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1 INTRODUCTION

Most of the world’s food is derived from agricultural, horticultural, and fishery processes. With a growing population, urbanization, and increased income, the food industry has become increasingly market driven. As a result of globalization and reduced trade barriers, it has grown to account for approximately 10% of the world’s gross domestic product (Murray 2007). Fortunately, environmental protection and sustainability are currently better aligned with the world’s consumption of natural resources. Over the past few decades, it has tried to adopt technologies to improve waste minimization and environmental performance. Although the most valuable elements are extracted from foods during harvest and processing, what remains in both the product-specific and product-nonspecific wastes may also contain other potentially valuable components.

Predicting future food production and associated by-products is complicated and has to take into account not only changes in population size, dietary composition, land requirements, and primary resources, but also climate and environmental aspects (Godfray et al., 2010a). Overall, increased global demand for animal-based products requires a substantially greater increase in plant and other feed resources, which will subsequently generate a much larger volume of protein-rich materials than currently produced.

The quantity of food materials wasted each year is exorbitant, and urbanization and the increasing per capita income will see this quantity rise further through increased consumption of staple foods and through diversification into animal products, such as meat, fish, and dairy. This
will be most challenging for transitional countries, which are expected to undergo a much more rapid increase in per capita meat consumption compared to high-income countries (ie, China will increase by $\sim 50\%$, from 49 kg in 2000 to 74 kg per capita per year in 2030 compared to an increase of $\sim 9\%$, from 86 kg to 95 kg per capita per year, in higher income countries) (Msangi and Rosegrant, 2011). Such nutritional transitions result in a rapid increase in animal products, putting a significant amount of pressure on food supply chains within transitional countries than those in the developed world.

A major facet of the problem we face, is being able to source adequate quantities of high-quality protein from which to feed both humans and animals, without intensifying the overall environmental impact (van Huis, 2013). Obviously, increasing production of animal-based products will result in a much higher consumption of grain and protein feeds to feed livestock, which are estimated to require $\sim 6$ kg of plant protein for every kilogram of protein they produce (Pimentel and Pimentel, 2003). However, this could be better perceived by the $\sim 30$ kg of grain required to produce 1 kg of edible boneless meat from grain-fed cattle (Foley, 2011). Conversely, while chicken and pork are more efficient converters of plant proteins, pasture-fed cattle are able to convert nonfood material into usable protein.

The technology for recovering nutrients and usable materials from industry is often feasible, but the regulations regarding what can be done with by-products of industry may not always allow for the technology to be adopted. Despite a concerted effort to better use by-products of the agricultural and food industry to improve the management of resources, sensible legislative incentives also need to be implemented. This chapter identifies areas of food production and related industries generating waste and by-products with high levels of recoverable protein, in particular, those derived from agricultural production itself. Current and future management options for the transformation and/or disposal of these wastes and by-products are then considered in light of current legislation and technological restrictions.

## 2 FOOD PRODUCTION CYCLE AND BY-PRODUCTS

The modern food cycle is comprised of several stages, including agricultural production, postharvest handling and storage, food processing and packaging, distribution and retail, and finally, end-of-life and consumption (Fig. 1.1) (Kummu et al., 2012). Agricultural production, postharvest handling, and storage of food give rise to unintended food losses and ancillary by-products, while processing and packaging and distribution and retail result in “food waste.” Food loss, by-products, and food waste are formed at every stage of the food production process. While the generation of by-products, such as crop residues and animal by-products (ABPs) during agricultural production is considered unavoidable, food losses, owing to a lack of market or degradation during handling or transportation could be avoided with care, but when considering statistics, it is often difficult to distinguish between the two.

For various reasons, approximately one-third of the food produced worldwide is wasted (Godfray...
et al., 2010a; Food and Agriculture Organization of the United Nations, 2011). These wastes (and possible by-products) are created during the manufacturing processes and are often removed in order to give the product the desired sensory and nutritional qualities. Although the magnitude of food losses, by-products, and food waste varies depending on the product type (Table 1.1) and the stage of production considered (Table 1.2), it is strongly influenced by the technology and infrastructure available to the region.

It has been estimated that around 60 million metric tons (MMT) of ABPs are produced worldwide every year (Leoci, 2014), along with significantly higher quantities of crop residues (Santana-Méridas et al., 2012). Obviously, industrial processing of any food, whether it is intended for human or animal consumption (or other industrial processes, such as biofuels) leads to a vast quantity of waste and by-products, typically ranging between 30 and 60% by weight (Table 1.1). In the case of crops, only 60% of global production is used for human consumption, mostly in the form of grains, pulses, oil plants, fruits, and vegetables, leaving 35% as by-products (used for animal fodder) and the remaining 5% for conversion to biofuel and other industrial products (Foley, 2011).

