Chapter 2

Waste Resources in the Food Supply Chain

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2.1 INTRODUCTION

As introduced in Chapter 1, food waste is a major global problem that has significant environmental, economic, and social sustainability implications. It is widely recognized that many of the conventional practices for handling food waste resources (Chapter 3) are inadequate in their ability to recover embodied energy and water. To begin to transition the global food supply chain (FSC) to alternative waste management technologies, including the waste-to-energy systems described in Chapters 4–9, it is necessary to first clearly define what is meant by food “waste” and “loss,” and then quantify how much waste occurs at each stage of the FSC: agriculture, food processing, consumer-facing businesses, and households.

Part of the challenge surrounding quantification of food waste is that there is no universal definition of what is actually considered “waste,” and as these materials move through the supply chain, they become increasingly heterogeneous and geographically dispersed. Huge volumes of waste are created in agricultural and food processing operations, but in many cases these waste streams are of fairly uniform composition and generated at a relatively small number of physical locations. At the other extreme, when food waste is generated at millions of individual residences, it is often a mixture of many different types of materials and usually combined with the rest of the solid waste typically produced in the normal function of operating a household. A significant complication is the introduction of packaging at the food processing stage, and this second material phase needs to be comprehended in developing potential waste-to-energy (WtE) solutions for converting waste generated downstream at consumer-facing businesses and households.

As discussed in a number of recent publications (e.g., Ebner, 2016; Hall, 2016; Derqui et al., 2016; Bellemare et al., 2017; Corrado et al., 2017), there is a wide variety of definitions that have been proposed for food waste materials, and proper quantification of resources available for alternative utilization pathways requires that these definitions are clearly established from the outset. The definitions proposed by the Food and Agriculture Organization of the United Nations (FAO, 2013) are summarized as follows:

- **Food loss** refers to a decrease in mass (dry matter) or nutritional value (quality) of food that was originally intended for human consumption. These losses are mainly caused by inefficiencies in the food supply chains, such as poor infrastructure and logistics, lack of technology, insufficient skills, knowledge and management capacity of supply chain actors, and lack of access to markets. In addition, natural disasters play a role.
- **Food waste** refers to food appropriate for human consumption being discarded, whether or not after it is kept beyond its expiry date or left to spoil. Often this is because food has spoiled but it can be for other reasons such as oversupply due to markets, or individual consumer shopping/eating habits.
- **Food wastage** refers to any food lost by deterioration or waste. Thus, the term “wastage” encompasses both food loss and food waste.

In an earlier publication from the same organization (Gustavsson et al., 2011), somewhat different definitions were recommended:

“Food losses refer to the decrease in edible food mass throughout the part of the supply chain that specifically leads to edible food for human consumption. Food losses take place at production, post-harvest and processing stages in the food supply chain (Parfitt et al., 2010). Food losses occurring at the end of the food chain (retail and final consumption) are rather called “food waste”, which relates to retailers’ and consumers’ behavior.”
Several studies also attempted to distinguish between FSC losses that are “planned” or “unavoidable,” from those that are “unplanned” or “avoidable.” For example, Quested and Johnson (2009) offered these definitions:

- **Avoidable Food Waste**: “Food and drink thrown away that was, at some point prior to disposal, edible (e.g. slice of bread, apples, meat).”
- **Possibly Avoidable**: “Food and drink that some people eat and others do not (e.g. bread crusts), or that can be eaten when a food is prepared in one way but not in another (e.g. potato skins).”
- **Unavoidable Food Waste**: “Waste arising from food or drink preparation that is not, and has not been, edible under normal circumstances (e.g. meat bones, egg shells, pineapple skin, tea bags).”

Although these definitions appear to be tailored for losses generated during the consumption phase, they may also apply to upstream FSC stages as well. For example, in the case of potatoes (described in detail in connection with Fig. 2.4), the skins are often generated as waste in the process of manufacturing frozen French fries or as a prepared food item in a grocery store or restaurant, and thus may be considered a “possibly avoidable” waste resource across the food supply chain.

For the purpose of defining the universe of food materials available for waste-to-energy conversion, it is reasonable to be as broad as possible, and identify any potential feedstocks that could be used as feedstock, even if currently they are diverted to beneficial use. For this purpose, we recommend the definition proposed by Stenmarck et al. (2016) for The European Union’s FUSIONS program, focused on reducing food waste through social innovation:

“Food waste: Fractions of 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, bioenergy production, co-generation, incineration, disposal to sewer, landfill or discarded to sea).”

Thus, in the discussion that follows, we make no distinction between food “waste” and “loss” and use the terms interchangeably to represent the mass of material that leaves the food supply chain for any reason prior to human consumption.

Once the geographic scale is appropriately constrained, it is important to acquire as much data as possible to adequately quantify total annual waste volumes and the generation locations, as well as significant temporal variations (e.g., due to production schedule, seasonal demand, etc.), waste phase (solid, liquid, packaged; Chapter 3), and physical/chemical characteristics that will dictate the “best” WtE conversion pathway.

