The concept of Zero Waste

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Chapter Outline

13.1 Introduction and background

In the early 1970s, a chemist, Paul Palmer, PhD, founded Zero Waste Systems (ZWS) Inc. (Palmer, n.d.). ZWS was a small company formed by Dr. Palmer and other chemists and drivers who traveled around the Bay Area, including the nascent Silicon Valley, collecting chemicals associated with electronics manufacturing, for example, acids, solvent mixtures, copper-rich etchant fluids, and finding other businesses that could utilize these materials as inputs (Palmer, n.d.). In the pursuant 40 + years, Zero Waste (ZW) has evolved and grown in a number of directions, but its core idea persists to this day: to render, fundamentally and systematically, the very notion of waste as obsolete.

The concept of ZW represents a paradigm shift that encourages a complete rethinking of current systems. According to the ZW International Alliance, "Zero waste means designing and managing products and processes to systematically avoid and eliminate the volume and toxicity of waste and materials, conserve and recover all resources, and not burn or bury them" (ZWIA, 2009). ZW challenges humanity to close materials loops such that no waste is generated during the production or

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consumption of any product or service. As a result, “Implementing ZW will eliminate all discharges to land, water or air that are a threat to planetary, human, animal or plant health” (ZWIA, 2009). Grounded in ecological theory, ZW calls upon humans “to emulate natural cycles, where all discarded materials are designed to become resources for others to use” (ZWIA, 2009). This concept is thus intended to inspire creative design innovations not simply at the waste management stage, but throughout every stage of production and consumption (Zaman, 2015).

Numerous institutions, municipalities, and governances have set ambitious ZW goals. Food waste (FW) is often a particular target as it is typically a large portion of the nonrecyclable municipal solid waste stream (Kim et al., 2011; EPA, 2014). The European Union adopted a set of waste reduction, recycling, and landfill diversion goals under the Circular Economy Package, including a goal to halve food waste by 2030 and to reduce disposal of municipal waste, including food, to a maximum of 10% by 2030 (EC, 2015). Landfilling of FW was banned in Korea in 2005 (Kim et al., 2011) and New York City has set a goal of achieving ZW for landfills by 2030, and is rolling out numerous campaigns to capture FW in particular (OneNYC, n.d.). To develop infrastructure capacity to manage all of the FW NYC is rolling out residential and commercial collections and treatment programs. As of 2017, NYC was collecting organics from one million residents (Balkan, 2017). In particular, a 2013 NYC law required some commercial businesses generating FW to divert their organics, starting with foodservice in hotels with 150 or more rooms, food manufacturers with greater than 25,000 ft^2, food wholesalers with greater than 20,000 ft^2, and stadiums and arenas with 15,000 seats or more (Balkan, 2017; The NYC Council, 2013). Similarly, the state of California passed Mandatory Commercial Organics Recycling legislation in October of 2014, which requires businesses generating more than 8 cubic yards (cy) of organic waste to recycle it on or after April 1, 2016, with a progressive inclusion of organic waste generating businesses to 2 cy by 2021 (California, 2017). An interactive database (maintained by ReFED, a multistakeholder nonprofit collectively dedicated to reducing US FW) is available for researching recent policies related to FW across the United States (ReFED, 2018)

ZW goals have also proved popular among sporting event venues, particularly in colleges and universities (NRDC, 2013). In practice, however, many such venues have operationalized ZW as diverting 90% of event-generated waste from entering landfills. Additionally, among such venues, recycling and composting still remain the most prevalent options for managing diverted waste. Beyond waste diversion, there are currently no requirements in place to delimit usage of the term ZW, and some, including this author, have criticized this laxity and have called for more stringent requirements given the robust standards of ZW philosophy (Costello et al., 2017). In addition to developing the infrastructure to divert waste, use of the term ZW should require a systematic evaluation of materials entering a facility and waste management options using clear metrics to define improved performance. Examples of environmental considerations could include greenhouse gas emissions (GHGs), energy use, nutrient recovery, and social impacts, for example, employment opportunities or disproportionate risk exposure. Importantly, not limiting the inquiry to waste management allows for more proactive options, for example, reducing the types of packaging materials to only those that are recyclable or compostable to increase the probability of fans properly sorting wastes (NRDC, 2013). Costello et al. found that FW was the largest portion of the waste stream during an audit at a college football stadium and that mitigating FW would result in the greatest GHG and energy savings over a range of management options including composting (2017). Management were averse to exploring strategies that would risk running out of food for customers, particularly those seated in the catered boxed seating areas. This reflects an ethos in hospitality management that should be explored more deeply.

Perishable organic materials, such as food, present unique considerations and challenges for ZW thinking, which was originally conceived for the management of chemicals and other materials that could be safely stored for long periods of time without changing form. Perishable organic materials undergo various biogeochemical transformations due to their perishable nature, or within the human body if they are consumed. As a result, the goals of ZW—such as closing materials loops, avoiding or eliminating volume or toxicity, and conserving or recovering resources from these materials flows through society—require a different set of strategies. The existing food production systems impose numerous constraints that are far more challenging than the relatively simple task of separating organic materials from a waste stream to prevent their deposition into a landfill. To truly eliminate FW could require reimagining the basic tenets of the hospitality industry, how residential communities are designed, the distance between croplands and animal production facilities, and the expectation that food will always be plentiful and cheap, as just a few potential examples.

One promising approach for accomplishing this kind of systematic evaluation is life cycle thinking, formalized through life cycle assessment (LCA) (International Standards Organization, 2006). LCA and ZW have similar motivations, which are to holistically and systematically account for the impacts of producing a good or service. LCA is an analytical approach for quantifying the material and energetic flows associated with a product, process, or service over its entire supply chain. This allows for the identification of the most resource-intensive or impactful portions of the supply chain to be identified as targets for improvement. That is, the materials and energy along with the corresponding environmental or social impacts associated with a product are considered in the analysis.