In high-income regions, most food waste occurs during distribution and consumption, with high losses also occurring during agricultural production of plant products and fish (Table 1.2). Harvesting of crops also results in an inedible portion of the biomass (including edible product lost during harvest) contributing to what is known as crop residues. For most common edible crops, the residue-to-crop-production ratio is between 0.9 and 3 to 1 (Scarlat et al., 2010). This mass is not accounted for in Table 1.2, however, typical quantities of some common food crops are given in Table 1.3. In lower-income regions, losses occur at every stage, particularly post-harvest, to a much higher degree, but occur significantly less at the consumption stage. Higher losses throughout production in low-income regions are an artefact of inadequate knowledge, skills, technologies, and infrastructure to support the food supply chain compared to the industrialized world (Godfray et al., 2010b).

Globally, billions of tons of agro-industrial residues and by-products are generated annually (Table 1.3). These include solid, liquid, and gaseous residues and can be seen as one of the most abundant, cheap, and renewable resources available (Santana-Méridas et al., 2012). Given that food waste has a typical composition of ~30–60 wt.% starch, 10–40 wt.% lipids, and 5–10 wt.% protein (Pleissner and Lin, 2013), millions of tons of protein, from plant and animal sources, could be better used. Agricultural production also has other unavoidable wastes

| TABLE 1.1 Percentage of By-Products and Waste Generated During Different Production Processes |
|----------------------------------|----------------------------------|
| Production process               | Converted to waste and by-products (%) |
| PLANT PRODUCTS                   |                                  |
| Cornstarch production            | 41–43                            |
| Fruit and vegetable processing   | 5–30                             |
| Potato starch production         | 80                               |
| Red wine production              | 20–30                            |
| Sugar production from sugar beet | 86                               |
| Vegetable oil production         | 40–70                            |
| Wheat starch production          | 50                               |
| ANIMAL PRODUCTS                  |                                  |
| Beef slaughter                   | 40–52                            |
| Crustacean processing            | 50–60                            |
| Fish canning                     | 30–65                            |
| Fish filleting, curing, salting, smoking | 50–75                 |
| Cheese production                | 85–90                            |
| Mollusk processing               | 20–50                            |
| Pig slaughter                    | 35                               |
| Poultry slaughter                | 31–38                            |
| Yogurt production                | 2–6                              |

Adapted from de las Fuentes et al. (2004).
associated with it, including manure and effluent, which also contain high levels of recoverable protein. These by-products and wastes find new life, often as animal feed ingredients.

### 3 PROTEIN-RICH BY-PRODUCTS

Waste materials generated during agricultural production, including inedible plant and animal parts, are removed during harvesting and postharvest processing. Other unavoidable nutrient-rich wastes, such as manure and deadstock, are also produced. Due to their high levels of recoverable protein, carbohydrate and fiber, many of the by-products and wastes of the agricultural industry currently find reuse as animal feeds or animal feed ingredients.

Animal feed ingredients are blended in such a way as to create a more nutritious food for livestock. Plant-derived ingredients include grains, such as maize, barley, sorghum, oats, and wheat (which can also be used for bioethanol production), from which the by-products are often diverted back to feed. These grain by-products include corn gluten meal, brewers and distiller’s grains, malt sprouts, brewer’s yeast, and wheat mill feed (Lefferts et al., 2006; Naik et al., 2010). More importantly, it has been assumed that by 2020, up to 10% of transportation fuels will be derived from biofuels, generating up to 100 MMT of additional protein (Scott et al., 2007). Higher value applications for inedible and nonessential amino acids derived from these by-products may eventually be commercialized, providing a feedstock for protein-based plastics.

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**TABLE 1.2 Combined Food Losses and Food Waste for Each Stage of the Food Production Chain, Expressed as a Weight Percentage of the (Edible Only) Incoming Resource**