### 2.2 GLOBAL PERSPECTIVE

There are a number of relevant studies that have considered the quantification of food loss and waste on a global scale (e.g., Parfitt et al., 2010; Lipinski et al., 2013; Ghosh et al., 2016). Although it is clear that consistent data are seriously lacking, especially in less economically developed countries, several general trends have been widely reported. First, the distribution of waste among different stages of the FSC varies greatly across different global regions (Fig. 2.1). In developing countries, the majority of waste occurs toward the agriculture end of the supply chain, due to inefficiencies in harvesting and immediate product handling, and the lack of suitable infrastructure for storage and refrigeration. In more affluent countries, the major source of food waste is at the consumption phase, often because of the wide disparity between the amount of food needed for healthy living and what is actually procured, some of which spoils before it can be consumed. As presented in Table 2.1, consumption losses range from 61% of total food waste in North America and Oceania to only 5% in sub-Saharan Africa, while combined production, handling, and storage account for 76% of waste in sub-Saharan Africa and 23% in North America and Oceania. The widely cited study of Gustavsson et al. (2011) considered different food waste dynamics among medium- and high-income countries in three regions (Europe including Russia; United States, Canada, Australia, and New Zealand; China, Japan, South Korea) and low-income countries in four regions (sub-Saharan Africa; North Africa, Central Asia and Western Asia; South and Southeastern Asia; Latin America), and identified these key differences:

- Medium- and high-income country food wastes result primarily from:
  - Deficient quality, including aesthetic defects.
  - Scraps generated during food processing, including transportation losses.
  - Poor environmental conditions during display in retail facilities, which accounts for over 50% of fruit and vegetable waste.
  - Lack of proper planning and communication in food service operations.
  - Use of “best by” dates that encourage consumers to discard food that is still edible.
Low-income country food wastes result primarily from:
- Poor storage facilities which result in rodent and insect infestation, especially in warm, humid climates.
- Poor infrastructure and transportation, combined with a lack of refrigeration.
- Inadequate market facilities that are unsanitary and also lack refrigeration facilities.
- Poor packaging that jeopardizes food products moving from the agriculture phase to processing and/or retail.

It is interesting to note that despite the widely different distributions of waste in these various regions, the data in Fig. 2.1 indicate that the total amount of waste as a percentage of available food resources is similar in Europe, Industrialized Asia, and sub-Saharan Africa (22%–25%). However, North America and Oceania have by far the least inefficient food systems (i.e., 42% of available food is wasted), and more than twice the per capita rate of food waste (on a kcal basis) of any other region.
The relative economic impacts of food loss in different global regions also play an important role. For example, in the United States food accounts for about 11% of the average household budget (Fig. 1.2; USDA, 2016), while in some developing countries (particularly in poor rural regions) a significant fraction of income is spent on food (Barrett and Dorosh, 1996).

2.3 NATIONAL PERSPECTIVES

The global food waste overview in Section 2.2 provides a macroscale picture of where opportunities may exist in different regions for upcycling food waste resources, including application of waste-to-energy conversion technologies. However, it is necessary to delve into country-level data to develop a better perspective of what options offer the best pathways for maximizing economic and environmental benefits of food waste utilization. As is the case in many areas of energy research, larger and more economically advanced countries tend to have available more reliable primary data, but as described later there are a number of published studies that focus on analysis of food waste resources in a variety of specific countries and regions. As reported by Parfitt et al. (2010), there are major gaps in the availability of accurate country-scale food waste data, with much of the information for developing countries acquired many years ago, and information for rapidly expanding countries (including the BRIC nations of Brazil, Russia, India, and China) largely absent altogether.

Thi et al. (2015) conducted a study of food waste trends in developing countries and found a strong correlation between per capita gross national income (GNI) and the food waste generation rate when few or no “zero waste” policies have been implemented. For example, with a per capita GNI of $1570 (US dollars, based on 2009–2013 World Bank data) India had a per capita food waste generation rate of 0.06 kg/day (Ranjith, 2012; Manipadma, 2013). Conversely, Brazil (the most affluent developing country studied, with per capita GNI of $11,690) had a per capita food waste generation rate of 0.17 kg/day (Corsten et al., 2012). Among developed countries, the United States had the highest food waste generation rate of 0.52 kg/person/day. However, it was also observed that many developed countries such as Germany, Singapore, Sweden, and Denmark have more advanced waste utilization strategies and thus the per capita food waste generated falls below the general trend that represents data for all the developing countries considered, but also Taiwan, the United Kingdom, and the United States. For example, with nearly the same per capita GNI as the United States, Singapore’s food waste generation per person is 23% lower (0.40 kg/day; NEA, 2013).
Because of the now global recognition that food waste is a major environmental, economic, and social challenge, there has recently been a growing number of published studies on region- and country-specific food waste characterizations and assessments of potential alternative utilization strategies. Since the publication of the work of Thi et al. (2015) that presented food waste data for 25 developed and developing countries, there has been a number of new studies, especially focused on rapidly expanding Asian economies. Ong et al. (2017) recently explored trends in food waste valorization in India, Thailand, Singapore, Malaysia, and Indonesia. They found that there is significant potential in waste-to-energy conversion and upcycling to value-added food products and “green” chemicals, but also that legislation and public perception play key roles in supporting these new industries. Minten et al. (2016) studied the potato sector in Bangladesh, India, and China and reported that product transportation contributes significantly to losses across the FSC and recommended investment in improved cold storage facilities to alleviate this problem. The research of Gokarn and Kuthambalayan (2017) identified challenges inhibiting the reduction of losses in the Indian food supply chain, which accounts for 20% of gross domestic product (GDP) and 50% of the population’s employment. They recommended that the greatest impact could be achieved by addressing challenges related to food characteristics (perishability, quality variation, seasonality, and bulkiness), supply chain uncertainty, market infrastructure, and food policy and regulation. In a focused study of food waste in the hotel sector of Jaipur City, India, Gandhi et al. (2017) showed there is significant potential for biogas production and economic return through improved collection efficiency and waste utilization. Several recent studies from China have also characterized food waste in particular FSC sectors or cities. For example, Wang et al. (2017) surveyed 195 restaurants in four cities and reported that waste produced per meal depends on many factors, with more waste produced in larger restaurants, and by tourists as opposed to local residents. De Clercq et al. (2017) also studied Chinese restaurant waste in the context of biogas production via anaerobic digestion (Chapter 4) and offered six national policy recommendations to accelerate this waste conversion pathway, including improving collection efficiency by incentivizing generators to direct waste from landfills or incinerators to biogas projects. Other recent studies have analyzed food waste resources in targeted Chinese cities, including Beijing (De Clercq et al., 2016; Ek, 2017) and Suzhou City (Wen et al., 2016). Other developing countries with large populations are also focusing their attention on the potential for productively utilizing food waste materials. For example, Salihoglu et al. (2017) recently conducted a comprehensive review of food loss and waste in Turkey and showed that a significant fraction of the national energy demand can be met by utilizing biomass lost in the initial phases of the FSC, combined with dedicated energy crops grown on fallow land.

