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Food Loss and Waste

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Substantially decreasing food waste is attainable as long as people are willing to take actions to change wasteful lifestyles and society enables such change with necessary support. (Photo from SpeedKingz/Shutterstock.)

Abstract

Reducing food loss and waste (FLW) is one of the key strategies to combat hunger and sustainably feed the world. In the United States, four major sources of data help describe the magnitude of the problem and illustrate potential opportunities for food waste reduction, recovery, and recycling: (1) at the retail and consumer levels, 60 million tonnes of food go uneaten annually (Buzby, Wells, and Hyman 2014 [2010 data]); (2) at landfills, estimated food waste totals 26.6 million tonnes, representing three-quarters of food waste generated (USEPA 2016a [2014 data]); (3) estimates based on human physiology and metabolism models coupled with obesity and food availability data put consumer food waste at roughly 78 million tonnes (NRDC 2012); (4) farm-to-fork system analysis indicates food waste totaling 56.7 million tonnes, which is partitioned into 9.1, 0.9, 22.7, and 24.5 million tonnes for wastage occurring at farms, in manufacturing, in consumer-facing businesses, and in homes, respectively (ReFED 2017a [2015 data]). Embedded in FLW are large amounts of resources, including 16 million hectares of land, 3.9 million tonnes of fertilizer nutrients, and 17 billion cubic meters of irrigation water for retail- and consumer-level food loss alone, plus other environmental and economic costs.

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Factors contributing to FLW vary depending on the stage or sectors of the food system. Market and human elements together with social and cultural forces interact to shape our relationship with food and influence our food behavior. Currently, citizens, organizations, businesses, and government agencies are undertaking a variety of food waste reduction efforts. It is estimated that annually in the United States, up to 2 million tonnes of food are rescued for humans, 15–16 million tonnes of food waste are recovered for animal feeding or other beneficial uses, and 7–8 million tonnes are recycled through composting. Of these amounts, roughly three-quarters (19 million tonnes) is achieved through FLW recovery or recycling at the manufacturing stage. Much work remains to substantially decrease FLW in the consumption stage involving consumer-facing businesses and homes.

The following critical needs are identified. First, since much effort has focused on food-waste composting, it is important to quantitatively assess and cross-compare those composting programs for their efficacies, costs and benefits, lessons and barriers, and potential limitations. Such information is essential for the nation to design strategic policies and priorities while avoiding inefficient outcomes. Second, a potential game changer to resolve food waste generated at the consumption stage is the development and adoption of innovative technologies that could convert wasted food into safe and nutritious feed for livestock animals. This requires creative policies and mechanisms to foster technological innovation, enable entrepreneurship, and support relevant research. Third, understanding consumer food behavior in light of established theories in social, behavioral, and psychological sciences—coupled with action-based research—is critically needed for the purpose of exploring new and innovative behavior-changing interventions in order to complement existing awareness-raising campaigns for broader impacts. The phenomenon of FLW has many drivers and influencing factors. To decrease FLW at a meaningful scale requires all workable solutions.

Introduction

Food is a basic necessity. Throughout human history, man labored for food—via hunt and gather, slash and burn, and other subsistence-agriculture practices. It was not until well into the 20th century that man shook off the yoke—today in developed countries less than 2% of the population is engaged in agricultural production, feeding the remaining 98%. The Green Revolution, initiated in the 1930s with the development and adoption of new technologies—including high-yielding varieties of cereal grains, synthetic fertilizers, irrigation, and new methods of cultivation—greatly advanced the ability to produce food to feed the rapidly growing human population. From 1961 to 2015, global food output increased by 390% (FAO 2017), outpacing the 240% growth in human population.

Despite tremendous progress, food insecurity, hunger, and malnutrition are still widespread. Today, 13% of the global population is undernourished (IFPRI 2017). Even in the United States, the land of plenty, 41.2 million people lived in food-insecure households in 2016 (Coleman-Jensen et al. 2017). The global population is projected to exceed 9.7 billion by 2050 (UN/DESA/PD 2017); food production will need to increase by 60–110% from the 2005 level (Tilman et al. 2011), or 25–70% above the current levels, according to a more recent study (Hunter et al. 2017), to keep pace with the growing demands of increases in population and prosperity. How can society address the unprecedented food security challenge?

Natural resources fundamental to agricultural production are limited. Globally, cropland (1.53 billion hectares [ha]) and pastures (3.38 billion ha) cover 38% of Earth's terrestrial surface (Foley et al. 2011). Much of the remainder is deserts, mountains, and tundra, deemed unsuitable for agriculture. Expanding agriculture into the marginal lands of sensitive ecosystems is an unsustainable path and would have tremendous negative impacts on habitats, biodiversity, carbon storage, and soil conditions (Foley et al. 2011). Meanwhile, current agricultural land use faces competition from urbanization and other sectors of the economy, amid the problems of land degradation due to salination, desertification, soil erosion, and acidification (Blum 2013).

Sustainable intensification to produce more food from existing agricultural land through enhanced production and resource use efficiencies is essential (Godfray et al. 2010). Sustainable intensification requires water security, among other things. Water insecurity, however, is a rising problem. Irrigation (one of the main Green Revolution contributing factors) accounts for approximately 70% of global freshwater withdrawals (Siebert et al. 2010). The soundness of this agricultural practice is now challenged because of regional water scarcity and unsustainable water withdrawal. For example, in the North China Plain, where 50% of China's wheat is produced, overwithdrawal of aquifers for wheat irrigation is causing steady declines in the groundwater table, by as much as 0.8 meters (m) a year (Pei et al. 2017). Elsewhere, such as in the Mekong River basin, water scarcity and disputes over water rights have become a geopolitical and economic matter of contention (Opperman 2012). In addition, drought throughout the Mediterranean region since 2012 has seriously impaired olive production with double-digit declines in countries like Italy, Tunisia, and Greece (Terazono 2017). The prolonged drought in California in recent years caused an estimated 9% reduction in agricultural output (Pacific Institute 2017), serving as a reminder of the critical importance of water security coupled with food security.

Meanwhile, agriculture has become a dominant force for the decline in water quality worldwide (Mateo-Sagasta, Zadeh, and Turral 2017). Nonpoint-source nutrients (primarily nitrogen and phosphorus) running off fertilized farmland are the most important contributors to algal blooms and the recurring "dead zones" in the Gulf of Mexico and many other water bodies around the world. Agricultural production is also linked with other environmental threats such as biodiversity loss, degradation of land, and climate change (DeFries and Rosenzweig 2010; Galford et al. 2010). To be sustainable, agricultural intensification for food security must simultaneously lessen environmental harm.

How can the grand challenge of sustainably feeding the world be addressed? There have been many debates and discussions worldwide, involving a wide range of concerned parties including but not limited to agricultural professionals, policymakers, academics, and leaders of civic organizations and businesses. A number of strategies have emerged. One set of these strategies centers on advancing production capacity (the amount of output) and productivity (e.g., greater yield per unit of land) with higher resource-use efficiency. Among these, closing yield gaps on underperforming lands on which yields are currently below average has the potential to add billions of tonnes of new production (Foley et al. 2011; Mueller et al. 2012). Advancement in crop breeding technologies offers great opportunities as well (Abberton et al. 2016; Brummer et al. 2011).

Another set of strategies to alleviate the dilemma has been offered, focusing on curbing the demand for food. Some believe that striving for a global population with a sustainable replacement rate is critical (Gilland 2006; Searchinger et al. 2013), particularly in regions where a high degree of food insecurity coexists with birth rates substantially greater than the world average, such as in sub-Saharan Africa. Furthermore, dietary shifts, even with small changes from beef to poultry or pork, for example, could enhance food availability and decrease the environmental footprint of agriculture (Eshel et al. 2014; Foley et al. 2011). Most important, as emphatically addressed in this paper, improving the use of food that is already produced by cutting back food loss and waste offers a great opportunity to simultaneously address food security and sustainability. This is a vital strategy that appeals to many worldwide (e.g., FAO/IFAD/WFP 2015; Foley et al. 2011; Godfray et al. 2010), with multiple benefits and relatively few conflicts or negative consequences.