|                      | Agricultural production (wt.%) | Postharvest handling and storage (wt.%) | Processing and packaging (wt.%) | Distribution (wt.%) | Consumption (wt.%) |
|----------------------|-------------------------------|----------------------------------------|-------------------------------|-------------------|------------------|
| **HIGH INCOME**      |                               |                                        |                               |                   |                  |
| Cereals              | 2                             | 2–10                                   | 0.5–10                        | 2                 | 20–27            |
| Roots and tubers     | 20                            | 7–10                                   | 15                            | 7–9               | 10–30            |
| Oilseeds and pulses  | 6–12                          | 0–3                                    | 5                             | 5                 | 4                |
| Fruits and vegetables| 10–20                         | 4–8                                    | 2                             | 8–12              | 15–28            |
| Meat                 | 2.9–3.5                       | 0.6–1                                  | 5                             | 4–6               | 8–11             |
| Fish and seafood     | 9.4–15                        | 0.5–2                                  | 6                             | 9–11              | 8–33             |
| Milk and dairy       | 3.5                           | 0.5–1                                  | 1.2                           | 0.5               | 5–15             |
| **LOW INCOME**       |                               |                                        |                               |                   |                  |
| Cereals              | 6                             | 4–8                                    | 2–7                           | 2–4               | 1–12             |
| Roots and tubers     | 6–14                          | 10–19                                  | 10–15                         | 3–11              | 2–6              |
| Oilseeds and pulses  | 6–15                          | 3–12                                   | 8                             | 2                 | 1–2              |
| Fruits and vegetables| 10–20                         | 9–10                                   | 20–25                         | 10–17             | 5–12             |
| Meat                 | 5.1–15                        | 0.2–1.1                                | 5                             | 5–7               | 2–8              |
| Fish and seafood     | 5.1–8.2                       | 5–6                                    | 9                             | 10–15             | 2–4              |
| Milk and dairy       | 3.5–6                         | 6–11                                   | 0.1–2                         | 8–10              | 0.1–4            |

Regions were grouped (Gustavsson et al. 2011) into medium- to high-income regions (Europe, United States, Canada, Oceania, and industrialized Asia) and low-income regions (sub-Saharan Africa, North Africa, West and Central Asia, South and Southeast Asia, and Latin America).
**TABLE 1.3** Estimates of Production By-Products and Crop Residues from Commodity Crops in Million Metric Tons (MMTs) Per Annum (*Santana-Méridas et al. 2012*)

| Production process | Residue production (MMT/year) | Production process | Residue production (MMT/year) |
|--------------------|-------------------------------|--------------------|-------------------------------|
| **Roots and tubers** |                               | **Cereals**        |
| Potato foliage, tops peels and pulps | 116.7                         | Rice straw         | 457.0                         |
| Cassava peels, stalks, bagasse         | 82.6                          | Wheat straw        | 475.1                         |
| **Fruits**                             |                               | Barley straw       | 105.0                         |
| Apple pomace                           | 20.9                          | Maize straw and stalks | 1266.6                      |
| Orange peels, pulps and membranes      | 34.7                          | Maize cobs         | 337.8                         |
| **Legumes**                            |                               | Millet             | 88.9                          |
| Beans straw and pods                   | 57.2                          | Banana leaves, stems/peels | 183.8                      |
| Soybeans straw and pods                | 392.7                         | Grape pomace       | 20.5                          |
| **Oil crops**                          |                               | *Slaughterhouse By-products* |
| Sunflower foliage/stems                | 15.3                          | **Cattle**         |
| Olive leaves and stems                 | 10.3                          | Protein meal       | 6.9                           |
| Coconut shells, husks/fronts           | 18.7                          | Tallow             | 4.2                           |
| Palm oil shells, husks/fronts          | 13.5                          | Bloodmeal          | 0.38                          |
| **Sheep**                              |                               | **Sheep**          |
| Groundnuts stalks/shells               | 71.1                          | Protein meal       | 0.58                          |
| Rapeseed straw                         | 73.8                          | Tallow             | 0.59                          |
| Cottonseed stalks                      | 80.1                          | Bloodmeal          | 0.05                          |
| **Pigs**                               |                               | **Pigs**           |
| Almond hulls and shells                | 0.9                           | Protein meal       | 3.7                           |
| Walnut shells                          | 1.70                          | Tallow             | 7.6                           |
| **Industrial crops**                   |                               | Bloodmeal          | 0.34                          |
| Sugarcane leaves and tops              | 168.5                         | **Chicken**        |
| Cotton stalks                          | 197.6                         | Protein meal       | 5.5                           |
| Fiber crops leaves/stalks              | 56.9                          | Tallow             | 2.6                           |
| **Vegetables**                         |                               | Bloodmeal          | 0.18                          |
| Onion leaves and stems                 | 35.0                          | **Fish**           |
| Tomatoes leaves and stems              | 72.9                          | Protein meal       | 6.2                           |
| Cucumber leaves and stems              | 25.9                          |                    |                               |

Slaughterhouse by-products calculated from the proportion of live weight in each rendering product for each species considered (*Wiedemann and Yan, 2014*), using the 2013 estimate of livestock slaughtered globally (*Food and Agriculture Organization of the United Nations, 2013*). Fishmeal estimate from 2002 (*Hardy and Tacon, 2002*).
biopesticides or commodity organic compounds (Naik et al., 2010; Scott et al., 2007).