For example, food products typically begin with using diesel-powered machinery to prepare soils, plant seeds, and apply pesticides and fertilizers. Combustion of fossil fuels results in the release of a myriad of molecules, for example, CO_2, nitrous oxides, particulate matter, to the atmosphere that have varying environmental and human health impacts (Union of Concerned Scientists, 2016). In addition, the application of nitrogenous fertilizers to agricultural soils are the leading source of GHGs in the agriculture sector (EPA, 2018) and together with phosphorous are the leading cause of eutrophication in waterbodies (Committee on Environment and Natural Resources, 2010; Dodds et al., 2009). Once applied reactive nitrogen (e.g., anhydrous ammonia, urea) begins to undergo a process called denitrification, a series of biogeochemical reactions involving nitrogen to return to its most stable form, N_2; along this path nitrous oxide forms (N_2O) and is released to the atmosphere. N_2O is a GHG that traps ~300 times more heat than a molecule of carbon dioxide CO_2 (EPA, 2018). Following harvest, which, again requires machinery, agricultural products are then transported using diesel- or gasoline-powered vehicles, processed using machinery, and packaged in plastics made of fossil fuels. Foods are distributed to retail stores, purchased by people who take them to their refrigerators and eventually prepare foods on a stove using electricity or natural gas and, finally if any food is not consumed they are disposed using a waste management technology. In theory all of these processes, including materials and energy associated with mining fossil fuels, are included in the LCA of a food product, though in many cases retail, cooking, and waste disposal are not included (de Vries and de Boer, 2010; González et al., 2011). From a life cycle thinking perspective, when food is wasted, all of these upstream inputs and impacts are wasted as well. Thus far, LCA studies on FW management identify source reduction as the most beneficial option by far (Hamilton et al., 2015), followed by wet then dry animal feed (Kim et al., 2011). Consideration of the entire supply chain can encourage more creative solutions to reduce impact than focusing on waste management alone. In this chapter, a life cycle thinking perspective will be employed wherever possible.

To illustrate difference between perishable organic (i.e., carbon-based biologically derived materials) and nonorganic (i.e., metals) or relatively stable organics (i.e., petroleum-based materials and synthetic chemicals) with regard to ZW, imagine the recovery and recycling of aluminum. Aluminum does not change in form over the course of its supply chain; it may go from ingots to rolled sheets to individual beverage cans, but the material itself is not fundamentally changed. At the end of its useful life aluminum materials can be baled and sit for long periods of time while waiting to be melted down and returned to a useful purpose, perhaps another beverage can. There are numerous upstream uses of energy for mining and smelting resulting in various environmental and human health impacts, but the refined aluminum is stable and truly recyclable. Further, recycling aluminum uses far less energy and materials than virgin aluminum so the advantage is very clear (EPA, 2015).

Now imagine a tomato, plucked from a plant—likely still green, packed into a box, loaded into a truck bed and then onto a rail car, which may or may not have climate control features. Upon arrival into a distribution center, the tomato—perhaps starting to turn red and beginning to soften—is loaded onto a tractor trailer, driven to a grocery store, unpacked—perhaps a few have gotten too soft or have a mold spot and are discarded—and arranged onto a shelf where discerning customers select for the qualities that they have been told indicate a delicious and safe tomato, then the customer transports this tomato to their home to their counter or refrigerator for later consumption. The consumer had imagined using the tomato in a salad to accompany dinner on a Wednesday evening, but on Wednesday morning something came up at work and she ended up grabbing a sandwich from a nearby shop so she could stay until well past dinner. Thursday her boss asked her to go to dinner with a client and by the time she's thought about the tomato again on Saturday it has a mold spot and she's afraid to eat it. Now there is a decision about what to do with this tomato. If the consumer is aware that the tomato is safe to eat, she may simply cut off the molded portion, greatly reducing the volume of food to be managed as waste. In either case, some or all of the tomato must now be managed as a waste.

Waste management options offer different abilities for recovering or recycling the resources embodied in them, particularly when we take a life cycle perspective. But, complete recycling is not entirely possible as the molecular composition of foods are changing in real time. While it is true that some nutrients, such as nitrogen (N), phosphorous (P), minerals, and carbon may be reintroduced to soils to both improve soil health and grow new foods, it is very rare, and sometimes energetically disadvantageous, to return these components of a food to the field from whence they came given that the distance can be hundreds of miles, for example, the distance from New York City to Des Moines, Iowa is about 1100 miles. Further, the amount of material and energy that can be recovered pales in comparison to the upstream input of materials and energy associated with producing the food item (Hamilton et al., 2015). And, finally, it is unclear whether it is physically possible given the geography of lands for cultivation in relation to population centers to produce sufficient human nutrition through the "localization" of food production, at least with the foods, and rates of consumption of those foods, that currently comprise the American diet (Zumkehr and Campbell, 2015; Peters et al., 2009; Dunbar et al., 2016).

13.2 A brief overview of the US agricultural system

To begin to consider the challenges of managing FW so as to close materials flow loops it is important to have a sense of the vast nature of the agricultural system in relation to populations of human and animals in the United States today. In press and conversation about FW management, people will often refer to the benefits of placing composted materials back onto land to recycle nutrients and add carbon back to the soil. Indeed, in an ideal situation, vegetative crops would be grown, fed to people and/or animals, animals would then eaten by people, and in a very progressive system the manure from animals, including humans, would then be composted to remove pathogens and applied to fields to grow more vegetative crops to continue this cycle. In this scenario the materials loop is closed. In the slightly more realistic, but still idealistic scenario, FW and losses would be fed to animals and the manure would again be composted and applied to fields.