In fact, a movement of food waste reduction, recovery, and recycling has rapidly spread around the world recently. The movement has been kindled by the report of the United Nations Food and Agriculture Organization (FAO) that about one-third of food produced for human consumption is lost or wasted; the amount totals 1.3 billion tonnes annually (Gustavsson et al. 2011), enough to feed more than a billion people. In low-income countries, much of the food loss and waste (FLW) takes place prior to the consumer stage, primarily because of infrastructural deficiencies. But in developed countries, much FLW occurs at the consumer level. Per capita FLW is 95–115 kilograms (kg) a year among consumers in Europe and North America, compared to 6–11 kg in sub-Saharan Africa or South and Southeast Asia (Gustavsson et al. 2011). Without a doubt, sustainably feeding the world will require the combination of many solutions, and wasting less to feed more represents an opportunity of significant magnitude.

The United States has an important role to play. On an annual basis, the United States produces more food than France, Germany, the United Kingdom (UK), Canada, Japan, and Australia combined (766 vs. 595 million tonnes) (FAO 2017 [2013 data]). The United States is the third most populous country (behind China and India), with per capita food supply among the highest in the world (FAO 2017). Of the 195 million tonnes of food available for consumption in the United States (2010 data), however, 60 million tonnes went uneaten at the retail and consumer levels (Buzby, Wells, and Hyman 2014). Cutting down FLW could be a relatively low-hanging fruit to meet the growing demand for food while addressing the various environmental challenges.

This paper provides a critical overview of U.S. FLW through an objective, balanced, and data-driven approach. There are four sections. First, the magnitude of the problem is described using four major data sources at the national level and the different scope and boundaries of these data are compared; there follows a discussion of the three fundamental resources for primary food production—land, water, and fertilizer—that are embedded in the lost and wasted food, plus other resource costs. Second, the authors discuss why FLW occurs, drawing attention to the many issues of the FLW problem at the consumer end—food-wasting behavior, the "whys," and the interacting influence of psychological, social, cultural, and economic factors; they also describe major actions that are being taken across the nation to decrease FLW. Third, a hard look at existing data on the quantity of food waste prevention, recovery, and recycling is taken by compiling all major sources of data that could be located, providing a "reality check" on how well the country is performing on lessening FLW. Finally, the authors present an interpretative and critical analysis concerning three key issues: How can the United States work toward the 50% reduction goal by 2030 knowingly and confidently? What technological innovations may be game changers? What other approaches could be explored to influence consumer food behavior for the better?

Magnitude of the Problem, Including Resource Costs

National-scale FLW Data

When comparing FLW estimates across various studies, the lack of common definitions for food loss and food waste worldwide is evident. Different studies have different research goals and thus may measure different aspects of food loss or food waste, making it difficult to precisely compare the data and information across studies. Not only are there different definitions of the measured variables (e.g., food loss, food waste), but studies may also use different reference bases (e.g., volume of sales vs. food supply value vs. quantities or weight delivered; edible vs. nonedible food) and different areas of coverage (e.g., stages in the farm-to-fork chain—such as at the farm, retail, or consumer levels—or the specific fruits, vegetables, and mixtures covered) in the analyses (Buzby et al. 2015). Other factors may include different destinations (e.g., composting, animal feeding) and the primary data sets and methods used (WRI 2016). In addition, data in other studies may not be sufficiently disaggregated for comparison—some provide FLW estimates for food groups and some for individual foods (Buzby et al. 2015). In this paper, phrases such as food loss, food waste, FLW, and wasted food are used interchangeably; weight is the reference base.

No single comprehensive estimate of FLW exists in the United States; however, work completed in this area provides important information and insights helpful to understanding the problems, challenges, and directions for significant solutions. Four major sources of national data on FLW are presented here to illustrate the magnitude of the problem.

The first major U.S. data source is the U.S. Department of Agriculture's (USDA) Economic Research Service's (ERS) Loss-Adjusted Food Availability (LAFA) data series (USDA–ERS 2017a), created to measure the quantities of foods eaten by Americans. As part of that accounting process, the series measures the amounts of foods that go uneaten, which is broader than just food waste. Included are factors such as cooking loss and natural moisture loss; loss from mold, pests, or inadequate climate control; and food waste. (The ERS uses the term food loss, defined as the edible amount of food, postharvest, that is available for human consumption but is not consumed for any reason, although the authors generally do not differentiate food loss and food waste elsewhere in the present paper.) The most recent ERS data on food loss in the United States amounts to 60 million tonnes at the retail and consumer levels, which is 31% of the 195 million tonnes of the available food supply at those levels in 2010 (Buzby, Wells, and Hyman 2014).

The second major source of data is from the U.S. Environmental Protection Agency (EPA), which provides estimates of the amounts of food waste entering municipal solid waste (MSW) facilities. (The EPA has collected and reported data on the generation and disposal of MSW in the United States for more than 30 years and uses this information to measure the success of waste reduction and recycling programs across the country.) Accordingly, food waste amounted to 34.8 million tonnes in 2014 (USEPA 2016a). Of this, an estimated 26.6 million tonnes entered landfills, which was the largest component (21.6%) of the MSW disposal in landfills.

The third source of data originates from a report by the Natural Resource Defense Council (NRDC) (Gunders 2012). This was based on analysis from Hall and colleagues (2009) using FAO food balance sheets and estimates of overweight individuals and obesity in the United States. Extrapolation from the Hall and colleagues study results in an estimate that 40% of the U.S. food supply was wasted in 2010, corresponding to approximately 78 million tonnes. The most recent NRDC report (Gunders et al. 2017) reiterates the previous report's conclusion.

The fourth estimate is from ReFED (Rethink Food Waste through Economics and Data), a multistakeholder nonprofit organization with the goal of providing a roadmap to decrease U.S. food waste by 20%. Using best available data and extrapolations from agricultural case studies, ReFED (2017a) estimates that 56.7 million tonnes of FLW was generated in 2015 from farm to fork—i.e., food loss and waste at farms, in manufacturing and processing, and throughout distribution and consumption.

Table 1 lists the four sources of U.S. FLW data, using the *Food Loss and Waste Accounting and Reporting Standard* developed by a multistakeholder partnership to help quantify FLW and encourage consistency and transparency (WRI 2016). Note the different "boundaries" associated with the four data sources—retail and consumer-level food loss (60 million tonnes) with the USDA–ERS data, food waste as a component of MSW (34.8 million tonnes) with the EPA data, consumer food waste (78 million tonnes) with NRDC, and farm-to-fork FLW (56.7 million tonnes) with ReFED. Actually, a closer examination of these data indicates that the gap between the estimates of ERS and ReFED or EPA may be considerably smaller if the following factors could be taken into account: (1) Feeding

Table 1. Comparison of FLW estimates across four U.S. studies.

Organization	Estimate	Time Frame	Includes Inedible Parts?	Boundary (Food products and food-system stages included in FLW estimate)	Method
USDA	60 million tonnes (66.5 million tons; 133 billion pounds [lbs])	12 months (2010)	No (except for some commodities at retail level, such as the inedible parts of discarded whole fresh apples)	Food categories: Approximately 215 basic commodities (no highly processed products). Food-system stages: Retail, Restaurant (consumer waste only), Foodservice/Institution (consumer waste only), Household	Estimate based on nationally representative surveys of retail inventories or shipments and household purchases and stated consumption. For details, see the USDA–ERS LAFA data series (2017a) and Buzby, Wells, and Hyman (2014).
EPA	Generated: 34.8 million tonnes (38.4 million tons; 76.8 billion lbs) Disposed: 33 million tonnes (36.46 million tons; 73 billion lbs)	12 months (2014)	Yes	Food categories: All food and beverage food-system stages—MSW, which includes Retail, Restaurant, Foodservice/Institution, Household	Estimate of "FLW generated" equals municipal solid FLW generation, which is estimated based on existing studies of the rate of generation applied to updated census estimates of number of businesses and households. Estimate of "FLW disposed" is determined by subtracting the amount of FLW going to composting (1.94 million tons) from total FLW generated (38.4 million tons). Composting estimates are based on publicly available state data. For details, see USEPA (2016b).
NRDC	40% (approx. 78 million tonnes [86 million tons; 172 billion lbs]) in 2010 using the USDA's food supply and consumption pattern assumptions)	12 months (2003)	No	Food categories: All food and beverage food-system stages: Distribution/Handling, Manufacturing, Retail, Restaurant, Foodservice/Institution, Household	Estimate derived by taking the percentage difference between the amount of calories in the U.S. food supply (derived from FAO food balance sheets) and the amount of calories consumed by end consumers (estimated from the weight of the U.S. population). For details, see Hall and colleagues (2009).
ReFED	56.7 million tonnes (62.5 million tons; 125 billion lbs)	12 months (2015)	Yes	Food categories: All food and beverage food-system stages: Farm, Distribution/Handling, Manufacturing, Retail, Restaurant, Foodservice/Institution, Household	Methodology applies estimates of commercial and residential FLW (from the best publicly available studies as of 2015) to 2015 U.S. census data on manufacturing, retail, food service, and households to produce national estimates. On-farm estimates are based on extrapolation from numerous agricultural case studies. For details, see ReFED Technical Appendix (2016a).