Oil production by-products (oil meals and press cakes) from processing oilseeds, such as soybean, canola, sunflower seed, linseed, palm kernel and others, are also important feed ingredients. Oil meals are obtained by solvent extraction of the oil cakes, which are obtained by pressing the seed. In 2013, 269 MMT of various oil meals were produced globally, of which 181 MMT was soymeal (United States Department of Agriculture, 2015a). In the United States alone, 36 MMT of soymeal is produced annually (United States Department of Agriculture, 2015a), representing more than two-thirds of the proteinaceous animal feed in the country (Lefferts et al., 2006). Other oilseed meals are lower in protein and higher in fiber and are often used for feeding ruminants. Cottonseed meal is also high in protein and is mainly used as cattle feed in the United States or as aquaculture feed. Unlike other seeds, the press cake obtained from castor seeds during castor oil production is inedible because of its high level of phytotoxins (ricin, a toxic protein), hydrocyanides, and other allergens, however, this too has a high level of protein, ~20–30% (Table 1.4).

Other plant ingredients may include alfalfa by-products, such as alfalfa meal, pellets, and concentrated alfalfa solubles, which are typically fed to ruminants. Further, various nuts, seeds, and their by-products, such as hulls and seed screenings; legume by-products, such as bean straw meal and hulls; and even dried roots and tubers, such as sweet potatoes and chipped or pelletized cassava, find use in animal feed.

Agricultural production—specifically the production of animal-derived goods—also results in by-products. In fact, around 30 wt.% of an animal produced for food is not used directly for human consumption, and downed or dead animals are another waste artefact of production. These waste materials are processed by the rendering industry, producing protein-rich products (Table 1.4). Global production of ABP meals from rendering is in excess of 13 MMT per year (Fig. 1.2). These products include meat meal, meat and bone meal, poultry by-product meal, poultry meal, blood meal, feather meal, hydrolyzed leather and leather meal, eggshell meal, hydrolyzed hair, unborn calf carcasses, ensiled paunch, bone marrow, and dried plasma (Lefferts et al., 2006).

Other than the preceding, about 30 wt.% of the fish caught globally each year is not used directly for human consumption; instead it is used to produce protein-rich marine by-products, in excess of 6 MMT per annum (Table 1.4). Typical animal feed ingredients derived from marine origin include fishmeal, dried fish solubles, crab meal, shrimp meal, fish protein concentrate, and other fish by-products (Lefferts et al., 2006).

Finally, animal waste has also been used as a feed ingredient, including dried ruminant waste (manure), dried poultry waste, dried poultry litter, dried swine waste, undried processed animal waste products, and processed animal waste derivatives (Lefferts et al., 2006). According to the Association of American Feed Control Officials, in the United States, these processed animal waste products must be treated appropriately to ensure that the product is free of harmful pathogens, pesticide residues, parasites, heavy metals, or drug residues (Association of American Feed Control Officials, 2007). Although recycled animal wastes have been knowingly incorporated into animal feed for almost 50 years, the Food and Drug Administration does not endorse the use of recycled animal waste (Lefferts et al., 2006). Regardless, protein content in dried manure ranges from 12 to 18 wt.% for cattle, 28 to 48 wt.% for poultry, and 22 to 25 wt.% for pigs (Chen et al., 2003), making it another source of valuable protein and nutrients. Just as the sources of waste are diverse, so too are the wastes generated, each with a different chemical and physical makeup, directly affecting how they are best used (Table 1.5). Many studies focused on the valorization of these and
### TABLE 1.4  Typical Protein Content and US and Global Production Quantities in Million Metric Tons (MMTs) of Some Protein Meals Produced from the Agricultural Industry

| Protein meal        | Crude protein (%) | US production (MMTs) | Global production (MMTs) |
|---------------------|-------------------|----------------------|--------------------------|
| **PLANT PRODUCTS**  |                   |                      |                          |
| Alfalfa meal        | 19.2              | 0.513–1.91<sup>a</sup> |                          |
| Canola seed meal    | 37.8              | 1.07<sup>b</sup>     |                          |
| Castor seed cake    | 31–36             |                      |                          |
| Castor seed meal    | 20.8              |                      |                          |
| Corn gluten meal    | 53.9–65.0         | 5.9<sup>a</sup>      |                          |
| Cottonseed cake     | 21.1–57.3         |                      |                          |
| Cottonseed meal     | 34.3–44.9         | 0.82–1.09<sup>bc</sup> | 10.3–15.5<sup>ac</sup>  |
| Cow pea seed meal   | 32.7              |                      |                          |
| Linseed cake        | 34.7              |                      |                          |
| Linseed meal        | 32.6–35.4         | 0.142–0.147<sup>bc</sup> | 1.02<sup>a</sup> | |
| Peanut meal         | 51.8              | 0.12–0.159<sup>ac</sup> | 4.32–6.83<sup>bc</sup>  |
| Rapeseed cake       | 35.6              |                      |                          |
| Rapeseed meal       | 34.1–37.9         |                      | 39.2<sup>b</sup>       |
| Sesame seed cake    | 32.8              |                      |                          |
| Soybean cake        | 40.1–49.1         |                      |                          |
| Soybean meal        | 44.4–53.8         | 39.1<sup>b</sup>     | 200.8<sup>b</sup>       |
| Sunflower meal      | 28.4–42.0         | 0.23–0.29<sup>bc</sup> | 16.0<sup>b</sup>       |
| **ANIMAL PRODUCTS** |                   |                      |                          |
| Bloodmeal           | 80.2–100.5        |                      |                          |
| Feather meal        | 81.2–92           |                      | 0.63<sup>d</sup>       |
| Hydrolyzed feather meal | 49.5–59.4      | 1.8–2.1<sup>de</sup> |                          |
| Meat and bone meal  | 51.7–58.4         |                      | 2.4<sup>a</sup>        |