In many countries of the European Union (EU), mature food waste valorization systems already exist, but research is still being conducted to identify additional opportunities in specific FSC sectors. Taking an EU-wide perspective, Sala et al. (2017) quantified food waste from the macroscale to single stages of the FSC, and used “top-down” and “bottom-up” approaches to provide estimates of waste generation rates. They considered the specific example of tomatoes to compile bottom-up data for losses from agricultural production, manufacturing, distribution, and consumption phases. Eberle and Fels (2016) reported that in Germany, the best opportunities for food waste reduction exist with products of animal origin, and especially in the context of agricultural production and consumption (both in households and out-of-home). Raak et al. (2017) conducted interviews with representatives of 13 German food processing companies and identified a wide range of causes of food waste and loss, resulting in recommendations such as alternate food production pathways for “second choice items” and greater deployment of backup power systems to avoid production waste during loss of grid power. Redlingshöfer et al. (2017) considered losses in the French food supply chain, with a specific focus on the primary production and processing phases. In 2013, up to 12% of fruit and vegetables were lost before the retail phase, and secondary food products and animal feed were identified as two pathways that could play a moderate role in reducing these wastes. In Sweden, Scholz et al. (2015) assessed food waste and the associated carbon footprint (CF) for supermarkets. Their analysis showed that fruits and vegetables contribute 85% of the mass of waste and 46% of the CF, but only three products (tomatoes, peppers, and bananas) accounted for nearly half of this portion of the CF. Conversely, meats contributed 3.5% of the waste mass, but 29% of the total CF.

In the United Kingdom (UK) there has been a strong centralized effort to improve FSC efficiency and minimize food loss, mostly through the efforts of the Waste and Resources Action Programme (WRAP), with a goal of a 20% reduction in per capita waste and greenhouse gas emissions associated with the food and beverage industry by 2025.1 This organization has compiled extensive data to characterize the trends in waste generation, especially at the household level (Quested and Parry, 2017), which accounted for 71% of waste, 7.3 MMT2 in 2015 (WRAP, 2017). Although there is generally a lack of data available for other stages of the FSC, several studies have focused on opportunities for minimizing food losses in the

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2. MMT = million metric ton. A metric ton is equivalent to 1000 kg and approximately 1.1 short tons.
retail sector and point to the importance of information sharing and management practices on the scale of an individual grocery store (e.g., Mena et al., 2011; Filimonau and Gherbin, 2017).

The overall size of the food industry in the United States is much larger than in the United Kingdom or any single country of the European Union, and thus the amount of food waste resources available are comparatively higher. Several studies have attempted to quantify the waste on a national scale, and published estimates vary somewhat depending on the definitions of food waste and loss, as described previously, and the sources of primary data. For example, in the widely cited report by ReFED (2016a), the total U.S. food waste level was estimated as 56.7 MMT, with agriculture, food processing, consumer-facing businesses (groceries, restaurants, institutional food service, etc.), and households accounting for 9.1, 0.9, 22.7, and 24.5 MMT, respectively. Several other publications have suggested that the ReFED report significantly underestimated the total level of food waste because it quantified only edible material going to landfills and cosmetically imperfect produce left unused on farms and in packing operations that can be repurposed for higher value use. For example, Dou et al. (2016) quantified total U.S. food waste at 96.2 MMT, with industry (handling, processing, manufacturing), retail and consumers accounting for 35.9, 19.5, and 40.8 MMT, respectively. Using primary data from Buzby et al. (2014) (based on data from the U.S. Department of Agriculture’s Loss Adjusted Food Availability databases; USDA, 2015) and reports of the Food Waste Reduction Alliance for losses in the food processing, wholesale and retail sectors (BSR, 2014), they estimated food waste across the FSC according to different food groups, as shown in Fig. 2.3. Here the values represent the percentage of food entering each of the supply chain sectors that is wasted by the food group in that sector. For example, in the vegetable food group, 31% of the total mass produced is lost in the industrial stage of the FSC, with retail and consumer stages accounting for 8% and 22%, respectively. In total, industrial, retail, and consumer losses accounted for 15%, 10%, and 21% of the mass of all food produced.

Beyond just quantifying the total mass of food that is wasted, there has also been significant interest in calculating the associated economic value of this waste. For example, Buzby and Hyman (2012) applied retail prices to retail and consumer level losses in the United States from 2008 and computed a staggering total value of $165.6 billion.