Note: Definitions (see the *Food Loss and Waste Accounting and Reporting Standard* [WRI 2016] for additional details)
Food and Inedible Parts
Food: Any substance that is intended for human consumption. It does not include crops intentionally grown for bioenergy, animal feed, seed, or industrial use.
Inedible parts: Components associated with a food that, in a particular food supply chain, is not intended to be consumed by humans (e.g., bones, rinds, pits/stones). What is considered inedible varies among users. "Inedible parts" do not include packaging.
Source: Modified by authors of the *Food Loss & Waste Data Comparisons* compiled by Further with Food: Center for Food Loss and Waste Solutions (FF–CFLWS 2017).

(human) food to family pets is a common practice; there are 70 million dogs and 74 million cats in the United States (AVMA 2012). (2) Backyard composting is common; uneaten food is often a major ingredient (USEPA 2017a). (3) Food residues/waste going down the drain via kitchen disposal into the sewer system are substantial—an estimated 7.4 million tonnes annually according to an EPA report (USEPA 2013). Deducting these losses from the 60 million tonnes would bring the ERS estimates much closer to those of ReFED or EPA.

To minimize confusion and facilitate discussion, this paper refers to the ERS food loss data hereafter when discussing FLW at the retail and consumer levels. This selection is based on two considerations—first, the ERS estimates are the most frequently cited national data on food loss in the country; second, the ERS estimates are derived from detailed databases that are long established, systematically collected, and annually updated. Nevertheless, ERS considers the LAFA data series to be preliminary because initiatives are under way to improve the data series.

FLW by Food Group

Figure 1 shows the amount of FLW for each food group by the size of the bar and also the breakdown between the retail and consumer losses. The food groups with the highest loss/waste in weight are dairy products, vegetables, and grain products. It is rather ironic that loss and waste of vegetables and fruit by American consumers totals 19.8 million tonnes (averaging 62 kg per person per year); meanwhile U.S. daily vegetable and fruit consumption is less than 40% of that recommended (Moore and Thompson 2015). The U.S. Centers for Disease Control and Prevention has developed strategies to encourage higher consumption of vegetables and fruit to counteract the rising rate of obesity. Therefore, eating more and wasting less fruit and vegetables serve multiple purposes.

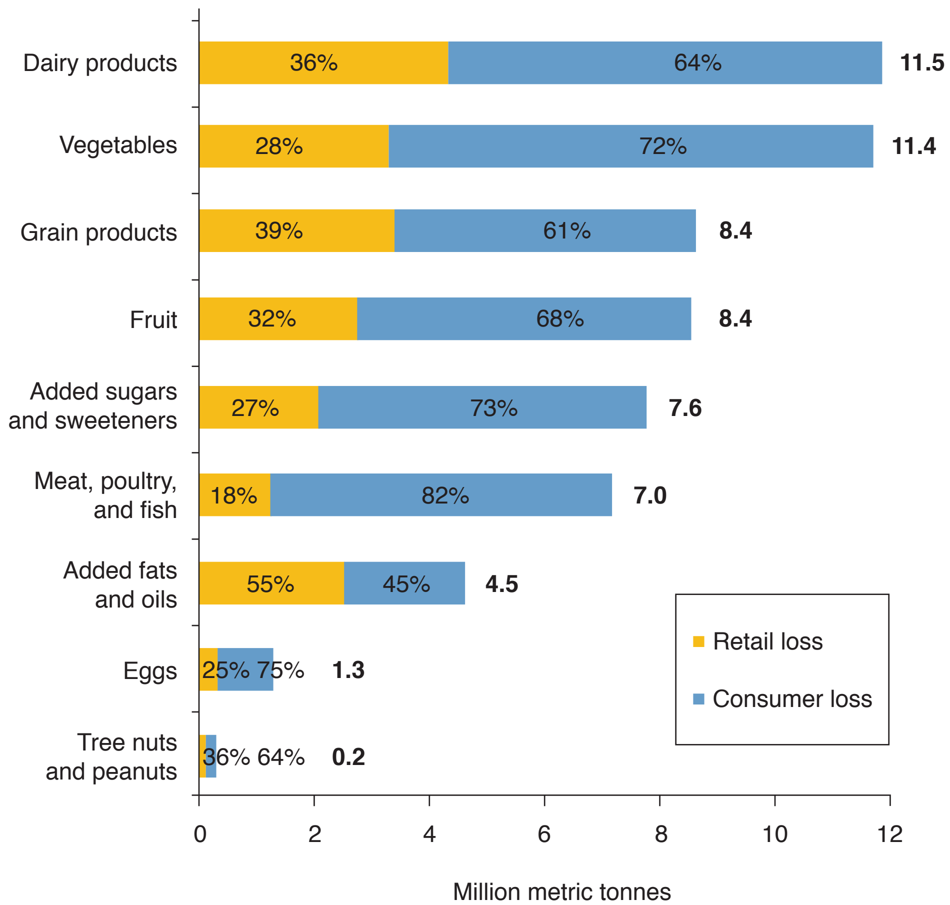

Figure 1. Retail and consumer food loss in the United States, by food group. Consumer loss includes loss in the home and in away-from-home locations; includes cooking losses and uneaten food. Numbers within bars represent percent of retail vs. consumer losses for each food group. Numbers at end of bars represent million metric tonnes of losses for food groups. Source: Buzby, Wells, and Hyman (2014).

FLW by Sector

On Farm

Nationally representative data on preharvest FLW are not available other than ReFED's estimate of 9.1 million tonnes (16% of the total FLW farm to fork) (ReFED 2017a). Relatively few peer-reviewed studies have provided on-farm FLW data. Of those that exist, all have a limited scope, such as the NRDC study, which interviewed 16 large commercial vegetable and fruit growers and shippers in central California in 2012 (NRDC 2012). This study obtained self-reported preharvest shrink estimates for select commodities (1–20% cherries, 5–15% pears, 10–30% plums, 3–6% head lettuce, 10–30% nectarines, and 5–20% broccoli).

Postharvest

Two general categories of postharvest FLW streams in the U.S. food chain are considered: (1) handling, processing, manufacturing, transport, and storage; and (2) distribution (wholesale, retail) and consumption.

For the first category, the ReFED estimate is 0.9 million tonnes (ReFED 2017a). There is another estimate, stemming from the Food Waste Reduction Alliance (FWRA; formed in 2011 by food manufacturers, retailers, and restaurants, with nearly 30 participating companies), as reported by Business for Social Responsibility (BSR 2013): 20.1 million tonnes FLW generated by U.S. food manufacturers. Of the 20.1 million tonnes of food waste, 98.3% was diverted from landfills to higher uses such as donation, animal feeding, or recycling (BSR 2013). Therefore, the two sources of estimates (ReFED and FWRA) would be comparable concerning the amount of food waste going from manufacturing to landfills.