The current US agricultural system includes numerous existing geographical constraints that make closing nutrient loops largely impossible. Recovering and transporting nutrients hundreds of miles—back to the fields from which they were taken up by plants and introduced to our food system—is difficult to make economical (Araji et al., 2001) and would almost certainly result in positive net energy and GHG emissions. The US agricultural sector is enormous in the amount of land that it occupies, resources that it consumes, and money that it generates. It is a system that supports ever-expanding urban populations domestically and abroad. The majority of people in the United States live in urban areas and the most populous areas are coastal states. In 2016 Census Bureau Director John H. Thompson stated that "Rural areas cover 97 percent (%) of the nation's land area but contain 19.3% of the population, about 60 million people" (US Census Bureau, 2016). The majority of crop production occurs in interior states and the majority of animal production is highly centralized, often distant from crop fields (Gollehon et al., 2001). The majority of chicken production occurs in the Southeastern states, pigs in the upper Midwest, and cattle in the Midwest and Western Plains states (USDA, 2017). Finally, even if it were possible to return recovered nutrients to the fields in which they were taken up by crops and eventually embodied in foods, the excess nutrients that runoff into the nation's waterways far exceed that which can be recovered through any waste management approach (Steffen et al., 2015; Galloway et al., 2008). It is a debatable question whether these production concerns should be considered within the context of Zero FW, but it is certainly a worthwhile and necessary conversation to be had.

To further illustrate the scale and geography of the US food system and, in particular, the role of commodity crops, that is, corn, soy, wheat, some statistics regarding the land occupation of major crops are provided. In 2017, the major commodity crops planted covered 243,720,000 acres (986,300 km^2) and 203,413,000 acres (823,180 km^2) or 83.5% of the total were located in the Midwest, Northern Plains, and Southern Plains (USDA, 2018). The majority of these crops are consumed in coastal locations where populations are more dense (Hong et al., 2013). The major commodity crops include corn, soybeans, wheat, cotton, oats, barley, rice, sorghum, sugar beets, and sugar cane. Vegetable production occupied 4,492,100 acres (18,180 km^2), fruit production occupied 3,086,900 acres (12,490 km^2), and nut production occupied 2,112,870 acres (8550 km^2) (USDA, 2012 Census Volume 1, Chapter 1: U.S. National Level Data, 2012), or relatively much less land area. Fruits and vegetables utilize less fertilizer input as well. Commodity crops are responsible for the majority of fertilizer inputs to produce the grains and oilseeds that are the starting point for the majority of the foods that we eat, either in processed forms (e.g., breakfast cereals, snack foods, pasta, bread, etc.) or are fed to animals to ultimately be consumed by humans. Humans are more likely to be located in a coastal state, so there is a direct flow of materials from the interior states to the coastal states. There are both real flows, that is, the foods themselves contain nitrogen that is physically transported, and virtual flows, that is, one can take the stance that the fertilizers applied in the interior states occur due to the demand by those living in coastal states (Zhang et al., 2018; Mekonnen and Hoekstra, 2011).

Another complexity introduced by feeding FW directly to animals or reintegrating compost or biosolids to agricultural soils is that, firstly, transporting material comprised of largely of water is energetically costly (Araji et al., 2001) and, secondly, existing agricultural operations, including equipment and labor practices, are not aligned with spreading solid materials. The majority of crops are fertilized using equipment that is designed for gaseous and fluid liquids, not solids. Options are then to change equipment or to use additional treatment technology to consolidate nutrients from the waste streams (Zeng et al., 2006; Yoshino et al., 2003). Additional discussion of utilizing FW as animal feed and options for recovering and utilizing nutrients is presented below.

13.3 Definitions of food waste

Prior to a brief discussion of options within each tier of the hierarchy, it will be necessary to provide some definitions of terms that will be used to characterize FW. Clarity about these terms is important for considering management options, though there remains a great deal of inconsistency (Jakobsen et al., 2016). Many authors and agencies, including the Food and Agriculture Organization, differentiate between food losses and FW. Food loss is define by the FAO as "the decrease in quantity or quality of food" (Food and Agriculture Organization of the United Nations, 2014). FW is considered a part of food loss and refers to "discarding or alternative (nonfood) use of food that is safe and nutritious for human consumption along the entire food supply chain, from primary production to end household consumer level" (Food and Agriculture Organization of the United Nations, 2014). A recent European project, Fusions, proposed the following definition, "Food waste is any food, and inedible parts of food, removed from the food supply chain to be recovered or disposed (including composted, crops ploughed in/not harvested, anaerobic digestion, bio-energy production, co-generation, incineration, disposal to sewer, landfill or discarded to sea)" (FUSIONS, 2016). Finally, the USDA's Economic Research Service defines food loss as "the edible amount of food, postharvest, that is available for human consumption but is not consumed for any reason" (USDA-ERS, n.d.). In relation to the US FW Challenge, launched on September 16, 2015, a general term of "food loss and waste" was adopted to describe reductions in edible food mass anywhere along the supply chain, though in some instances of food recycling "waste" is stretched to include nonedible parts of food, that is, shells, banana peels, bones (USDA ERS, n.d.).

As can be seen above, distinctions are sometimes drawn regarding whether the food materials are edible to humans or not. Many foods have portions that are typically not considered to be edible, for example, peels, skins, and bones; these portions of food are inedible FW, and also sometimes categorized as unavoidable (Costello et al., 2016; Parfitt et al., 2010). Edible food losses and waste are typically considered avoidable (Parfitt et al., 2010). There is debate about whether foods that have rotted should be considered inedible; in this chapter these foods will be considered edible based on the assertion that these organics could have been consumed or preserved for later consumption. These definitions are made to generate policy and management interventions, which vary along the food supply chain. Definitions are often helpful from the technical perspective as well as a management or treatment technology will differ for many tons of only bones versus collecting and treating FW generated at the household level.