(Continued)
other waste streams in a profitable way. Obviously, for protein meals that can be fed to livestock or fish, the price for which they are sold will generally cover the cost of producing them, and in the case of ABPs, the revenue generates a reasonable profit. However, for inedible protein meals (including meals which either have no market or limited market access), adding value through conversion into novel products is of greater necessity. The problems with imparting additional value to these products is not necessarily related to the scientific or technological feasibility or even cost, but are most commonly associated with the perceived risks and often restrictive supporting legislation.

### 4 BIOSECURITY AND RISK GOVERNANCE

Every nation strives to maintain its biosecurity to protect its ecological and economic resources from disease and invasive pests. The most effective means of governing the risks posed by the importation of dangerous or questionable materials, and the harm they may cause to animals or humans, is to impose legal restrictions. The importance of maintaining biosecurity is most apparent when considering the risks of international trading. The introduction of invasive pests and disease through international trade could lead to adverse effects, not only on plant
## TABLE 1.5 Residues of Food Processing and By-Products

| Industry | Food processed                      | Residues and by-products                      | Products from by-products                      |
|----------|----------------------------------|---------------------------------------------|-----------------------------------------------|
| **PLANTS** | | | |
| Grain crops | Grain, flour, bread, biscuits, crackers, cakes, starch, bakery goods | Straw, stems, leaves, husks, cobs, hulls, fiber, bran, germ, gluten, steep liquor | Biomass for ethanol production |
| Fruits and vegetables | Tinned fruits and vegetables, juices, vegetable oils, starches, sugars | Rotten fruits and vegetables, stem waste, pits, seeds, peels, pulp | Pectin, pigments, sweeteners, antioxidants, essential oils, proteins, vitamins, sterols, ethanol, yeast, enzymes |
| Edible oils | Oils, hydrogenated fats | Press solids and oil cakes, oil water emulsions, rancid fats, shells of oilseeds | Biosurfactants |
| **ANIMALS** | | | |
| Fish and seafood | Canned fish, filleted fish, smoked fish, salted fish, processed crustaceans and mollusks | Scales, fins, bones, guts, fish oil and shells | Fishmeal, fish oil, polyunsaturated fatty acids, fish protein concentrate, hydrolysate, collagen, gelatine, chitin, chitosan, calcium carbonate |
| Meat | Processed meat and poultry products | Blood, hides, hair, heads, horns, hooves, offal, fat, meat trimmings, feathers, feet, giblets | Bloodmeal, meat meal, fat, feather meal, hydrolysate, bone meal, plasma, red blood cells, collagen, gelatine |

(Continued)
These measures must consider not only the scientific evidence supporting such a restriction, but must also consider any reasonable precautions that can act to offset any deficiencies in a solely scientific approach. Hence, during the development of a new policy, a risk analysis is first performed, followed by evaluation of that risk through the lens of current legal, institutional, social, and economic circumstances, all of which is undertaken by the stakeholders who represent them (Mills et al., 2011). As such, risk governance deals with the management of both perceived and scientifically founded risks.

Although risk management implemented through public policy is focused at the national level, many food and natural resource policies operate at levels both below and beyond the national level (Mills et al., 2011). However, as a result of the discrepancies between each state’s local policy making and a lack of cohesive global regulations, the intersection between risk and commerce continues to be a major challenge facing the international trading system.

