnamara, S. Zicari, A. King, H. H. Stein, and Y. Liu. 2018. Enzymatic digestion turns food waste into feed for growing pigs. *Anim. Feed Sci. Technol.* 242:48–58. doi:10.1016/j.anifeedsci.2018.05.006
- Lardy, G., V. Anderson, and C. Dahlen. 2015. Alternative feeds for ruminants. North Dakota State University Extension service. <https://www.ag.ndsu.edu/publications/livestock/alternative-feeds-for-ruminants/as1182.pdf>. (Accessed 10 November 2020).
- Leroy, F., and N. Cofnas. 2020. Should dietary guidelines recommend low red meat intake? *Crit. Rev. Food Sci. Nutr.* 60:2763–2772. doi:10.1080/10408398.2019.1657063
- Leupp, J. L., G. P. Lardy, K. K. Karges, M. L. Gibson, and J. S. Caton. 2009. Effects of increasing levels of corn distillers dried grains with solubles to steers offered moderate-quality forage. *J. Anim. Sci.* 87:4064–4072. doi:10.2527/jas.2008-1711
- Levis, J. W., M. A. Barlaz, N. J. Themelis, and P. Ulloa. 2010. Assessment of the state of food waste treatment in the United States and Canada. *Waste Manag.* 30:1486–1494. doi:10.1016/j.wasman.2010.01.031
- MacRae, R., A. Siu, M. Kohn, M., Matsubuchi-Shaw, D. McCallum, T. H. Cervantes, and D. Perreault. 2016. Making better use of what we have: strategies to minimize food waste and resource inefficiency in Canada. *Can. Food Stud.* 3:145–215. doi:10.15353/cfs-rcea.v3i2.143
- Matthews, C., F. Crispie, E. Lewis, M. Reid, P. W. O’Toole, and P. D. Cotter. 2019. The rumen microbiome: a crucial consideration when optimising milk and meat production and nitrogen utilisation efficiency. *Gut Microbes* 10:115–132. doi:10.1080/19490976.2018.1505176
- McGuire, S. 2015. FAO, IFAD, and WFP. The state of food insecurity in the world 2015: meeting the 2015 international hunger targets: taking stock of uneven progress. Rome (Italy): FAO, Oxford University Press.
- Nguyen, D. D., S. W. Chang, J. H. Cha, S. Y. Jeong, Y. S. Yoon, S. J. Lee, M. C. Tran, and H. H. Ngo. 2017. Dry semi-continuous anaerobic digestion of food waste in the mesophilic and thermophilic modes: new aspects of sustainable management and energy recovery in South Korea. *Energy Convers. Manag.* 135:445–452. doi:10.1016/j.enconman.2016.12.030
- NZWC. 2018. How to measure food waste: a guide for measuring food waste from households in Canada. Vancouver (Canada): The National Zero Waste Council. Available from [http://www.nzwc.ca/Documents/LFWH\\_GuideToMeasuringFoodLossAndWaste.pdf#search=A%20Guide%20for%20Measuring%20Food%20Waste%20from%20Households%20in%20Canada](http://www.nzwc.ca/Documents/LFWH_GuideToMeasuringFoodLossAndWaste.pdf#search=A%20Guide%20for%20Measuring%20Food%20Waste%20from%20Households%20in%20Canada).
- Petrusan, J.-I., N. Klinkwitz, and U. Lehrack. 2016. NOSHAN-Sustainable production of functional and safe feed from food waste. *Berichte aus dem Julius Kühn-Institut*. European Commission. p. 57.
- Ribeiro, G., and T. McAllister. 2016. Can the beef value of beer barley be rated with just one test? Available from <https://www.country-guide.ca/crops/cereals/barley/can-the-beef-value-of-beer-barley-be-rated-with-just-one-test/> (Accessed 10 November 2020).
- Richter, A., K. T. Ng, and C. Pan. 2018. Effects of percent operating expenditure on Canadian non-hazardous waste diversion. *Sustain. Cities Soc.* 38:420–428. doi:10.1016/j.scs.2018.01.026
- Salami, S. A., G. Luciano, M. N. O’grady, L. Biondi, C. J. Newbold, J. P. Kerry, and A. Priolo. 2019. Sustainability of feeding plant by-products: a review of the implications for ruminant meat production. *Anim. Feed Sci. Technol.* 251:37–55. doi:10.1016/j.anifeedsci.2019.02.006
- Salemdeeb, R., E. K. Zu Ermgassen, M. H. Kim, A. Balmford, and A. Al-Tabbaa. 2017. Environmental and health impacts of using food waste as animal feed: a comparative analysis of food waste management options. *J. Clean. Prod.* 140:871–880. doi:10.1016/j.jclepro.2016.05.049
- Salim, H., Z. Kruk, and B. Lee. 2010. Nutritive value of corn distillers dried grains with solubles as an ingredient of poultry diets: a review. *World’s Poult. Sci. J.* 66:411–432. doi:10.1017/S0043933910000504
- Shahin, M. A., and S. J. Symons. 2011. Detection of Fusarium damaged kernels in Canada Western Red Spring wheat using visible/near-infrared hyperspectral imaging and principal component analysis. *Comput. Electron. Agric.* 75:107–112. doi:10.1016/j.compag.2010.10.004
- Spang, E. S., L. C. Moreno, S. A. Pace, Y. Achmon, I. Donis-Gonzalez, W. A. Gosliner, M. P. Jablonski-Sheffield, M. A. Momin, T. E. Queded, K. S. Winans, et al. 2019. Food loss and waste: measurement, drivers, and solutions. *Annu. Rev. Environ. Res.* 44:117–156. doi:10.1146/annurev-environ-101718-033228
- Sugiura, K., S. Yamatani, M. Watahara, and T. Onodera. 2009. Ecofeed, animal feed produced from recycled food waste. *Vet. Ital.* 45:397–404.
- Trenholm, H. L., B. K. Thompson, K. E. Hartin, R. Greenhalgh, and A. J. McAllister. 1985. Ingestion of vomitoxin (deoxynivalenol)-contaminated wheat by nonlactating dairy cows. *J. Dairy Sci.* 68:1000–1005. doi:10.3168/jds.s0022-0302(85)80921-8
- Truong, L., D. Morash, Y. Liu, and A. King. 2019. Food waste in animal feed with a focus on use for broilers. *Int. J. Recycl. Org. Waste Agric.* 8:417–429. doi:10.1007/s40093-019-0276-4
- UN. 2015. Transforming our world: the 2030 agenda for sustainable development. United Nations Resolution A/RES/70/1. United Nations. p. 25.
- van den Bos Verma, M. V. D. B., L. de Vreede, T. Achterbosch, and M. M. Rutten. 2020. Consumers discard a lot more food than widely believed: estimates of global food waste using an energy gap approach and affluence elasticity of food waste. *PLoS One* 15:e0228369. doi:10.1371/journal.pone.0228369
- White, R. and Hall, M. 2017. Nutritional and greenhouse gas impacts of removing animals from U.S. agriculture. *PNAS* 114:E10301–E10308.