For the second category (wholesale, retail, and consumption), two ERS studies have provided supermarket shrink estimates for individual fresh fruits and vegetables as a proxy for food loss and provided limited data on supermarket losses for fresh meat, poultry, and seafood (Buzby et al. 2009; Campuzano et al. 2016). The estimates for the first study are currently used in the LAFA data series, and the estimates for the second study are being reviewed by an expert panel for possible inclusion in LAFA. Accordingly, retail-level food loss totaled 19.5 million tonnes; consumer-level food loss totaled 40.8 million tonnes (Buzby, Wells, and Hyman 2014). From the ReFED report (2017a), FLW amounts to 22.7 million tonnes with consumer-facing businesses (supermarkets, grocery stores, distribution centers; full-service restaurants; institutions and food services; limited service restaurants; government) and 24.5 million tonnes in homes. In addition, the FWRA estimated 1.7 million tonnes FLW in the retail and wholesale sectors, of which 55.6% was diverted to higher uses (BSR 2013). In the peer-reviewed literature, there have also been studies over time aimed at losses for particular commodities, such as postharvest losses during marketing of papaya (Paull et al. 1997), or commodity groups, such as fresh produce (Kader 2005).

To put the amount of resources embedded in FLW into perspective, the 16 million ha of land associated with the retail- and consumer-level FLW is approximately half of the total area of the U.S. National Park System, or roughly the total land area of Maryland, Delaware, Pennsylvania, New Jersey, and Rhode Island combined. The 3.9 million tonnes of fertilizer nutrients embedded in FLW at retail and consumer levels is 150% of the total annual fertilizer use in sub-Saharan Africa; and the 17 billion m^3 of irrigation water lost in FLW is equivalent to the area of the city of Philadelphia covered by 50 m of water. Using a different metric—for a typical family of four, there would be 0.2 ha of land, 50 kg of fertilizer, and 225,000 liters of irrigation water associated with food loss.

These different measurements all inform understanding of the magnitude of FLW in the United States among the sectors of the food system. Such understanding helps inform the research communities, policymakers, industry sectors and organizations, and individual citizens about the extent of the problem as well as opportunities for new policy initiatives, technological innovations, enhanced food-handling practices, education, and consumer behavioral changes that ultimately decrease food waste and conserve resources.

Resources Embedded in FLW

The amounts of land, water, and fertilizer nutrients embedded in the annual FLW in the United States were estimated by Toth and Dou (2016) using official data on crop acreage (USDA–NASS 2015a), fertilizer usage (USDA–NASS 2015b), and irrigation records (USDA–NASS 2013), coupled with food-loss estimates derived from the USDA–ERS LAFA database. Briefly, there are 16 million ha of cropland, 17 billion m^3 of irrigation water, and 3.9 million tonnes of fertilizer nutrients (nitrogen, phosphate, and potash) embedded in the retail- and consumer-level FLW. Animal products (meats, eggs, dairy products) contribute 35% by weight of the U.S. food supply, 38% of food available for consumption, and 30% of calories in American diets (Buzby, Wells, and Hyman 2014). But the production of animal-based food products requires very nearly half of the total resources (land, irrigation water, and fertilizer nutrients) used for food production (Toth and Dou 2016). This has an important implication globally, considering the rapidly growing middle-class populations in developing countries and their desire for increasing consumption of animal products (Steinfeld et al. 2006). At a minimum, decreasing the wastage of animal food products, along with the reduction of other food groups, is important for a sustainable food system.

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Nationally, in the United States, energy embedded in edible food waste was estimated at 2.1 x 10^{18} joules, according to Cuéllar and Webber (2010). This energy loss is 25% of total energy consumption in the entire farm-to-fork food system and approximately 2% of all-purpose use of energy in the entire country. Other resources/costs associated with FLW, although no quantitative data are available at the national level, include labor cost for producing and supplying food, decreases in biodiversity and habitat loss due to cropland cultivation, and pollution of water, as well as emissions of greenhouse gases. For the latter, the World Wildlife Fund (WWF 2017) estimates that globally "about 10% of all human-caused greenhouse gas emissions are linked to food waste." Further, using estimated national average retail prices for each LAFA commodity, Buzby and Hyman (2012) reported the economic value to be $46.7 billion for retail food loss and $114.9 billion for consumer-level food loss. ReFED (2016b) estimates are $2 billion for FLW in the manufacturing sector, $57 billion for consumer-facing businesses, and $144 billion for consumer food waste.

Why FLW Occurs/ Current Mitigation Efforts

On Farms

Estimated on-farm food loss and waste totals 9.1 million tonnes (ReFED 2017a), the vast majority of which ends up being returned to the soil. Although losses can occur with any type of crop, fruits and vegetables suffer the most losses in the field. Food loss at farms occurs for a variety of reasons. Some are natural or biological (e.g., damages caused by weather events or insect/disease infestation); others stem from human factors (e.g., market conditions, food safety concerns, or labor shortage). Grading of produce based on cosmetic standards—such as shape, size, or color—to meet consumer demand can be a major cause of food loss.

Food rescue through gleaning—i.e., collecting food still remaining in the field after the main harvest—has had a long tradition and is widespread, often organized by churches or hunger-relief groups with participation of countless volunteers. The National Gleaning Project sponsored by the Vermont Law School has published a compilation of gleaning organizations across the country (VLS n.d.). In recent years, grassroots food-rescue efforts have taken it a step further with innovation that simultaneously addresses hunger, nutrition, food waste prevention, and community strengthening.

Among the many successful stories is Rolling Harvest Food Rescue (RHFR 2016), a nonprofit organization in Bucks County, Pennsylvania. Rolling Harvest Food Rescue (RHFR) was created in 2010 to rescue food from area farms and farmers markets and deliver it to food pantries, soup kitchens, and low-income senior housing. Today, RHFR has established partnerships with 36 farms and markets and more than 60 hunger-relief sites, with about 130 volunteers. Gleaning (the traditional food rescue method) contributes to approximately 20% of the total food volume, whereas scheduled truck pickups (prearranged to minimize disruption or inconvenience to donating partners) and spontaneous response to last-minute calls (emails or texts from growers who have leftover produce from previous days' markets or harvested excess food that they will not be able to sell) each account for 40% of the food volume annually.

In addition, new for-profit businesses are emerging to capture surplus food on farms or produce that does not meet cosmetic standards of the regular supermarkets and sell that food to consumers via a secondary market or alternative channels such as scheduled direct deliveries. Imperfect Produce (2017) and Hungry Harvest (n.d.) are two examples; more information can be found at The Food Waste Innovator Database (ReFED 2017b).

Food Industry

The food industry, including manufacturers and consumer-facing businesses, generates 23.6 million tonnes of food waste (ReFED 2017a). Given this large amount and considering the intrinsic influence the industry has on consumer food behavior (e.g., through packaging, date labeling, marketing, etc.), the food industry must play a central role in the food waste reduction endeavor.

Food-manufacturing waste occurs because of inefficiencies or unavoidable production processes as raw, inherently perishable agricultural products are transformed to finished goods. For example, products can require trimming for use in end products, leading to edible parts going unused (e.g., ends and skins). They are also prone to unplanned bulk losses related to packaging or last-minute changes in purchasing orders (Gunders et al. 2017). Perishable manufactured products are exposed to some of the same distribution risks as produce from farms, although on a smaller scale; these risks include sensitivity to temperature control and packaging damages. Nevertheless, large manufacturers have an advantage in diverting waste from landfills because the predictability of the quantity and quality of the waste stream lessens the risk for solutions including animal feed, energy generation, etc. Therefore, the amount of food waste that ends up in landfills from U.S. food manufacturers is relatively small, about 0.9 million tonnes (ReFED 2017a), whereas consumer-facing businesses generate 22.7 million tonnes of loss.

Drivers for food waste in consumer-facing businesses are complex. Consumer demand for variety and consistency in food products strains inventory management. Supermarkets and grocers are reluctant to change stocking practices or product sizes if those practices are intricately tied to their brand identities. Also, high customer standards for freshness lead businesses to dispose of safe, edible food when it is perceived to be past its prime. Restocking contracts with vendors also require levels of throughput that result in waste. Many grocers also manage their culled products in ways that make it difficult to repurpose them. Products that are not sent directly to compactors or waste bins may be stacked in ways that cause damage, making the food unsuitable for desirable purposes like hunger-relief donation.