![Estimated food loss across the U.S. supply chain](image)

**FIG. 2.3** Estimated food losses across the U.S. supply chain, based on percentages of total production in each food group (Dou et al., 2016).
Meat (including poultry and fish), vegetables, and dairy products were the largest contributors, accounting for 41%, 17%, and 14% of the total value, respectively. The ReFED report and associated Technical Appendix (2016a,b) applied a combination of wholesale and retail prices to compute total loss values in agriculture, manufacturing, consumer-facing businesses, and households of $15 billion, $2 billion, $57 billion, and $144 billion, respectively (Fig. 1.8). Others have questioned the methodologies applied in these studies and have concluded that the loss values are highly inflated and thus of limited value to policymakers (e.g., Koester, 2013). In any case, when assigning economic value to food losses in the context of evaluating potential investment in food waste-to-energy systems, it is critical that a consistent and transparent methodology be applied.

An excellent source of information for food supply chain material flows and losses is the United States Department of Agriculture (USDA) Economics, Statistics and Market Information System (ESMIS) that contains nearly 2500 reports and datasets from several agencies within USDA.3 This resource covers U.S. and international agriculture and provides many time series datasets in spreadsheet format that are updated annually. Using this data, it is possible to develop a detailed picture of how much commodity crops move through the FSC, including where major waste streams are generated in agriculture, processing, retail, and consumption stages. For example, in Fig. 2.4, data for the potato supply chain in the United States are presented as a Sankey diagram, whereby total supply on the left (26.42 Mt) is distributed among fresh consumption, processed consumption, and mass losses, the latter accounting for 41% of total supply. Mass losses during processing were estimated using factors adapted from Hung et al. (2006):

- 15% mass loss in chips/shoestring processing, other frozen and miscellaneous products
- 12% solid mass loss during dehydration,
- 26.5% during frozen French fry production and canning
- 2.5% mass loss in starch/flour production.

Also, mass loss factors of 10% and 6% were used in the retail stage for fresh and processed potatoes, respectively, and for the consumption phase loss factors of 22% and 16% were applied for fresh and processed potatoes (Buzby et al., 2014).

A subset of the data in Fig. 2.4 related to the specific solid, oil based, and aqueous waste streams has been reconfigured in Fig. 2.5 to highlight the waste volumes as well as the potential for waste-to-energy conversion. Potato peel waste quantities were calculated using a factor of 12% (Hung et al., 2006); mass losses from trimming and blanching operations are not

![FIG. 2.4 Sankey diagram showing mass losses in U.S. potato supply chain. All mass flows were calculated based on production and utilization data averaged over the 2000–2006 period, as obtained from USDA’s food availability database: http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1235. (c) Losses not calculated; (d) includes losses due to shrinkage, unavoidable waste during processing, and losses due to cooking, but does not include losses from water evaporation; (μ) approximately 60% of the mass is water evaporated during dehydration (Hung et al., 2006); however, water loss due to evaporation is not included in mass loss calculation as this water does not represent a waste stream. (z) 2015 data (National Potato Council, 2017). Note that “Mt” indicates million short tons, where a short ton is equivalent to 2000 lb., or approximately 0.91 metric ton.](http://usda.mannlib.cornell.edu/MannUsda/homepage.do)
<table>
<thead>
<tr>
<th>Processing Type</th>
<th>Peel Waste, Mt</th>
<th>Waste Oil, Mt</th>
<th>Waste Water, GL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frozen French fries</td>
<td>1.1</td>
<td>1</td>
<td>84.16</td>
</tr>
<tr>
<td>Chips/shoestrings</td>
<td>0.37</td>
<td>0.89</td>
<td>30.02</td>
</tr>
<tr>
<td>Frozen (other)</td>
<td>0.14</td>
<td>NA</td>
<td>13.18</td>
</tr>
<tr>
<td>Dehydration</td>
<td>0.32</td>
<td>NA</td>
<td>6.13</td>
</tr>
<tr>
<td>Canned (all)</td>
<td>0.14</td>
<td>NA</td>
<td>1.34</td>
</tr>
<tr>
<td>Misc. (salad, vodka)</td>
<td>0.1</td>
<td>NA</td>
<td>0.82</td>
</tr>
</tbody>
</table>

*FIG. 2.5* Solid (peel) waste, oil based, and aqueous waste streams associated with potato processing operations. (c) Biomethane potential, 23 m$^3$/wet ton potato peels (Hamilton, 2012). Electricity potential was calculated using an energy value of 6.4 kWh/m$^3$ for biomethane and 35% electric conversion efficiency (Deubking and Steinhauser, 2008); (f) estimated using 80% conversion efficiency; biodiesel density is 874.6 kg/m$^3$. (¥) Estimated for wastewater streams (55% of the total) excluding wash water, with the following assumptions/data used: starch content of waste water is 15% (Hung et al., 2006; Beynelmilel Food Corp, 2008), ethanol conversion efficiency of starch (glucose) is 51% (Lee et al., 2015), cellulose density is 1500 kg/m$^3$, and ethanol density is 789 kg/m$^3$. (π) COD values from Hung et al. (2006). Note that “Mt” indicates million short tons, where a short ton is equivalent to 2000 lb., or approximately 0.91 metric ton.
included in solid waste stream, as starch from these operations accumulates in the wastewater stream. The wastewater flows of 5625, 4275, 1668, and 2345 L/raw ton of potatoes were used to calculate wastewater quantities for washing, peeling, trimming, and blanching, respectively (Hung et al., 2006; Beynelmilel Food Corp, 2008). In chips/shoestring production, 530 kg oil are used per ton of potatoes and 63% are wasted; in frozen French fry production, 200 kg oil are used for prefrying one ton of potatoes and 80% of this amount enters the waste stream (Beynelmilel Food Corp, 2008). Potato peel waste quantities were estimated using a factor of 12% mass loss (Hung et al., 2006).