The point at which a food is lost or wasted along the supply chain also has important implications for waste mitigation and management. Indeed, much of the organic materials derived from agricultural products or commodities (i.e., major staple grains and animal carcasses) during food processing supply chains are utilized in secondary markets, for example, offal is utilized in pet food manufacturing, animal bones can be used as fertilizers, and fruit and vegetable losses or wastes hold promise for the production of a variety of valuable materials and chemicals (Galanakis, 2012). Stages of a typical food supply chain, adapted from Parfitt et al. (2010), include:

1. Harvesting and collection from the field: losses occur due to rodents, insects, poor agricultural techniques. Loss reduction is aligned with pest management and optimization of agricultural equipment.
2. Drying: transport and distribution of grains and oilseeds—it is important that harvested grains and oilseeds be properly dried before storage and distribution to avoid spoilage.
3. Storage: lack of infrastructure for storage leading to losses due to pests, disease, spillage, contamination. In developed nations this and the previous two stages are highly studied, infrastructure is quite good, and losses are minimal. In developing nations these stages account for considerable losses of nutritious organic material.
4. Primary processing: cleaning, classification, dehulling (for grains), pounding, grinding, packaging, soaking, drying, sieving, milling. This is the stage in which bulk grains and oils seeds are processed into flours and other feedstocks for food manufacturing. Losses occur due to contamination or poor facilities. In some cases, by-products are recovered and sold into animal food markets.
5. Secondary processing: mixing, cooking, frying, molding, cutting, extrusion, that is, the production of many of the foods found in stores today, for example, breakfast cereals, snack foods, chicken nuggets. Again, losses can occur due to production malfunctions and by-products may be utilized in other markets.
6. Product evaluation: products may not meet company specifications for quality and thus are not allowed to enter the market.
7. Packaging: Losses may occur due to packaging damaging the foods or being insufficient in protection against pests such as rodents or insects.
8. Marketing: publicity, selling, distribution—losses may occur during transport due to insufficient temperature control or protection. If a product is not successfully marketed and consumers are not interested it may expire on the shelves.
9. Preparation: Inedible portions of foods, spoiled foods generated in kitchens that serve food to people generate a relatively pure stream of organic waste to be managed.
10. Postconsumer: Food that is discarded after being purchased or prepared by an individual consumer. This is the area that attracts the most attention and is perhaps the most challenging to manage with regard to final treatment as it is generated by the hands of many, many people thus increasing the risk of contamination with nonorganic or other toxic organic materials.

13.4 The hierarchy of options for managing food losses and wastes

The Environmental Protection Agency has developed a Food Recovery Hierarchy to demonstrate the preferential order for FW management; see Fig. 13.1. The EU and ReFED have also adopted this order of preferential treatment options. ReFED

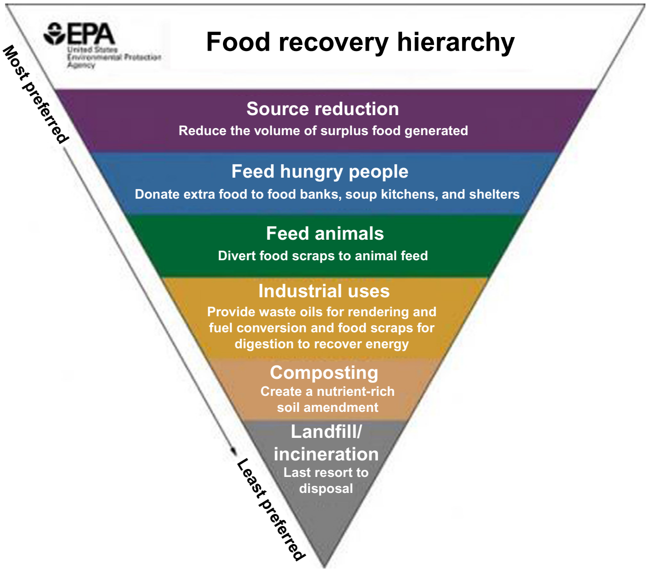

Figure 13.1 Prioritization order for FW management according to Environmental Protection Agency.

has estimated the economic values of implemented a variety of FW abatement options and the results confirm that the largest potential for economic savings lies in prevention efforts, followed by recycling efforts; see Fig. 13.2. This section will explore each of these tiers of the hierarchy in relation to ZW and life cycle thinking. Sensibly, the most preferred option, and often the most difficult to implement, is Source Reduction, that is, to avoid wasting food in the first place. Pursuit of this option typically involves behavioral or cultural change. The second option in the hierarchy is to Feed Hungry People, which requires that the food be edible and that a distribution network exists. The third option is to Feed Animals, in megaregions, such as the Northeast Corridor the proximity of majority of animal production is quite distant from this supply of FW; further, the methods employed by the vast majority of animal food production in the United States does not align with the wet, heterogeneous FW stream. To be utilized in the most prevalent swine operations the FW must be processed to reduce risks to the health of animals and dried into pellet form. The fourth option, Industrial Uses, includes anaerobic digestion (AD) and industrial uses of fats, oils, and grease. This would also include processes that generate value-added materials from FW streams. These options employ FW to generate energy through methane or through use as biodiesel. Food is generally not digestible on its own; human or animal manures are a common option for successful codigestion (Chen et al., 2008). In some cases, a municipal wastewater treatment plant may have sufficient capacity to accept FW. The fifth option down the hierarchy, despite its popularity, is aerobic composting. And, finally, congruent with ZW philosophy, landfill or incineration is the last option in the hierarchy.