The food-service and restaurant industries have their own set of waste-reduction challenges as they prepare and offer prepared food to customers. The NRDC report (Gunders et al. 2017) lists top waste drivers as excessively large plate portions, leftover foods on buffet lines, overproduction in the kitchens, fixed ordering and preparation requirements among chain restaurants that must accept off-site preparation of food products, and the inherent challenges of matching menu items to daily fluctuations in customer flows. Institutional services in schools, for example, are always challenged to prepare food that children and young adults will actually eat, coupled with daily variation in the number of patrons.

The food industry is increasing its commitment to decreasing food waste and deploying a variety of prevention, recovery, and recycling solutions. The NRDC report (Gunders et al. 2017) presents many innovative models and success programs. Several large-scale initiatives include the following: (1) The Consumer Goods Forum's commitment to tackling the global food waste challenge by agreeing to halve food waste within the operations of its 400 retailers and manufacturers by 2025 (The Consumer Goods Forum 2015). (2) Fifteen major U.S. companies became inaugural U.S. Food Loss and Waste 2030 Champions by pledging to reduce FLW in their operations by 50% by 2030 (USEPA 2016b). (3) In February 2017, the Food Marketing Institute (FMI) and Grocery Manufacturers Association (GMA 2017a) announced a voluntary initiative, in line with USDA guidance, for retailers and manufacturers to standardize date labels in order to decrease confusion that leads consumers to throw food out prematurely (see more discussion later). (4) The FWRA, since its inception in 2011, has continued to raise awareness in the industry, publishing two best practices tool kits, in addition to their biannual studies on food waste generation and disposal as well as food donation (BSR 2012, 2013, 2014; FWRA 2016).

As progress, investment, and innovation in the food industry increase, barriers identified by industry members have shifted, according to the FWRA reports. Whereas these reports cannot be compared directly because different companies responded in different years, the results over time are illustrative of what industry sees as progress and remaining barriers. For example, in 2014 more than two-thirds of manufacturers responding to the FWRA survey identified liability concerns, regulatory constraints, and transportation as key barriers to food donation (BSR 2014). Two years later, liability concerns and transportation barriers declined to 50% and 25%, respectively (FWRA 2016).

For food waste recycling via composting, the situation is different—over the past four years, insufficient infrastructure and transportation were the dominating barriers for 75–90% of manufacturers, according to FWRA (2016). Lowering those barriers has been successful in recent years among retailers and wholesalers. Concerns of liability decreased from 67% of survey respondents in 2012 to 54% in 2014 and 25% in 2016. Furthermore, education and awareness (including liability protection for food donation provided by the Bill Emerson Good Samaritan Food Donation Act [1996]) have dramatically enhanced food donation. Barriers to food waste diversion among restaurants and food services have also declined. Issues related to storage, liability, regulations, and transportation were identified by more than 50% of the respondents in 2014, but that dropped substantially in 2016 (FWRA 2016). Transportation was the only constraint "voiced" by more than 40% of the respondents in 2016. If liability concerns (by 39% of restaurants and storage facilities) can be eased, the likelihood of large food waste reduction through donation for human consumption in this sector could be significant.

Beneath the surface of the various "whys" or "excuses" lie psychological, social, cultural, and economic factors that interactively influence our relationship with food and our food behavior.

Consumers

No one buys food to throw it away. But consumer level FLW is the single largest component of all FLW in the U.S. food chain. People throw away food because it is no longer desirable, whether the food is plate leftovers, spoiled, wilted, dried, or stale; food that has passed its label date; or food that is simply no longer wanted. Reasons leading to the point of food discard vary. Surveys of United States and other developed country consumers have identified a variety of "whys" (Corrado 2007; Graham-Rowe, Jessop, and Sparks 2014; Newsome et al. 2014; Parfitt, Barthel, and Macnaughton 2010; Quested et al. 2013). Beneath the surface of the various "whys" or "excuses" lie psychological, social, cultural, and economic factors that interactively influence our relationship with food and our food behavior. We find comfort in food, which is inherent in our genes as well as in our psyches. This is exploited by market forces—the American consumer is literally surrounded by food, well beyond supermarkets to specialty shops, quick marts and convenience stores, even gas stations and airports housing food and drink kiosks. We like large portion sizes, oftentimes equating value with quantity. The buffet mindset prevails, leading vendors to continually seek differentiation through quantity-related pitches (e.g., supersize packaging, buy one get one free), regardless of whether or not the consumer can finish what is offered or purchased. We favor aesthetically pleasing food items (color, size, shape; i.e., the "look"), and marketers cater to and reinforce our bias with discriminative grading. Many people are unaware of how crops grow in nature; urban customers are separated from food production physically (in terms of distance) and mentally, having little knowledge of how food is produced or the resources and environmental costs incurred in the food they purchase.

Furthermore, food is more affordable in developed countries. In 2015, U.S. consumers spent 6.4% of their disposable income on food, compared to 15% across most developed nations (USDA–ERS 2017b). People in countries such as Guatemala and Kenya spend 40–50% of their income on food (Gray 2016). Discarding unwanted food is easy with seemingly little consequence (Qi and Roe 2016). In short, the ubiquitous presence of affordably priced, consistently appealing, abundant, and always available food, plus effective waste collection and disposal services, make it easy to discard food. People have grown accustomed to throwing away unwanted food instead of taking measures to avoid wasting food.

The internal and external factors make it extremely difficult to change the wasteful behavior of consumers. Nevertheless, public campaigns in a variety of formats, scales, and delivery mechanisms have intensified in recent years (see Gunders and colleagues [2017] for more information) with the essential message of savor food, reduce waste. Awareness is growing;

change is happening in every corner of society. For example, civic-minded chefs create dishes or value-added food products using otherwise marginalized food items (O'Donnell et al. 2015; Quinn 2017). College students are collecting dining hall (safe-to-eat) food surplus and delivering it to community hunger-relief centers (FRN 2017). Successful and diverse innovators in consumer education are providing tools to teach people how to store and manage their food purchases or buy farm "seconds" (i.e., imperfect fruits and vegetables). Information about these and other initiatives are available in the ReFED innovators database (ReFED 2017b).

Strategies to engage consumers and enable them to substantially cut down household food waste include targeted interventions. One example is the food-too-good-to-waste (FTGTW) toolkit (USEPA 2017b) developed by the EPA to engage participating households to adopt waste-reduction practices. The work was guided by consumer-based social-marketing principles, which identify barriers to behavior change and then develop strategies to overcome those barriers. The starting point is to help participants realize how much and what kind of food they waste. Once they understand how food waste originates in their homes, they are more likely to decrease it. The easy-to-use toolkit helps participants implement smart shopping, smart storage, smart saving, and smart food preparation. Food-too-good-to-waste pilot projects have been implemented in 15 communities across the country; per capita food waste reduction ranges from 7% to 48%. The challenge is to find mechanisms to enable the widespread adoption of this and other successful models.

Consumer confusion about date labeling and the associated food safety concerns can be a significant contributor to food waste (Neff, Spiker, and Truant 2015). One survey found that 84% of survey respondents reported disposing of food according to the date label (Broad Leib et al. 2016). Whereas date labels are typically designed to convey a level of freshness, they are often incorrectly perceived as a measure of the food's microbial safety, leading food-safety-conscious people to prematurely discard food. Responding to this dilemma, the USDA Food Safety and Inspection Service now recommends that a quality-based label—"best if used by"—be placed on food packages by manufacturers and retailers for the express purpose of reducing food waste (USDA–FSIS 2016). Subsequently, the GMA and the FMI announced the launch of "best if used by" to inform consumers regarding the quality (i.e., the food may have passed its peak flavor profile) and "use by" to connote safety (i.e., do not consume after this date) (GMA 2017b). Transition to the new system is expected to be completed by 2018 where permitted by local laws. The new labeling system is likely to decrease confusion among consumers, lowering the rate of premature food discards. A similar initiative has been used in the UK (WRAP 2017). But for those consumers who want the freshest food at all times, the new date labeling may or may not make any difference.