As described in Sections 2.2 and 2.3, many studies have been conducted to characterize waste at the global scale and in certain select countries. However, most of these sources lack the granularity needed to fully understand the nuances of FCS interactions that often lead to food waste and loss. It is also pertinent to note that significant financial resources are required to quantify and characterize waste in a scientifically rigorous manner, and the process of acquiring accurate food waste data may be impractical in many developing countries and less economically advanced regions of developed countries. Moreover, as recently discussed by Reutter et al. (2017) in connection with food waste research in Australia, there are different methods available to quantify food waste at a national scale, and these methods do not necessarily yield consistent results. There is no “one-size-fits-all” solution to food waste valorization, and the most sustainable outcome will depend on the local waste resource availability, existing conversion facilities, demand for energy and fuel, policy and regulatory framework, etc. Therefore, characterizing food waste at a more local scale with the greatest possible level of detail is an important precursor to assessing potential waste-to-energy pathways. Because it is obviously impossible to provide in this document such detailed data for all global regions, we focus our attention in Section 2.4 on New York State as an example of a relatively highly populated region that has a diverse mix of large urban centers with surrounding suburban zones, medium-sized cities, and rural areas comprised of smaller towns and villages. Finally, we proceed to even finer resolution and illustrate the process whereby the available food resources in a smaller, well-defined region can be identified and quantified to support consideration of alternative food waste valorization strategies.

### 2.4 ASSESSMENT OF STATE AND REGION-SPECIFIC FOOD WASTE RESOURCES

Our group has been actively involved in research focused on food waste valorization in New York State (NYS), an effort largely motivated by the expectation that in the future NYS will join other Northeastern states (Connecticut, Massachusetts, Rhode Island, and Vermont) and California in passing a food waste landfill ban (Jones, 2017; Breunig et al., 2017). This legislation was mentioned in the 2016 State of the State address, in which Governor Andrew M. Cuomo directed that any commercial entity producing more than two tons of food waste per week, such as grocery stores, colleges, hospitals, and restaurants, would be required to donate or recycle these materials and thus divert them from methane-producing landfills (Cuomo, 2016). However, to effectively implement a landfill ban and achieve the desired environmental benefits while avoiding excessive economic burdens on food sector companies and institutions, there needs to be a comprehensive understanding of where waste is generated, the amounts generated (including seasonal variations), and the physical and chemical characteristics of the waste in terms of its phase (solid, liquid, packaged), moisture content, volatile solids content, pH, etc. Acquiring, organizing, analyzing, and disseminating this information requires cooperation and collaboration across the food supply chain, and a willingness among sector stakeholders to work toward the common goal of food system sustainability.

As part of the effort to enhance understanding of state-level food waste challenges, The New York State Pollution Prevention Institute (NYSP2I) at Rochester Institute of Technology has developed the Organic Resource Locator (ORL), a publicly accessible, web-based mapping tool that according to the web site:

“… provides information on organic waste resources and utilization pathways in New York State. The goal of the Organic Resource Locator is to enable efficient and increased utilization of organic resources by connecting producers of organics with those who have a use for them, diverting a valuable resource from our landfills. NYSP2I hopes this effort will help reduce environmental impacts, promote economic development and encourage the development of green technologies.”

As shown in Fig. 2.6, this tool enables the user to identify generators in hospitality, restaurant, institutional, and retail sectors, which are clearly concentrated in the Upstate population centers of Buffalo, Rochester, Syracuse, and Albany, as well as in the New York City and Long Island regions.

To further facilitate improved understanding of available food waste resources and potential valorization opportunities (including waste-to-energy), the New York State Energy Research and Development Authority (NYSERDA) recently sponsored a study to quantify the food waste originating from “large” generators, that is, those producing >2 tons/week as earlier defined in the State of the State address (Manson, 2017). This report used data for large food waste generators from an earlier publication by Labuzetta et al. (2016). Because New York City (NYC) already has a landfill ban in place,
this report identified the total number of food waste generators outside of NYC that would be affected by a landfill ban, and the associated annual waste generation rate, as summarized in Table 2.2. Because many food processing companies already divert a significant fraction of their waste to animal feed or other valorization pathways, this study focused on three specific sectors:

- **Institutions**, including colleges and universities, hospitals, nursing homes, and correctional facilities.
- **Retail**, including wholesale facilities, big box stores, convenience stores, supermarkets, and supercenters.
- **Service and hospitality**, including hotels/motels and restaurants.
Higher generation rates would be computed for large generators if we included the mass currently being diverted to beneficial use facilities. Labuzetta et al. (2016) estimated that 42% of food waste from wholesale and distribution sectors is diverted to food banks, composting, and anaerobic digestion (AD). If these additional resources were included, the total large generator food waste mass would increase from about 456,000 ton/year to over 588,000 ton/year.

To facilitate meaningful discussion of what technologies may be suitable for valorization of food supply chain resources, data for waste volumes and characteristics need to be available at a scale that is commensurate with the expected size of a deployed conversion facility. For example, to support a centralized anaerobic digestion or fermentation facility, it is likely that all feedstocks would need to be available within about a 50 mile (80 km) radius, otherwise the economic and environmental burdens associated with transport and handling would make the entire enterprise impractical. Also, to achieve broad support among local policymakers and industry stakeholders, it makes sense to align such large investments with existing geographic, political, or commercial boundaries. In New York State, a convenient framework for exploring potential investment opportunities in waste-to-energy or other food valorization projects is the system of 10 Regional Economic Development Council (REDC) zones. The Finger Lakes REDC zone (Fig. 2.7), so-called because it contains finger-shaped lakes formed by the glacial ice sheet that retreated 10,000 years ago, is a 9-County region in the western part of the state, with Rochester as the largest city. The east-west and north-south extents are approximately 90 miles (144 km) and 70 miles (112 km), respectively, so it is conceivable that a centrally located facility could be supplied with feedstocks that originate in any part of this REDC zone.