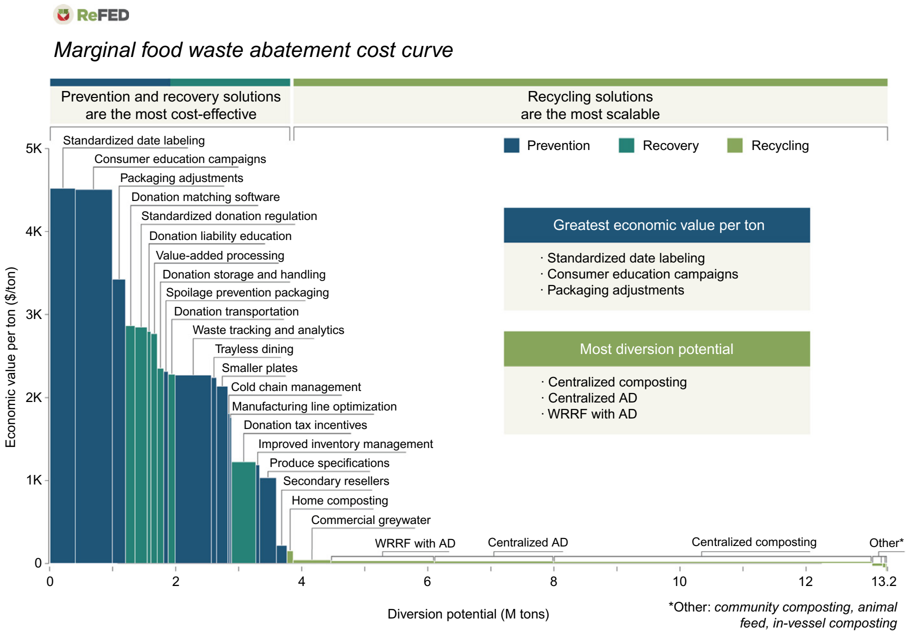

Figure 13.2 Marginal waste abatement curve (Cochran et al., 2018).

13.4.1 Source reduction

Not wasting food at all will have the greatest environmental and materials use benefits (Jakobsen et al., 2016; Hamilton et al., 2015). Strategies and definitions of source reduction depend on the stage in the food supply chain under consideration and are also tied to definitions of FW. If "food" is understood as being edible to humans, then many by-products generated during food processing, for example, peels, trimmings, bones, or recalled food items may not be eligible for source reduction, but may still be utilized to recover materials (e.g., bones used as fertilizer) or energy (e.g., vegetable by-products used as feedstock in an anaerobic digester).

In developed nations there is considerable research, effort, and infrastructure to mitigate losses in the first four stages of the food supply chain and thus loss rates for most grains and oilseeds are fairly small, for example, barley losses are estimated to be less than 3%, while loss rates for fruits and vegetables can be considerably higher ranging from 2% to 23%, average 12%, depending on the type (Parfitt et al., 2010). As will be described below, the potential for capturing food losses or wastes to feed animals, create value-added products, or to produce energy from losses or waste at stages 5 and 9 are much greater than in stages 8—10. This is due to the relative homogeneity, greatly reduced risk of contamination with nonedible materials, and scheduled, larger-in-volume and consistent production rates compared to consumer-generated waste streams. And, similar to stages 1—4 there is already more effort and research to capture these materials than in the consumer waste streams. For these reasons, the remainder of this section will focus more on the research and challenges associated with source reduction in homes, restaurants, and other food-service institutions, like cafeterias, buffets, and stadiums. In many municipalities, FW is the largest category by weight in the waste stream and is thus a good target for reducing waste that is to be managed by a municipality (Zacho and Mosgaard, 2016).

13.4.1.1 Food waste reduction in households

A great deal of the discussion around FW reduction has centered on individual behavioral change. Suggestions for reducing FW include outreach efforts to inform consumers about product expiration dates (Abeliotis et al., 2014) and “ugly” fruits and vegetables and the environmental, social, and personal economic benefits of FW reduction. Other suggestions include offering specific skill-building courses on meal planning, safe storage of foods, and cooking with leftovers (Zacho and Mosgaard, 2016; Graham-Row et al., 2014). It is worth noting that there is often a disconnect between waste managers often tasked with devising communications strategies to reduce waste are most often engineers or scientists lacking the skillsets required to launch such campaigns, which typically require expertise from psychology, sociology, education, communications, and humanities fields (Zacho and Mosgaard, 2016).

While appealing to individuals is an important element of addressing the problem of postconsumer FW, it is also important to consider broader social and physical issues that contribute to the wasting of food. Recognizing the realities of how our communities are structured, portion sizes provided, cultural norms that exist, the demanding nature of work and school, and other societal factors beyond most individuals’ reach of control may offer additional approaches to successfully mitigating FW. Southerton et al. (2011) describe three contexts in relation to influencing sustainable consumption practices including:

- The individual, referring to initiatives that focus on education in the hopes of influencing attitudes and ultimately behavior change, for example, reducing the amount of food thrown away at the household level;
- The social, which refers to social norms, cultural conventions, and shared understandings of consumer practices;
- The material, which refers to objects, technologies, and infrastructures that both enable and constrain ways of behaving.

These three contexts allow for a much more comprehensive set of approaches toward reducing FW streams by recognizing that there are many complex factors at play beyond a simple understanding that something is “bad” and thus “should not be done.” Evans conducted and in-depth study of 18 households in the United Kingdom to determine individual, social, and material reasons that people wasted food (Evans, 2011, 2012). A complex combination of a desire to provide “proper,” that is, healthy, fresh/not frozen or prepared, well-balanced meals made from scratch, combined with the bulk of groceries obtained during a shopping event occurring every 7–10 days at a distant larger store, and demanding and unpredictable work, child (e.g., sports), and other social activities not aligning with the expectations of meal preparation for the week led to FW. Advice focused on meal planning, meal preparation, freezing of leftovers, etc., is good and well-intended, but for many people they simply don't have the time to accommodate the additional labor given the competing demands on their time and a primary goal of ensuring that there is adequate food for themselves and their families. Or even more anecdotal, but highly relatable, children are notoriously picky eaters and may not respond well to improvised meals based on leftovers (Evans, Blaming the consumer—once again: the social and material contexts of everyday FW in some English households, 2011).