A significant amount of trade conflict experienced at the World Trade Organization has involved the United States, Canada, and/or the European Union (Hornsby, 2013). Some topics that became the focus of either formal or informal disputes have included hormone-fed beef, bovine spongiform encephalopathy (BSE), raw milk cheese, genetically modified organisms, chlorine-washed chicken, and wood packing materials. Such disputes imply the presence of a transatlantic divide over what constitutes a legitimate risk regulation, however, this is an oversimplification. Although the risk regulations set forth by the European Union take a precautionary approach, acting in light of scientific uncertainty and taking into account public concerns, the US system is based on a “sound science” approach, free from political influence, however, this has not always been the case. It has been argued that the United States used to be more precautionary than the European Union (Hornsby, 2013), but was pressured to limit the calculation of risk in public policy. The EU’s regulatory failures during food safety crises served to undermine public trust in the EU institutions, resulting in the use of a precautionary approach (Hornsby, 2013). Overall, it has also been proposed that both regions partake in “occasional and selective application of precaution to different risks in different places and time” (Wiener, 2011). Nevertheless, there are some consistencies around the world regarding the safe handling, distribution, and disposal of food, animal wastes, and by-products.
5 POLICY REGARDING PLANT AND ANIMAL BY-PRODUCTS

The degree to which protein by-products, particularly ABPs, can be used is limited by the customs, religions, and regulatory requirements of the region. All feedstuffs imported into a country must comply with rules regarding hygiene, traceability, contaminants, labeling requirements, and health issues given its expected use. The use of the product is then subject to more specific rules, largely limiting the use of those feedstuffs containing animal-derived products. The first diagnosis of BSE in the United Kingdom in 1986 and the subsequent publication in 1996 that new variant Creutzfeldt–Jakob disease in humans had most probably arisen from exposure to BSE-infected meat, sparked a global crisis with respect to food safety and risk management.

Up until the outbreak of BSE during the 1980s, almost all protein by-products were used as feed supplements for livestock. In 1989, the practice of feeding ruminant animal protein meals to other ruminants was banned, along with the use of specified bovine offal (brain, spinal cord, other organs potentially infected with BSE) (Ockerman and Hansen, 2000). More recent infectious disease outbreaks, such as avian influenza and severe acute respiratory syndrome, have further jeopardized diplomatic relations, frightened the public, and caused massive economic losses by disrupting global commerce (Karesh and Cook, 2005). Since then, concern over the risks posed by ABPs, including infectious diseases (such as swine fever, foot and mouth) and other contaminants (such as dioxins), to human and animal health, has resulted in strict regulations regarding their safe handling and disposal (Cunningham, 2003; Department for Environment Food and Rural Affairs, 2011). As such, most countries now have local regulations put in place that are typically broad in scope and directly affect any person or business that generates, uses, disposes, stores, handles, or transports food waste containing animal products and ABPs derived from the food processing industry.

Currently, most countries no longer allow animal by-product meals containing any amount of ruminant tissue to be fed to other ruminant animals, although meat and bone meals containing ruminant tissue are still able to be fed to nonruminant animals, such as poultry, swine, pets, and aquaculture species in most countries, including New Zealand (Garcia and Phillips, 2009). To the contrary, throughout the European Union, meat and bone meals are banned from the feed of any animal that may become human food, and as a result, in the European Union, meat meal and meat and bone meal are primarily incinerated or used as an ingredient in pet food (Kirchmayr et al., 2007).

In most countries, legislation for waste disposal and disposal of dead animals and of slaughterhouse materials (animal rendering) is already in place. In Germany, the Animal Disease Act, the Meat Hygiene Act, the Poultry Meat Act, and the Meat Hygiene Ordinance also regulate the disposal of slaughterhouse offal. To protect animal and human health, the Canadian Food Inspection Agency (CFIA) enforces federal regulations governing the production and use of rendered materials that may be used in animal feed. However, a policy established by the National Renderers Association, which prevented ovine material (sheep) from being used in meat and bone meals in the United States and Canada, and has been withdrawn (Malone, 2005).

Compared to Canadian and US policy, the framework of the EU regulations regarding ABPs and derived products is complex, resulting from ongoing reviews by the EU Commission. Each updated regulation is a result of the successive amendment to the initial Regulation (EC) 1774/2002, most recently amended with (EU) No. 749/2011. The regulation covers the safe disposal
options available for all animal products, including meat, fish, milk, and eggs not intended for human consumption, and other products of animal origin, including hides, feathers, wool, bones, horns, and hooves. It also prohibits catering waste being used as livestock feed and covers disposal of fallen stock, companion animals, and wild animals if they are suspected of being diseased. The regulations also control the use of ABPs as feed, fertilizer, and technical products with rules for their transformation via composting and biogas operations and their disposal via rendering and incineration (Department for Environment Food and Rural Affairs, 2011).