With our geographical region of interest suitably defined, it was possible to begin the process of identifying potential sources of food waste materials in agriculture, food processing, food distribution, and food service stages of the FSC, as originally outlined by Chan et al. (2013), and later expanded and updated. This analysis also relied in part on a much more extensive and comprehensive analysis conducted by Ebner (2016) that considered all food waste resources throughout New York State. Useful information and methods were also obtained from prior studies published by agencies in different states, including Connecticut (CDEP, 2001), Massachusetts (MDEP, 2002), California (CEPA, 2006), and North Carolina (NCDENR, 2012), but these generally focused on the food waste fraction of municipal solid waste (MSW) and less so on waste generated in other sectors.

2.4.1 Agriculture Sector

- **Crop residues**: Assumed to be insignificant because of generally low volumes and current use as nutrient-rich materials tilled back into the soil for the next growing cycle.
- **Unsold crops**: Also assumed to represent a relatively small volume, and more suitably diverted to donation or animal feed.

2.4.2 Food Processing Sector

This information is generally the most difficult to obtain because it is controlled by private or publicly-traded corporations that may see little financial or competitive value in such disclosures. Also, as mentioned previously in connection with the detailed study by ReFED (2016a), many food processing operations already divert generated waste materials to productive use, often as animal feed. Therefore to estimate the available food processing waste resources, we relied on limited company survey responses, public domain data for wastewater discharges to the publicly owned treatment works (POTW), and empirical relationships reported in earlier publications.

- **Company survey results**: The North American Industry Classification System (NAICS) and ReferenceUSA were used to first identify the population of nearly 7000 businesses in the 9-County Finger Lakes region that could potentially be involved in the FSC. This population was then further constrained by eliminating small businesses, defined as those with <2500 ft$^2$ of operation space or less than $1$ million in annual revenue. From this much smaller population, we identified 300 business enterprises in the food processing sector that were determined to be large enough to potentially generate significant waste. Although the survey response rate was rather low (about 10%), the data revealed some interesting trends and also identified several sources of very large wastewater discharges, including nearly 19 million L/year from a dressing and prepared sauce manufacturer, about 7 million L/year from a beverage company, and nearly 4 million L/year from a coffee and tea manufacturing plant. Based on a more extensive surveying effort and using public record resources, Ebner (2016) identified state-wide food manufacturing and processing resources of 777,000 ton/year, but from this data it was not possible to separate out the contribution from the Finger Lakes Region only.
FIG. 2.7 New York State Regional Economic Development Council (REDC) zones, with Finger Lakes the focus of detailed food waste characterization study.
**TABLE 2.3 Largest Food Processing Wastewater Surcharges Paid in Monroe County, NY (Trabold et al., 2011)**

<table>
<thead>
<tr>
<th>Food Company Sector</th>
<th>Average BOD&lt;sup&gt;a&lt;/sup&gt; (mg/L)</th>
<th>Water Consumption (1000 gal/year)</th>
<th>Wastewater Surcharge&lt;sup&gt;b&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Animal by-products, oils</td>
<td>7003</td>
<td>10,875</td>
<td>$224,637</td>
</tr>
<tr>
<td>Milk</td>
<td>1473</td>
<td>25,399</td>
<td>$143,123</td>
</tr>
<tr>
<td>Baked goods</td>
<td>1326</td>
<td>19,485</td>
<td>$97,250</td>
</tr>
<tr>
<td>Tomato products</td>
<td>426</td>
<td>308,722</td>
<td>$89,468</td>
</tr>
<tr>
<td>Baking supplies</td>
<td>2803</td>
<td>11,026</td>
<td>$57,516</td>
</tr>
<tr>
<td>Soft drinks</td>
<td>3598</td>
<td>6793</td>
<td>$56,434</td>
</tr>
<tr>
<td>Baked goods</td>
<td>9211</td>
<td>1697</td>
<td>$33,387</td>
</tr>
</tbody>
</table>

<sup>a</sup>BOD, biological oxygen demand.

<sup>b</sup>Surcharges based on BOD, suspended solids, and phosphorous content of wastewater, and paid in addition to normal water supply charges.

- **POTW discharge data:** Freedom of Information Law (FOIL) requests were submitted to County-level environmental services agencies to acquire data for discharges from food processing companies (Trabold et al., 2011; Rankin et al., 2012). Of the 62 counties in New York State, only eight have POTWs that charge wastewater surcharges and thus maintain records for discharges received from specific companies. The most detailed data were available for Monroe County, part of our 9-County study (Table 2.3).

- **Previously published studies:** Because of the difficulty in obtaining data directly from food processing companies, we relied on empirical relationships developed in the above-referenced state reports, as well as the Ph.D. dissertation of Ma (2006) which provided annual waste generation rates based on multiplicative factors applied to the number of employees, as summarized as follows:

<table>
<thead>
<tr>
<th>Business Sector</th>
<th>Multiplicative Factor (A)</th>
<th>Waste Generated (kg/year) = # Employees * A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dairy</td>
<td>3541</td>
<td></td>
</tr>
<tr>
<td>Bakery</td>
<td>459</td>
<td></td>
</tr>
<tr>
<td>Meat processing</td>
<td>9.5</td>
<td></td>
</tr>
<tr>
<td>Fruit</td>
<td>2605</td>
<td></td>
</tr>
<tr>
<td>Mixed produce</td>
<td>198</td>
<td></td>
</tr>
</tbody>
</table>

Also, CDEP (2001) determined that beverage distributors generate waste at a rate of about 16,500 kg/year per facility.