At the household level, many of the typical suggestions for people to reduce their FW would translate to additional hours of domestic labor, which many people simply do not have. Based on the calculation of the average annual hours worked (defined by the OECD as the "total number of hours actually worked per year") divided by the average number of people in employment per year, Americans worked 34.4 hours per week (OECD, 2018). In the United States the time spent on household work has decreased considerably from 1965 to 2010 from 54 hours to 43 per week based on the assumption of a two-adult (male and female) household (Bridgman et al., 2012). In 1965 women spent approximately 40 hours per week on domestic labor and 12.8 of those hours were spent on cooking, compared with 26 hours total with 5.9 hours spent on cooking in 2010 (Bridgman et al., 2012). In 1965 men spent about 14 hours per week on domestic labor with 1.8 hours on cooking compared with 17 hours per week with 2.4 hours spent on cooking in 2010 (Bridgman et al., 2012). This amounts to an overall net reduction of 11 hours spent on domestic labor and a reduction of 6.3 hours on time spent cooking per week from 1965 to 2010. It is also important to realize that these statistics assume a two-adult household comprised of healthy adults capable of a full load of work for monetary compensation as well as domestic labor, which is not always the lived reality of individuals. While an increasing number of people are taking up gardening and cooking as hobbies, at the end of the day the provisioning and preparation of food is labor, which is not compensated. For many the additional labor associated with personal FW reduction techniques is simply infeasible in the calculus of time and demands on individual's time in our society.

13.4.1.2 Food waste reduction in hospitality and institutions

Source reduction of FW at hotels, restaurants, and institutions can include customer education as well as service options that mitigate the potential for FW. For example, institutions that serve food via buffets have found that eliminating trays leads to less postconsumer FW (Aramark, 2008). Other approaches for reducing the probability of customers taking more food than they can eat include offering smaller plates (in conjunction with a tray-less service) and staffing the buffet so that customers have to ask for additional portions, which has been shown to reduce waste

(Deutsch, 2018). Steve Finn, vice president of FW reduction at LeanPath, also suggests making FW visible to the consumer (Deutsch, 2018). One way to do this would be to conduct FW audits and share results with consumers (Deutsch, 2018). Campus dining operations at the University of Missouri initiated a program to regularly conduct FW audits and share results with customers and initially saw reductions in waste per customer, which eventually plateaued (Costello et al., 2016).

Beyond trying to influence consumer behavior, ReFED has identified a number of actions that could reduce FW in restaurants and has charted them along two dimensions: profit potential and feasibility; see Fig. 13.3 (Cochran et al., 2018). They identify the highest profit potential in the implementation of waste tracking and analytics and inventory management and production planning (Cochran et al., 2018). These approaches are often implemented in larger organizations such as schools, prisons, and large franchised restaurants. In addition to the other strategies already noted in this section, ReFED identifies the following approaches: portion choices and customized dishes (medium profit potential, highly feasible), produce specifications, and menu design (Cochran et al., 2018). ReFED also identifies a number of options that align with other options on the Food Recovery Hierarchy, such as donation liability education, donation matching partnerships, animal feed, centralized composting or AD, and cooking oil recycling (Cochran et al., 2018). Many of these FW source reduction options involve considerable shifts in management mentality and operations, which can be painful for people at first, but presents

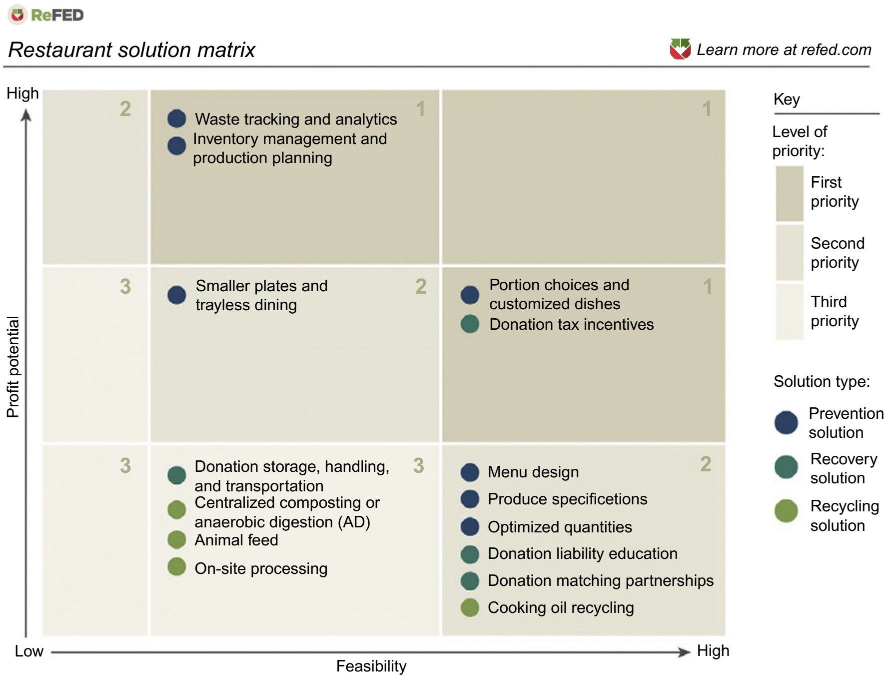

Figure 13.3 ReFED Restaurant Solution Matrix (Cochran et al., 2018).

enormous potential and, ultimately, the largest potential for GHG and energy savings (Costello et al., 2017; Hamilton et al., 2015).

13.4.2 Feed hungry people

In instances where excess food meets the requisite health and safety requirements it can be directed away from landfills and provided to people. Two important pieces of legislation have been enacted by the United States to encourage donations of edible foods to those in need. The Bill Emerson Good Samaritan Food Donation Act, which protects donors and recipients from liability (Government Printing Office, 1996). And, the 2015 Protecting Americans from Tax Hikes Act food donations entitles eligible food business to claim deductions in relation to the value of the donated food (Cochran et al., 2018). Food must be safely packaged and transported with care to maintain food at proper temperatures to prohibit microbial growth, that is, cool foods at 41°F or below, frozen foods at 0°F or below, and hot foods at 135°F or above (Public Health Alliance of Southern California et al., 2018). However, many managers are either unaware of these pieces of legislation, are still too risk-averse to pursue food donations, or don't find the time investment to pursue these options as worthwhile (Cochran et al., 2018).