6 CURRENT MANAGEMENT OPTIONS

When looking at the existing options available for management of these by-products (and/or wastes), both legal regulations and the best ecological and economical solutions need to be considered. Whether a material is deemed to be a valuable by-product (or a waste that needs to be disposed of) depends on the social, legal, and technological framework surrounding its origin. From there, the most sensible form of management becomes a compromise between what is viewed as acceptable, based on legal requirements and local perceptions, and what is technologically and financially feasible (Fig. 1.3).

Although it is most desirable to prevent waste and by-product formation, followed by reuse or recycling into other product lines, the formation of by-products and waste is inevitable, and management options must be innovative and also meet local regulatory requirements. Waste management is then possible through several media: to use it in its current form, dispose of it through incineration or landfill, or add value to it through bioprocessing or valorization technologies (Fig. 1.4). The choice of media used will largely depend on the cost, customs, and regulatory environment. For example, converting the by-product to animal fodder (bioreduction) may not be feasible in all countries.

Excess and waste food has been used as animal fodder for centuries, and in many parts of the world, farmers still use waste food to feed their animals—primarily pigs and poultry. The practice of feeding waste material containing meat products to pigs was banned in the United Kingdom in 2001 (Statutory Instrument 2001, No. 1704 The Animal By-products Amendment) to prevent further spread of BSE, and soon after, a new regulation was implemented throughout the European Union (The Animal By-Products Regulation, EC No: 1774/2002) prohibiting catering waste from being fed to farmed animals. This includes all waste food and used cooking oils, as well as waste from vegetarian restaurants and kitchens. Based on these laws, only certain types of waste food can be given to livestock and must first be treated appropriately.

If the by-product cannot be immediately used as it is or treated appropriately for use as an animal feed, it must be safely disposed of.
Because of the time and expense of treating these food wastes, most end up in landfill. Currently, landfilling and incineration account for the treatment of greater than 95% of food waste in most European countries (Melikoglu et al., 2013). In general, using the biomass waste in the form it is in, either as an animal feed or fertilizer or as a fuel to generate electricity, is the most simplistic approach and generates a value of \( \sim \) US$70–200 per metric ton of biomass (Tuck et al., 2012).

### 6.1 Incineration

Incineration is the simplest means of waste disposal, with its major advantage being the significant reduction in volume of the waste stream, which is up to 90% for waste streams with high amounts of paper, cardboard, plastics, and horticultural waste (Hoornweg and Bhada-Tata, 2012). However, most food wastes are not appropriate for incineration, owing to their high moisture content. When properly equipped, an incinerator can be used as a means of energy recovery to generate electricity. Heat released from the combustion of waste can be used to produce steam, which can turn a steam turbine, generating electricity. However, because of the increased concentration of toxins in the ash, incinerators must be operated alongside landfill systems in order to dispose of them. Combustion destroys chemical compounds and disease-causing bacteria, leaving it pathogen free, but causes serious environmental problems through the production of carbon dioxide, nitrogen oxides, sulfur dioxide, and trace quantities of toxic pollutants, such as heavy metals and dioxins. The remaining residues are often landfilled, owing to their high heavy metal content.

### 6.2 Pyrolysis and Gasification

Thermochemical conversion of food and industry wastes are an effective means of converting energy-rich biomass into a more easily used...
liquid or gaseous intermediate. High temperatures can be used with minimal (gasification) or no oxygen present (pyrolysis) to break down hydrocarbon containing wastes, resulting in combustible syngas mixtures, containing carbon monoxide and hydrogen (85%), with small amounts of carbon dioxide and methane. This syngas intermediate can be further processed to produce bio-based gasoline, diesel, or jet fuel, or be used in a fuel cell to generate electricity or steam.

6.3 Landfilling

Landfills—burying the material—are a common final disposal site for waste and the residues remaining from other treatment options. At atmospheric pressure, 1 metric ton of organic material generates approximately 200–500 m$^3$ of landfill gas over a 10–20 year timeframe (Jardine et al., 2004), comprised of 60–65% methane and 35–40% carbon dioxide, which represents around 8% of the anthropogenic methane (CH$_4$) emitted worldwide (Melikoglu et al., 2013). Methane has 21 times the global warming potential of carbon dioxide and can be recovered and burned (with or without energy recovery) to reduce greenhouse gas emissions (Hoornweg and Bhada-Tata, 2012). Other serious environmental implications of landfilling include the risk of leachate (potential toxic liquid that drains from landfills) entering surrounding soils and groundwater.

Although the use of landfills is common, their use has been discouraged through the implementation of landfill taxes and directives, such as the UK “Landfill Tax” in 1996 and EU Landfill Directive established in 1999 (Jardine et al., 2004). Obviously, other disposal options are preferred to landfilling, which costs $\sim$US$400 per metric ton.