### 2.4.3 Food Distribution Sector

This sector is well represented in the state studies mentioned previously and in the dissertation of Ebner (2016), and these sources were used to establish the multiplicative factors summarized later. For wholesale and retail food establishments, the total resources available were considered to be a combination of the materials sent to landfill and diverted to nonenergy beneficial uses.

<table>
<thead>
<tr>
<th>Business Sector</th>
<th>Multiplicative Factor (A)</th>
<th>Waste Generated (kg/year) = # Employees * A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wholesalers</td>
<td>478</td>
<td></td>
</tr>
<tr>
<td>Retailers (combined supermarkets and convenience stores)</td>
<td>2000</td>
<td></td>
</tr>
</tbody>
</table>
2.4.4 Food Service and Institution Sector
Waste data from this sector is also difficult to obtain, because food materials must be physically separated from the MSW stream during an auditing process that can be quite time consuming and costly. Again, previously published studies were used to develop appropriate multiplicative factors as discussed later and summarized in Table 2.4. These businesses are especially critical to food waste resource quantification and characterization because they are so prevalent and generally have relatively high waste generation rates. More than half of the generators identified in this 9-County study were in this sector.

- **Restaurants**: The study by CEPA (2006) audited 50 restaurants to identify wasted and diverted food materials, the combination of which was used for the multiplicative factor recommended in Table 2.4. It is important to note that a large part of the diverted fraction corresponds to waste cooking oil or other fats, oils and grease (FOG), known to be an effective and productive feedstock for both anaerobic digestion (Chapter 4) and transesterification (Chapter 6).
- **Universities**: In the previously cited study from Connecticut (CDEP, 2001), waste generation rates were proposed based on an assumed generation rate of 0.16 kg/meal and the different number of meals per student at residential and non-residential universities. More recently, Ebner et al. (2014) updated and improved this relationship by conducting bottom-up and top-down assessments of food waste generated at Rochester Institute of Technology, in combination with published studies from 11 other universities and colleges in the United States.
- **Schools**: Block (2000) conducted an assessment of elementary, middle, and high school students in Wichita, Kansas and computed a waste generation rate of 15 kg/year for each enrolled student, assuming 150 meals per year. Clark (2014) reported roughly the same per-student food waste generation rate for a similar study in South Carolina, although an even more recent study of K-12 students in Iowa determined that the waste rate was significantly higher at 34 kg/year (Feeney, 2017). Ebner (2016) recommended a value of 15 kg/student/year based on an average from seven prior state-level studies, and therefore this same value is used in the current analysis.
- **Hospitals and nursing homes**: Ma (2006) developed a waste generation relation based on data provided in CDEP (2001) and MDEP (2002), assuming an average of 5.7 meals/bed/day and 0.27 kg average waste per meal. A similar relation was applied for nursing homes, assuming 3 meals/bed/day and 0.27 kg average waste per meal.
- **Correctional facilities**: As cited by Marion (2000), inmates housed by the New York State Department of Corrections produced food waste at a rate of about 0.45 kg per day, and most of this material originated from scraps generated in food preparation, not consumption.
- **Food pantries**: Based on data obtained directly from our local food bank organization (Foodlink), it was determined that about 6% of the mass of total food donations received is generated as waste or diverted to beneficial uses, and both quantities were considered available for WtE conversion.

From the data summary presented in Table 2.5, it is clear that the majority of food waste originates from a only a few food supply chain subcategories, with retail groceries and restaurants accounting for nearly 86% of the total mass of waste available in the 9-County region. Although waste materials in excess of 100,000 metric tons per year seem like a significant amount, it should be recognized that in many cases there can be significant seasonable variations that must be considered.

<table>
<thead>
<tr>
<th>Business or Institution Sector</th>
<th>Relation Used to Compute Waste Generation Rate (kg/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Restaurant</td>
<td>Number of employees ($N_{R}$) × 1538 kg/year</td>
</tr>
<tr>
<td>Fast food</td>
<td>Number of employees ($N_{R}$) × 1134 kg/year</td>
</tr>
<tr>
<td>University</td>
<td>Number of enrolled students ($N_{U}$) × 26 kg/year</td>
</tr>
<tr>
<td>School</td>
<td>Number of enrolled students ($N_{S}$) × 15 kg/year</td>
</tr>
<tr>
<td>Hospital</td>
<td>Number of beds ($N_{H}$) × 576 kg/year</td>
</tr>
<tr>
<td>Nursing home</td>
<td>Number of beds ($N_{N}$) × 298 kg/year</td>
</tr>
<tr>
<td>Correctional facility</td>
<td>Number of inmates ($N_{I}$) × 166 kg/year</td>
</tr>
<tr>
<td>Food pantry</td>
<td>Total food bank donations (kg/year) × 0.06</td>
</tr>
</tbody>
</table>
when designing conversion systems (including waste-to-energy) that would rely on these feedstocks for continuous operation. Also, these FSC resources should be viewed as only one component of a broader organic biomass ecosystem, where other feedstocks could reasonably be combined to maximize environmental and economic benefits. For example, locally derived lawn and forest residues could serve as cofeeds for thermochemical conversion processes (Chapters 8 and 9), and many existing anaerobic digestion systems (Chapter 4) operate using food waste codigested with livestock manure. In fact, the 9-County region featured in this study has a large milk and yogurt industry that depends on over 100,000 milking cows, producing in excess of 2.5 million ton/year of manure (Chan et al., 2013). It should also be emphasized that some of the FSC resources summarized previously are likely underestimated, especially the food processing sector wastes for which very little primary data is available. Additionally, as discussed by Ebner (2016), wastes generated in households would be a significant contribution to the overall food resource portfolio, but these materials were not included in the earlier analysis.