Cross-sector Food Waste Recycling and Government Measures

Besides various food waste reduction efforts occurring at different stages of the food chain, food waste recycling (primarily through composting) has emerged as a major action that is increasingly adopted by communities, organizations, and businesses, with support measures taken by a number of state and local authorities.

Currently, five states have laws or regulations that require the commercial and institutional sectors to divert food waste from landfill disposal—California, Connecticut, Massachusetts, Rhode Island, and Vermont. Only Vermont's law (Act 148, Universal Recycling Law) includes food waste from the residential sector. Early evidence seems to indicate some positive broader impacts of these regulative measures. For example, the Vermont Food Bank reported 3.0 million tonnes of food that was rescued or donated rather than disposed of in landfills in 2015, nearly a 40% increase since Act 148 was enacted in 2012 (VT ANR 2017)—although it is worth noting that this dramatic increase came from one major retailer in the state beginning a food donation program, so it may not be representative of effects in other states. In Massachusetts, the Department of Environmental Protection reported measurable economic benefits for the state's organic waste haulers, organic waste processors, and food rescue organizations after the Commercial Food Waste Disposal Ban took effect in October 2014 (Fischer and Johnston 2017)—the number of employees across the three segments increased from 190 in 2010 to 490 in 2016; the average annual amount of material received or processed increased by 765%; the three sectors generated more than $46.8 million in labor income, contributed $76.8 million in value added to gross state product, and produced $174.6 million in industry activity in Massachusetts.

A number of states have created funding mechanisms to foster food waste reduction actions—for example, sharing the cost of food waste composting and anaerobic digestion (AD) facilities, food waste preprocessing to remove contamination and food packaging materials, or equipment to facilitate food donation (e.g., refrigeration). In California, proceeds from the state's Cap-and-Trade auction are deposited in the Greenhouse Gas Reduction Fund, which is used to support food waste reduction and recycling initiatives through competitive grant programs. In fiscal year 2016–2017, $12 million was made available for composting projects, $12 million for AD projects, and $5 million for new or expanding existing food waste prevention projects (CalRecycle 2017). In Massachusetts, up to $500,000 was awarded to two food waste haulers and one AD facility to purchase equipment to depackage and decontaminate food waste for AD (MassDEP 2016). In spring 2017, the Tennessee Department of Environment and Conservation announced the availability of $3 million in grant funding for food waste diversion under its Organics Management Grant program (TNDEC n.d.).

At the local level, some municipalities and counties have established zero waste goals that include food waste reduction and landfill diversion initiatives. Only a handful, however, have adopted laws that require food waste diversion as part of achieving their zero waste goals. These include Austin, Texas; Boulder, Colorado; New York City; San Francisco; and

Seattle. The laws of the cities of Boulder, San Francisco, and Seattle cover both residential and commercial sectors. The Austin and New York City laws apply to the commercial sector only. For example, New York City's Local Law 146, which became enforceable in January 2017, requires large food manufacturers and wholesalers, arenas and stadiums with more than 15,000 seats, and food-service establishments in hotels with 150 or more rooms (about 300 entities in total) to separate organic waste. To comply, businesses can arrange for collection by a private carter, transport organic waste themselves, or manage it on site. In July 2017, the New York City Department of Sanitation announced a proposal to require additional commercial food establishments to separate organic waste. The new proposal applies to food-service establishments larger than 7,000 square feet, such as restaurants, chain food-service establishments with 50 or more locations in New York City, and retail food stores, including grocery stores and big-box stores, larger than 10,000 square feet. Approximately 2,000 establishments are in this size tier.

Numerous initiatives exist at the local level to prevent, recover, and recycle food waste. In many jurisdictions, these initiatives are introduced and managed by local solid-waste agencies. For example, in Alameda County, California, Stop-Waste, the public agency responsible for reducing solid waste, launched the Smart Kitchen Initiative. This is a collaboration with LeanPath Inc. to subsidize the cost of preconsumer food waste measurement and tracking systems for in-county food-service providers, caterers, and commercial kitchens with an annual food budget of $300,000 or more (Johnston 2016). The Public Health Department in Orange County, California, launched the Waste Not Orange County Coalition (Waste Not OC) to help eliminate hunger and decrease food waste by capturing excess food from local restaurants and businesses and transporting it to local pantries (Goldstein 2016). County health inspectors use restaurant inspections as an opportunity to teach about donation and explain liability protections and food safety procedures. To help identify food-insecure families, the Public Health Department developed a set of screening standards for clinics to address the relationship between food insecurity and health. If families screen positive, they may go through health assessments and be connected with Waste Not OC's food pantry through Google Maps technology.

At the federal level, in September 2015, the USDA and EPA announced the first-ever national goal to decrease FLW by 50% by the year 2030, in alignment with Target 12.3 of the UN Sustainable Development Goals (SDKP 2017). Federal funding, in terms of grants and loan guarantees, for food waste recycling is minimal. The EPA's regional offices offer grants, typically in the $5,000 to $25,000 range, for food waste reduction initiatives, e.g., funding for the Rhode Island Food Policy Council to implement the FTGTW Ambassador program. The USDA's Rural Energy for America Program (REAP) provides grants and loan guarantees to farmers, ranchers, and small businesses to install renewable energy and energy-efficiency systems, including anaerobic digesters for livestock manure. Farm-based digesters in some states are allowed by state law to accept food waste streams that are codigested with livestock manure to boost biogas generation. Unfortunately, funding for REAP has been cut in recent years.

Quantitative Data on Food Waste Reduction, Recovery, and Recycling

The EPA's food waste reduction hierarchy (Figure 2) prioritizes different solutions for food waste through various efforts, which can be grouped into (1) source reduction/prevention (e.g., wastage avoided at homes and food service places or food rescued for human use from farms or marketplaces); (2) recovery/diversion (e.g., food waste directed to beneficial uses, such as feeding animals, rendering, or reprocessed fat and oil for biofuel); and (3) recycling through AD, composting, or incineration with the heat captured for energy. The logic of the hierarchy is self-explanatory; a debate is hardly necessary. In reality, however, competing interests may arise—for example, financial incentives designed to promote food waste composting may result in waste streams being diverted from a higher priority (e.g., rendering) to composters, which would lead to less desirable outcomes. This kind of situation should be avoided whenever possible while recognizing regional or site-specific conditions.

How well is the United States doing

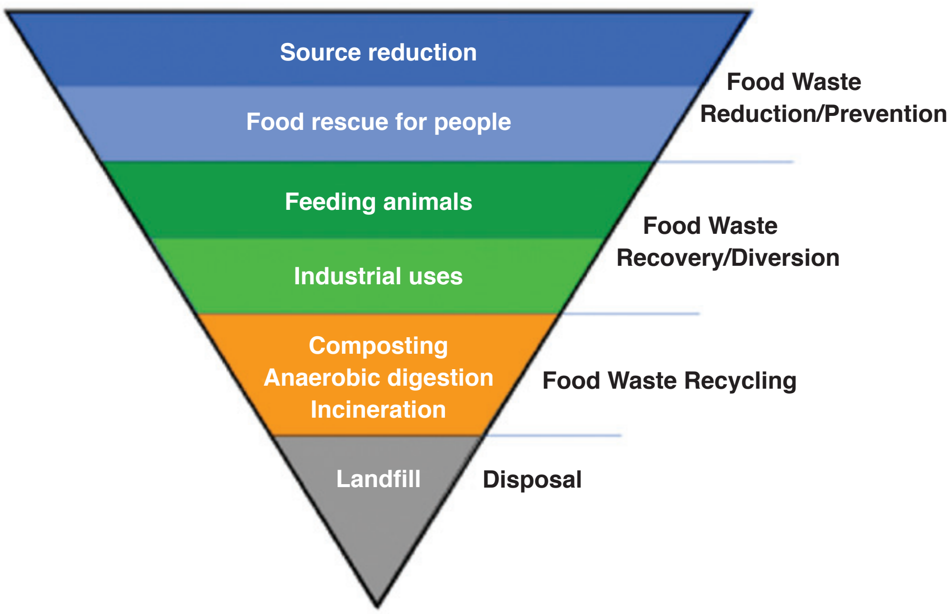

Figure 2. Food waste reduction hierarchy. Adapted from Golan (2016).