In larger cities this is a bit easier to accomplish given the increased probability of being able to connect excess food with people within the time constraints associated with ensuring food safety. A variety of apps and other web-based services have been developed around the globe in efforts to connect restaurants, institutions, and retailers with near expiration food products to those that can utilize them at reduced costs or for free (Wong, 2017; Food Cowboy, 2018). These apps provide a variety of services to facilitate connections between food producers and those in need of food and sometimes offer incentivizing services like keeping track of donations for restaurants, hotels, and institutions that can be translated into tax savings.

13.4.3 Feed animals

It is possible to directly feed food scraps to some livestock, but in most cases additional treatment is required to ensure animal safety and to reduce the risk of foodborne illness to humans. As noted previously, residual organic materials from farms or food processing operations are more likely candidates for livestock feed than retailer or postconsumer FW as these feedstocks are more homogeneous and less risky with regard to potential contamination (Mirabella et al., 2014; Rivin et al., 2014). These feedstocks must still comply with federal and state regulations to ensure animal and human safety. Feeding FW to livestock is illegal in most cases in the European Union (Salemdeeb et al., 2017). Collection, treatment, and processing of postconsumer FW into feedstocks commiserate with existing animal feeding infrastructure present additional significant challenges. Educating individuals about proper sorting of FWs and developing the requisite infrastructure and logistics, that is, a separate vehicle fleet for collection of wet FW are nontrivial and significant challenges, as previously noted by Elizabeth Balkan, the NYC Director of Policy for the NYC Department of Sanitation (Balkan, 2017). Following collection, these perishable organic materials must be sorted to remove debris such as plastic and metals and then thermally treated as specified by the laws of the location, described in more detail below (Salemdeeb et al., 2017; Kim et al., 2011).

The US Federal Drug Administration allows for ruminant livestock, for example, cattle, to be fed with "inspected meat products which have been cooked and offered for human food and further heat processed for feed... milk byproducts... and any product whose mammalian protein consists entirely of porcine or equine protein." (Rivin et al., 2014). Postconsumer FW can be fed to livestock, with the exception of bovine brains and spinal cords or bovine spongiform encephalopathy—infected bovine to other bovines, if the material is treated for foodborne pathogens by boiling for 30 minutes (Rivin et al., 2014).

It is also legal in the United States to feed FW to swine so long as the requirements of the Swine Health Protection Act are met, but it is not legal in all states (Rivin et al., 2014). A 2009 amendment to the Swine Health Protection Act allowed for the following exceptions to the rule of 30 minutes of boiling prior to being used as feed for rendered products, bakery waste, candy waste, eggs, domestic dairy products (including milk), fish from the Atlantic Ocean within 200 miles of the continental United States or Canada and fish from inland waters of the United States or Canada that do not flow into the Pacific Ocean, and processed materials [derived in whole or part from the meat of any animal (including fish and poultry)] that have, at minimum, been cooked to a temperature of 167°F (75°C) for at least 30 minutes or has been subjected to an industrial process demonstrated to provide an equivalent level of inactivation of disease organisms, or as approved by the Administrator (Rivin et al., 2014). In 2007, only about 3% of swine producers (representing about 0.12% of swine marketed) utilized garbage as feed (US Government, 2009).

In addition to these collection, pretreatment, and heating requirements important for animal safety, significant technical hurdles remain with regard to integration of postconsumer FW into prevailing livestock operations. Novel production systems that might be more readily adaptable to accepting and feeding wet agricultural/FW are much less numerous and would still require screening and thermal treatment to reduce pathogens and to remove nonfood materials. The predominate swine production methods that supply the vast majority of pork meat in the United States do not readily allow for feeding of wet food materials, such as FW, as the majority of these operations offer dry feeds to swine (Safranski, 2018). Thus, without the possibility of drastic changes to these operations, and potentially supply of bacon, FW must be dried and pelletized to be integrated to existing US swine production infrastructure (Safranski, 2018). Use of foods that might vary in nutrient content can also reduce growth rates for animals, ultimately impacting the economics for the producer. Despite these requisite energy expenditures, recent LCAs on the utilization of FW as animal feeds have found that both dry and wet FW as animal feed are preferable across a variety of environmental impacts to AD and composting; see Table 13.1 (Salemdeeb et al., 2017; Kim et al., 2011).

Table 13.1 Comparative overview of food waste management options in relation to commonly cited metrics for evaluation of environmental performance

Management option	**Process energy needs**	**Direct process greenhouse gas emissions**	**Electricity generation possible?**	**Methane generation**	**Nutrient recovery—N**	**Nutrient recovery—P**
Wet feed to animals	Low	Low—negligible	No	NA	NA	NA
Dry feed to animals	Medium	Low—negligible	No	NA	NA	NA
Landfill w/ CH_4 capture	Low	Low	Yes	Yes	No	Potential if mined in the future
Landfill w/o CH_4 capture	Low	High	No	No	No	
Aerobic composting	Low	Variable	No	No	Yes	Yes
Anaerobic digestion	Medium	Low	Yes	Yes	Yes	Yes
Incineration	High	Low	Yes	No	No	No

Note: NA = Not applicable (1) Swine manure, including urine, can be treated via composting or anaerobic digestion and the resulting materials can be applied as fertilizer.

13.4.4 Industrial uses

Industrial uses is a broad category, which could include production of value-added products from FW (Galanakis, 2012), but is more typically realized through AD and recovery of oils to be utilized as biodiesel. The extraction of value-added products is most likely to occur through the utilization of food processing byproduct streams, rather than postconsumer FW (Mirabella et al., 2014). This is due to the more homogeneous and consistent nature of food processing operations, which is more conducive to subsequent engineered extractions of specific compounds. Examples include phenolic compounds that may be used as antioxidant food additives, essential oils (citrus rinds), proteins, pectin, and a variety of other specialty chemicals (Galanakis, 2012).