## 2.5 CONCLUSIONS

Understanding the quantities and characteristics of waste resources across the food supply chain is an essential first step to exploring the economic and environmental viability of waste-to-energy system deployment. Very large quantities of waste are known to exist on a global scale, but the nature of these materials and their distribution among different FSC sectors

### TABLE 2.5 Summary of Food Waste Resources Identified in 9-County Finger Lakes Region

<table>
<thead>
<tr>
<th>FSC Category</th>
<th>Subcategory</th>
<th>Food Waste Relation*</th>
<th>Number in 9-County Region</th>
<th>Waste Quantity (metric ton/year)</th>
<th>% of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Food processing</td>
<td>Beverages</td>
<td>(N_f \times 16,526) kg/year</td>
<td>90</td>
<td>1490</td>
<td>1.1</td>
</tr>
<tr>
<td></td>
<td>Dairy</td>
<td>(N_f \times 3541) kg/year</td>
<td>131</td>
<td>464</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td>Bakery</td>
<td>(N_f \times 459) kg/year</td>
<td>1032</td>
<td>473</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td>Meat</td>
<td>(N_f \times 9.5) kg/year</td>
<td>196</td>
<td>1.9</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td></td>
<td>Fruits and vegetables</td>
<td>(N_f \times 2605) kg/year</td>
<td>483</td>
<td>1258</td>
<td>0.9</td>
</tr>
<tr>
<td></td>
<td>Mixed produce</td>
<td>(N_f \times 198) kg/year</td>
<td>1698</td>
<td>336</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td>Wastewater to POTW</td>
<td>Solids content of wastewater discharges reported to Monroe County, obtained via FOIL request (Table 2.3)</td>
<td>472</td>
<td>0.4</td>
<td></td>
</tr>
<tr>
<td>Food distribution</td>
<td>Wholesale</td>
<td>(N_f \times 478) kg/year</td>
<td>9747</td>
<td>4659</td>
<td>3.5</td>
</tr>
<tr>
<td></td>
<td>Retail</td>
<td>(N_f \times 2000) kg/year</td>
<td>19,484</td>
<td>38,968</td>
<td>28.9</td>
</tr>
<tr>
<td>Food service and institutions</td>
<td>Restaurants (full-service)</td>
<td>(N_f \times 1538) kg/year</td>
<td>43,286</td>
<td>66,574</td>
<td>49.4</td>
</tr>
<tr>
<td></td>
<td>Restaurants (fast food)</td>
<td>(N_f \times 1134) kg/year</td>
<td>8822</td>
<td>10,004</td>
<td>7.4</td>
</tr>
<tr>
<td></td>
<td>Universities</td>
<td>(N_f \times 26) kg/year</td>
<td>100,979</td>
<td>2625</td>
<td>1.9</td>
</tr>
<tr>
<td></td>
<td>Schools</td>
<td>(N_f \times 15) kg/year</td>
<td>104,757</td>
<td>1571</td>
<td>1.2</td>
</tr>
<tr>
<td></td>
<td>Hospitals</td>
<td>(N_f \times 576) kg/year</td>
<td>3479</td>
<td>2003</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>Nursing homes</td>
<td>(N_f \times 298) kg/year</td>
<td>8457</td>
<td>2520</td>
<td>1.9</td>
</tr>
<tr>
<td></td>
<td>Correctional facilities</td>
<td>(N_f \times 166) kg/year</td>
<td>6006</td>
<td>997</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td>Food pantries</td>
<td>6% of mass of total donations</td>
<td>424</td>
<td>0.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total food waste in 9-County region</td>
<td>134,840</td>
<td>100</td>
<td></td>
</tr>
</tbody>
</table>

*\(N_f\), number of facilities; \(N_e\), number of employees; \(N_s\), number of students; \(N_b\), number of beds; \(N_i\), number of inmates.
varies greatly across global regions. In developing countries, the greatest opportunities for food waste valorization exist in the upstream stages of the supply chain, mostly in connection with agriculture and first-line product handling, whereas consumer-facing businesses and consumption are the stages best positioned for improved efficiency in developed economies. Many published studies have also been conducted with a focus on a specific country or region, with the greatest concentration in Europe and North America, but even finer data granularity is needed to determine where a food waste-to-energy system shall be located to achieve maximum environmental and economic benefits. In the United States, certain states are accelerating the focus on food waste valorization because of existing or impending landfill bans that will necessitate the development of alternative technologies including composting, anaerobic digestion, and fermentation, in addition to the other technologies discussed in Chapters 4–9. These states often have the most developed information and waste data resources, but there is often a need for even more comprehensive data at a localized scale, commensurate with the distance over which feedstocks would be transported to support a centralized waste-to-energy conversion system. Such a study has been conducted in our region of western New York State, and the results indicate that food waste resources on the order of 100,000 ton/year are available, suitable for deployment of one or more centralized systems that could viably serve the region’s current needs and support future growth and expansion. In addition to comprehensive data on food waste resources themselves, other data are needed regarding existing facilities and infrastructure, roads and transport/hauling services, distribution of electrical and natural gas service, water pipelines, and locations of natural water bodies (rivers, streams, lakes, ponds) that could potentially be impacted by WtE system outputs, such as the high-strength effluent from anaerobic digesters. Also, whenever considering the potential viability of new technologies, it is essential that the performance and value proposition of existing conversion facilities (e.g., landfills, wastewater treatment, etc.) are fully comprehended. These conventional food waste management technologies are discussed in detail in Chapter 3.

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FURTHER READING