toward its goal? Quantitative data at the national level are limited. Table 2 compiles all major sources of data the authors have found. Primary data sources for food waste reduction/prevention for humans include donations from manufacturers (0.32 million tonnes) and retail/wholesale sectors (0.30 million tonnes), as well as food rescue through gleaning (0.008 million tonnes, based on a report from the Society of St. Andrew [SoSA 2016]) plus a Feeding America report (Weinfield et al. 2014) of food donation (0.19 million tonnes). In addition, an EPA report listed donations of 0.56 million tonnes, citing two specific sources (Feeding America and Food Donation Connection). Another EPA report also listed food-manufacturer donations of 0.62 million tonnes, citing an industry source. It is likely that the data cited in the EPA reports overlap with the data already tallied earlier. Food waste recovery/diversion data for (nonhuman) beneficial uses include 14 million tonnes in the manufacturing and retail/wholesale sectors for animal feeding, based on survey-result extrapolation (BSR 2013, 2014). In addition, there are approximately 1.1 million tonnes of fat, oil, and grease recovered from restaurants through rendering, according to an EPA report (see Table 2).

For food waste recycling, available data show 5.53 million tonnes via composting in the manufacturing and retail/wholesale sectors per the BSR reports (Table 2). The EPA estimates 1.42 million tonnes of food waste composting; this is comparable to the result of a recent organics-recycling survey of states showing a total of 1.66 million tonnes of food waste recycled at composting and AD facilities (27 states reporting, 2 of which reported 0 tons of food waste recycled) (Goldstein 2017). It is not clear whether or not the data tallied here include food waste recycling via numerous community-based small-scale composting operations around the country. Preliminary data from *BioCycle*'s biannual nationwide survey on "Residential Food Waste Collection Access in the U.S." (Streeter and Platt 2017) finds 343 cities and counties that provide residents access to curbside food waste collection services and 261 that provide access via drop-off sites, primarily for composting. The total number of households with collection access in those cities and counties is 9.2 million (compared to more than 110 million households in the country). The preliminary data reflect a significant increase from *BioCycle*'s 2015 report, which identified 198 cities and counties with residential food waste collection and 2.74 million households with access (Yepsen 2015).

An additional data point of significance is food waste discarded through the sanitary sewer system as industrial liquid waste (19.8 million tonnes) and consumer kitchen disposal/drain (7.4 million tonnes), according to an EPA report (USEPA 2016c). This large amount of food waste going down the drain adds to the burden of wastewater treatment plants, contributing to water quality degradation of streams, rivers, and estuaries. This is an important issue that should be analyzed to identify better solutions.

To summarize, from farm to fork and based on the most current data available, the amount of food waste reduction for the highest purpose—to feed people—falls in the range of 1–2 million tonnes; food waste recovery/diversion for nonhuman beneficial use approximates 15–16 million tonnes; and food waste recycling, primarily through composting, is roughly 7–8 million tonnes.

The data listed in Table 2 are associated with uncertainties; over- or underestimation is likely; data overlap between different sources of reporting is also possible. Nevertheless, taken together, the quantitative information provides a broad picture on how well the nation is doing—all in all, roughly 23–26 million tonnes of food is rescued, recovered, or recycled annually. Of these, about 19 million tonnes (76%) is achieved through food waste recovery or recycling at the manufacturing stage. Considering the large amounts of FLW generated in the consumption stage, much work remains to be done.

Analysis and Critical Needs

The national goal announced by the USDA and EPA is to decrease the nation's FLW by 50% by the year 2030. According to the EPA, "2010 was selected as a baseline at 218.9 pounds of food waste per person sent for disposal. The 2030 FLW reduction goal aims to reduce food waste going to landfills by 50 percent to 109.4 pounds per person" (USEPA 2017a). This baseline and the reduction target are not as clear cut as they seem. First, the EPA data are for food waste from residences, commercial establishments, and institutional sources; preconsumer food waste from food manufacturing and packaging industries is not included (USEPA 2017c). In addition, the EPA data do not capture waste disposed of in privately held landfills, in incinerators, or through sewer systems. In other words, the amount of food waste decreased at landfills (by or after 2030) would not equate to food waste reduction in the nation's food system.

Data limitations preclude using the USDA's LAFA food loss estimates (i.e., the 60 million tonnes food loss at retail and consumer levels in 2010) as a true baseline before and after 2030. A second source of potential information that could increase understanding about meeting the 2030 goal, however, would be if the ERS repeated a specific data study underlying the ERS loss estimates, such as repeating the supermarket food-loss data collection before and after 2030. The same methodology must be followed to make the comparison meaningful.

From the data tallied in Table 2, excluding data related to preconsumer food waste prevention, recovery, and recycling (e.g., donation and diversion from manufacturers as well as rendering), what is currently achieved in the nation is rather small—approximately 2 million tonnes of food waste recycling (vs. an estimated 31 million tonnes of food waste entering landfills in 2010; derived from the USEPA [2017a]) and roughly 1–2 million tonnes of waste prevention/reduction via food rescue and donation (vs. the 60 million tonnes of food loss at retail and consumer levels).

The road to a 50% reduction is long and time is short, regardless of what baseline may be appropriate.

Moving forward, how can the United States address the issue of FLW for a more sustainable future? What can government, businesses, organizations, and citizens do to decrease food waste and conserve resources? ReFED (2016a,b) has provided a road map about food

Table 2. Summary of quantitative data on food waste prevention/reduction for feeding people, food waste recovery/diversion for nonhuman beneficial uses, and food waste recycling in the United States. Amounts diverted/recycled in U.S. tons are in parentheses.

Hierarchy	Amount (10^6 tonnes/10^6 tons)	Notes
Food rescued/recovered to feed people	0.32 (0.36)	Manufacturer donation based on survey[a]
	0.30 (0.33)	Retail/wholesale donation based on survey[a]
	0.008 (0.009)	On-farm gleaning from Society of St. Andrew report[b]
	0.19 (0.21)	Donation, based on Feeding America report[c]
	0.56 (0.62)	Donation from consumer and retail[d]
	0.62 (0.69)	Donation of manufacturing and produce[e]
Food diverted to nonhuman beneficial use	13.9 (15.4)	Manufacturer diverted to feed animals[a]
	0.1 (0.1)	Retail/wholesale diverted to feed animals[a]
	1.1 (1.21)	Restaurant grease[f]
Recycling	5.0 (5.6)	Manufacturer-reported composting[a]
	0.53 (0.59)	Retail/wholesale-reported composting[a]
	1.42 (1.58)	Composting[d]
	1.66 (1.91)	Response of 24 states to a survey[g]

[a] BSR (2012, 2013, 2014)
[b] SoSA (2016)
[c] Weinfield et al. (2014)
[d] USEPA (2016c)
[e] USEPA (2013)
[f] USEPA (2014)
[g] Goldstein (2017)

(A very large quantity of food-processing by-products is routinely fed to animals, including 30.4 million tonnes of oilseed meals, 10.9 million tonnes of mill by-products, and 2.5 million tonnes of animal proteins fed to livestock animals on an annual basis [Ferguson 2016]. In addition, an estimated 27 million tonnes of ethanol and brewer by-products are also fed to animals. Furthermore, the U.S. rendering industry collects 25 million tonnes of raw materials [bone, feather, blood, offal, etc.] from slaughterhouses annually and processes them into various value-added products such as meat and bone meals for beneficial uses [Meeker and Meisinger 2015]. All these by-products and their recovery/diversion are not included in Table 2 because by convention they are not considered in the FLW domain.)

…evidence-based quantitative data are essential for the nation to move beyond setting the goal and work toward attaining the goal.

waste reduction, recovery, and recycling with 27 actionable items, coupled with cost-benefit analysis. The NRDC report (Gunders et al. 2017) presents a suite of recommendations along with many useful tools and success stories. Those recommendations and the road map for actions serve as valuable resources.