6.4 Bioprocessing

Around 60% of the municipal waste sent to landfill is biodegradable and mostly comprised of food waste (Hoornweg and Bhada-Tata, 2012). This makes bioprocessing, such as composting and anaerobic digestion, sensible options for disposing of these organic waste streams.

A common means of obtaining a safe end product is achieved through composting. This involves a combination of chemical and micro-biological processes occurring throughout three stages that convert organic materials to a stable, soil-like product called compost (Som et al., 2009; Verbeek et al., 2012). Provided composting is carried out well, the volume and mass of the waste can be reduced by up to 40%. For composting to occur efficiently, the conditions of the composting process must be maintained at an optimal level to encourage microbial growth. Because of changes in the composition of waste material with location and over time, the compost mixture needs optimization through regular adjustments. For example, if the system becomes anaerobic, offensive odors can be produced, and if it becomes too wet or too dry, the process will halt altogether. Some of these organic waste materials require specific pretreatment before composting can occur. In the United Kingdom, EU standards must be implemented over and above UK standards if the site treats category 2 ABPs, which have first been pressure rendered, or category 3 ABPs if they exclude catering waste. Exceptions apply for some types of ABPs in the United Kingdom, which can be composted in closed reactors at 70°C for more than 1 h or in housed rows of piled green-waste (windrows) at 60°C for more than 8 days under strict operating parameters with a maximum particle size of 400 mm.

Although compost is of limited value, it is still a more economic option compared to landfilling. Other bioprocesses can be employed that produce more valuable products. Biofuels can be produced using fermentation, valued at US$ 200–400 per metric ton more than the initial biomass waste (Tuck et al., 2012). Anaerobic digestion is another means of disposing of organic waste materials and is carried out in an enclosed vessel. The methane generated can either be flared or collected for combustion to generate heat and/or electricity, which also adds value to the waste biomass.
The maximum value can be recovered from these waste materials by converting them into more purified streams and using them in the manufacture of lubricants, surfactants, plastics, fibers, and industrial solvents. Theoretically, all ABPs in the European Union could be combusted as fuel for energy, provided the EU Commission formulates the appropriate rules and regulations, which as of yet has not been done.

Although there are many technologies currently available (or in developmental stages) that aim to valorize by-products of industry, legislation has yet to be passed that explicitly deals with higher technology outcomes. Most current law deals with the safe handling and disposal of animals, their products, and by-products and animal feeding. Although it is necessary to contain health and environmental risks through appropriate legislation, it is becoming apparent that the use of ABPs and food wastes (excluding crop residues and some agro-industrial by-products) for animal fodder and composting is not only obsolete, but in many nations, illegal.

7 VALUE ADDITION

Many technologies exist that aim to valorize by-products of the agricultural industry. Although the edible portion of these protein-rich by-products could be used for recovery of essential amino acids for human consumption, or as is for use in animal feeds, higher value applications for inedible and nonessential amino acids may include providing a feedstock for protein-based materials, such as plastics, and for the production of biopesticides and commodity organic compounds (Naik et al., 2010; Scott et al., 2007).

Along with more obvious uses of protein hydrolysates—animal feeds and biomass for energy recovery—protein-based meals from crop residues and agro-industrial by-products also find value addition through use in biological processes. An example is the use of various oilseed cakes, which have been shown to be ideal mediums for many types of bacteria and fungi responsible for producing a variety of enzymes, antibiotic and antimicrobial compounds, and bioactive metabolites (Ramachandran et al., 2007). Protein-based raw materials can be used for the production of 1,2-ethanedi-amine and 1,4-butanediamine from the amino acids serine and arginine, respectively (Sanders et al., 2007). Furthermore, protein-based surfactants are valuable mild surfactants, because the structure and properties of the amino acids in the surfactants are similar to the amino acids that make up the tissue of skin.

If valorization technologies are to be implemented on a commercial scale, they must work within current legal constructs. However, this does not deal directly with the science involved and may inhibit progress if new legislation is not developed that more closely examines the evidence and whether risk regarding human and animal health is still an issue. In light of current legislation and potential markets for value-added commodities, it is becoming apparent that the use of protein-rich agricultural by-products for lower value applications, such as animal fodder, is no longer a sensible use of such a valuable resource.

LIST OF ABBREVIATIONS

| Abbreviation | Description |
|--------------|-------------|
| ABP          | Animal by-product |
| BSE          | Bovine spongiform encephalopathy |
| CFIA         | Canadian Food Inspection Agency |
| EC           | European Commission |
| EU           | European Union |
| UK           | United Kingdom |
| US           | United States |

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I. GENERAL INTRODUCTION
I. PRODUCTION STATISTICS, LEGISLATIVE RESTRICTIONS, AND MANAGEMENT OPTIONS

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