AD is a process that relies on microorganisms to break down organic materials into methane gas, and the solids remaining following digestion contain nutrients that can be used as a soil amendment. In addition, AD can be an option for reducing the volume of solid waste that needs to be managed, even if the methane is simply flared and the solids are ultimately disposed of in a landfill. This gas can be recovered and combusted to directly produce heat or within a generator to produce electricity, Table 13.1. AD is often utilized in the management of manures and is often a component of municipal wastewater treatment plants. FW is often codigested with other materials such as human or animal manures to increase chemical stability of the process (Zhang et al., 2014). AD of FW alone is inhibited due to nutrient imbalances including lack of trace elements, excess macronutrients, a carbon to nitrogen ratio outside of ideal ranges, excess lipid concentrations (Zhang et al., 2014). In the case of fruit and vegetable processing byproducts the addition of manure can provide sufficient N and P to the microbial community (Callaghan et al., 2002). AD of FW often requires mechanical and/or thermal pretreatment stages to stabilize various chemical properties of the FW (Zhang et al., 2014). While some technical challenges remain, overall AD is a viable option for recovering nutrients and generating electricity from FW.

13.4.5 Aerobic composting

Composting is the last option in food recovery hierarchies. Composting involves the aerobic microbial decomposition of organic substrates into a stable, humus-like material (EPA, 2015). Composting offers the potential for recycling nutrients and is relatively easy, if land is available and affordable, compared with other, more infrastructure-intensive waste management options; see Table 13.1. In a municipal setting, the collection equipment, that is, vehicle fleet, and logistical challenge collecting FW, and pretreatment to remove debris and shred the materials described above would apply (Cornell Waste Management Institute, 1996). However, as mentioned above, the potential to fully close the loop on the flow of nutrients through the food supply chain is limited due to geographic realities of human populations in relation to where the majority of foods are grown.

Many people chose to compost at home, though successfully keeping a compost pile aerated and well-balanced biogeochemically is fairly complex and studies suggest that home composting results in positive GHG emissions due to the formation of anaerobic pockets that generate methane (Amlinger and Peyr, 2008). Home composting is often not an option in dense urban environments due to the potential for attracting insect and animal pests. Vermicomposting may be a useful option in urban environments due to the more rapid nature of the decomposition and potential for small indoor setups (EPA, n.d.).

Composting at a municipality scale is often a better option as routine maintenance in accordance with optimal pile operations reduces methane formation and rapid breakdown of organics (Amlinger and Peyr, 2008). Larger composting operations can also achieve the conditions required to break down biobased polymers though rates are still not as rapid as other organics, but which are highly unlikely to breakdown in home-scale compost piles at all (Mohee et al., 2008; Mohee and Unmar, 2007). Common options for composting at a municipal scale include aerated (turned) windrow and aerated static pile composting. In-vessel composting may be another option for municipalities or food-service providers.

Windrow composting is particularly suitable for large volumes of food and yard waste and involves the formation of long rows, "windrows," that are 8 ft tall and 14−16 ft wide (EPA, n.d.). Piles are periodically turned using machinery that can pass over the pile. The pile size is large enough to generate and maintain temperatures up to 140°F, even if the outside of the pile becomes frozen, and small enough in some dimensions to allow oxygen to flow through to the core (EPA, n.d.) again these advantageous features for decomposing biobased plastics.

Aerated static piles are suitable for larger quantity generators of yard trimmings, food scraps, and paper products and cannot readily accommodate animal by-products or grease from food processing industries (EPA, n.d.). The piles must be aerated using either layers of bulking agents, such as wood chips or shredded newspaper or by using a network of perforated pipes to ensure continual airflow (EPA, n.d.). Both windrow and aerated static pile composting may require measures such as installing a shelter or misting system to maintain optimal moisture rates in the pile (EPA, n.d.).

Finally, in-vessel composting involved feeing organic waste into an enclosed container, which can allow for greater control of the conditions, for example, temperature, moisture, mechanical turning of the pile, and airflow (EPA, n.d.). If managed properly compost can be created in just a few weeks (EPA, n.d.). This may be an option for smaller operations that generate a steady stream of organic waste to install on premise (EPA, n.d.).

In all cases, considerable technical expertise is required to maintain composting operations (Cornell Waste Management Institute, 1996). Utilizing compost can be challenging since it is relatively heavy and has low value as a soil amendment, so it is usually marketed close to the composting facility at fairly low prices (Morris et al., 2014).

13.5 Life cycle assessment and systems analysis of food waste management options

A few studies have systematically compared FW treatment options from a life cycle perspective to determine which options result in the least environmental impacts. Generally speaking, LCA results align with the Food Recovery Hierarchy. Source reduction is the most preferable option for energy and phosphorous savings (Hamilton et al., 2015). Salemdeeb et al. (2017) found that wet and dry animal feed production performed better than AC or composting across 13/14 and 12/14 environmental metrics, respectively. And Kim et al. (2011) also found wet animal feed production to be the most preferable option from a life cycle costing analysis, with dry animal feed production the second. However, and incongruent with basic ZW definition, Kim et al. (2011) found that waste incineration coupled with electricity production performed better than AD or composting. Results of these works demonstrate that selecting an optimal FW management option is likely to be a multicriteria decision problem that will need to be made with respect to stakeholder priorities and existing infrastructure.

13.6 Concluding thoughts

If the philosophy of ZW is to be stringently applied to FW, it challenges humanity to deeply consider our relationships with food and the systems that we have constructed to supply us with plentiful and varied food. And a deep consideration of the societal reasons for why food is wasted, for example, sociology, class/labor, poverty, urban planning, and zoning. In particular, over the past hundred or so years humans have radically altered the land surface and disrupted nutrient cycling through the production and application of synthetic fertilizers and the separation and aggregation of animal production operations (Steffen et al., 2015; Galloway et al., 2008). As urbanization increases, devising approaches to close these loops presents enormous challenges that will require a diversity of tactics to successfully manage. In the near term, focusing on reducing the occurrence of FW and developing infrastructure to separate and recover as much use as possible from FW streams will be beneficial, but it is not the end of the road.

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