Attempting to broaden the path toward food waste reduction for a sustainable future, the authors present a critical analysis from a different perspective, focusing on three key issues:

- How can the nation work knowingly and confidently toward the 50% reduction goal?
- What technological innovations may function as game changers?
- What other approaches could be explored to influence consumer food behavior?

How Can the Nation Work toward the 50% Reduction Goal Knowingly and Confidently?

As described earlier, a great deal of effort has gone into promoting food waste composting (and AD, to some extent), with a number of states, cities, and municipalities having established legislative- or incentive-based programs/measures. The focus of these programs/measures has largely been on commercial generators. For the nation to work toward the 50% reduction goal, it is important to quantitatively assess the effectiveness of the current programs and measures to address the following sets of questions: (1) How well do those programs/measures work? Do incentive- vs. legislative-based programs work equally well? What is the best-case scenario (most effective) and the worst-case scenario (least effective)? (2) What is the range of setup and operation costs (i.e., dollars per tonne of food waste composted, digested, and recycled), and what are the measurable benefits besides perceivable environmental impacts? How do the estimated benefits compare to the estimated costs? What are major lessons, barriers, and potential issues for widespread adoption and implementation of food waste composting and AD practices? (3) Regarding the U.S. 2030 reduction goal, how can the nation scale up the food waste recycling programs? Would 90–100% compliance by businesses be adequate, or is household participation a necessity to attain the 50% reduction goal?

The answer to the last question would be yes, based on the estimates of 22.7 million tonnes of food waste from consumer-facing businesses and 24.5 million tonnes at home (ReFED 2017a). That means the nation needs to step up with plans and schemes to engage consumers for household food waste collection for composting and AD. Again, evidence-based quantitative data are essential for the nation to move beyond setting the goal and work toward attaining the goal. In addition, the United States may benefit from a thorough review of lessons learned by other developed countries in reducing FLW. Of course, composting and AD should be the last resort in the food waste reduction hierarchy; it would work best in tandem with prevention and recovery efforts higher in the hierarchy (Figure 2).

What Technological Innovation May Function as a Game Changer?

A potential game changer in the realm of food waste reduction, recovery, and recycling is to convert food waste generated at the consumption stage (consumer-facing businesses as well as homes), the largest food waste streams, into animal feed. This would simultaneously serve food security, sustainability, and waste management purposes, because the replaced feed grains can be added back to the human food supply while livestock animals fed with recovered food waste enrich the human food supply by providing meat, milk, and eggs. As noted earlier, food manufacturers routinely divert large volumes of food-processing by-products to animal feed, favored by the economies of scale and adding profit to the bottom line.

Why is this not happening with wasted food at the consumption stage? Several major barriers exist, hindering widespread adoption of the practice in the United States (and other developed countries). First is the concern over animal health and relevant biosecurity measures. For example, by law, food waste must be heated to 100°C for 30 minutes before being fed to pigs (also known as the Swine Health Protection Act; U.S. Congress 1980). Another barrier is related to the "characteristics" of the food waste—it can be in any form, cooked or uncooked, wholesome or spoiled. The food waste at this stage is extremely diffuse, scattered among roughly 1 million restaurants and more than 110 million households across the country, resembling "nonpoint sources" in contrast to the "point sources" of food waste streams at large manufacturing or processing sites (Dou et al. 2016). Furthermore, consumer food waste varies a great deal in composition and nutritional attributes, making it incompatible with the precision feeding for maximal efficiency of today's animal production systems (Banhazi et al. 2012).

The technological innovation needed for a game changer is one that can effectively dehydrate, sanitize, and homogenize food waste materials to simultaneously surmount those barriers. With the development of such a technology, the logistics of collecting and handling food waste from the diffuse sources would be similar if food waste composting were to be adopted and implemented across the nation. Notably, animal feed derived from food waste would have much higher economic value compared to compost. How much the value addition might be requires research—e.g., to characterize the nutrition profile (i.e., energy density, protein content, and other nutritive attributes) of the food waste, document the range of variability, and explore ways to optimize feeding scenarios for production efficiency and sustainability purposes.

Other practical issues to address include what animal species (cattle, swine, or poultry) would be most suitable or would benefit the most from feeding (treated) consumer food waste; at what capacity (minimum/maximum amount per head per day) or boundary (minimum/maximum concentration for a given nutrient) without compromising animal performance; and at what price and conditions relative to traditional grain-based feeding programs. Such technological innovation, coupled with research addressing the production and economic essentials, could have the potential for a transformative change of the current food waste management paradigm. Toward that end, creative policies and mechanisms to foster technological development, enable entrepreneurship, and support relevant research are crucial. It is important to note that South Korea has provided a working model with demonstrated success—about 45% of all food waste generated in the nation, including that at the consumption stage, is collected and treated into safe, nutritious, and value-added animal feed, as summarized in a recent review article (Dou, Toth, Westerndorf 2018).

What Other Approaches Could Be Explored in the Consumer Food Behavior Domain?

Ultimately, changing consumer behavior from wasteful to sensible use of food is the best option for the most desirable outcome—to prevent food from being wasted in the first place. Human behaviors, whether they are about food or other important matters such as health or wealth management, are complex. The decisions and actions consumers make and take are not necessarily rational nor straightforward but subject to the influence of many internal and external factors (Moseley and Stoker 2013). Recent research has started to examine the phenomenon of food-wasting behavior in light of established theories in social, behavioral, and psychological sciences. For instance, Block and colleagues (2016) set forth a behavior theory-based agenda to explain consumer behaviors in the "squander sequence," from preacquisition (purchase) to acquisition to consumption and disposal. The advanced work by the UK's Waste and Resources Action Programme (WRAP) demonstrates that consumer food waste behaviors have a "marked habitual element" and a "pronounced emotional component" (Quested et al. 2013). Considering the subject of food waste through the lenses of different academic disciplines has helped WRAP develop public engagement campaigns on food waste issues, contributing to the great success of 21% reduction in avoidable food waste in UK households (Quested, Ingle, and Parry 2013).

> ***…when seeking to develop a capacity for consumer behavior change in a modern and democratic society, the micro-foundations of human behavior and how cognitive pathways, social norms, and moral convictions influence thinking and behavior need to be understood.***

New insights from psychology and behavioral economics, which, according to Moseley and Stoker (2013), have encouraged a "paradigm shift" in the policy arena toward a focus on "nudge" strategies as in contrast to "command-based" interventions, are of particular interest. The new way of thinking is that when seeking to develop a capacity for consumer behavior change in a modern and democratic society, the micro-foundations of human behavior and how cognitive pathways, social norms, and moral convictions influence thinking and behavior need to be understood. Although skepticism remains (especially concerning the limitation of nudging in addressing powerful social problems such as obesity or other health issues), "nudge works best" when there is shared consensus about expected behavior changes that are widely viewed as "the right thing to do" (John et al. 2013). Clearly, the ability to meet the challenges of food waste reduction, resource conservation, and environmental sustainability hinges to a large extent on individual consumers' willingness to alter their habits and behavior and cut down their foodprint. Nudging may hold considerable potential as a new tool to help change aspects of consumer behavior. Toward this end, action-based research is needed to help uncover new insights about how to approach consumers or perhaps emphasize ways of understanding that have not been explored.

Humans have always wasted food, but the scale of the problem today is unprecedented in history. For the past 60–70 years, society has largely succeeded in producing more to feed more. Looking back, the path taken has been a lopsided approach—pushing for greater production with little regard to sustainable consumption. Looking around, there is evidence of environmental damage as a consequence of this long-time negligence. Looking ahead, feeding 9 billion people cannot be addressed by pushing for greater production alone; sustainable consumption and decreasing food waste must be incorporated into the food security and sustainability agenda. Wasting less to feed more offers multifaceted benefits of combating hunger, enhancing food availability, improving resilience of food systems, and strengthening resource and environmental performance.

Substantially decreasing food waste is attainable. Opportunities exist throughout the supply chain. Meaningful progress can be made household by household, business by business, and step by step, as long as people are willing to take actions to change wasteful lifestyles and society enables such change with necessary support in terms of policy, research, innovation, and technology development.

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