A Roadmap to Reduce US Food Waste by 20%

Technical Appendix

Latest Revision: March, 2016

ReFED | Rethink Food Waste
Through Economics and Data

Table of Contents

Summary of Overall Methodology

ReFED set out to understand the most cost-effective strategies to reduce food waste, the resources needed for implementation at scale, and the expected financial and non-financial impacts. The *Roadmap* was developed through a four-step process:

(1) Baseline Definition – ReFED built one of the broadest data sets and literature reviews to date to establish a map by stakeholder and region of existing food waste sent to landfill and left on farms.

(2) Solutions Evaluation - A wide list of solutions was gathered from stakeholders, and narrowed to a short list of 27 priority solutions for detailed analysis that met criteria around data availability, cost effectiveness, feasibility, and scalability.

(3) Data Analysis - A robust cost-benefit analysis was conducted for the 27 solutions. Prevention and Recovery solutions were analyzed based on potential for each stakeholder and food category. Recycling solutions were analyzed using regional inputs for the top 50 municipal service areas. A Marginal Food Waste Abatement Cost Curve ranked solutions by cost-effectiveness and landfill diversion potential. Additional calculations included Business Profit Potential and Non-Financial Impacts.

(4) Data Validation – ReFED conducted over 80 expert interviews, including multiple reviews by a multi-stakeholder Advisory Board, to refine assumptions and methodology. Additional detail on the data validation process is available in the technical appendix.

This technical appendix contains further details on each of these four steps, plus additional detailed background information.

Limitations

The *Roadmap* provides a baseline understanding of the economics of a dramatic increase in food waste prevention, recovery, and recycling. Given the scale and complexity of the U.S. food system, the modeling used a common methodology to incorporate as much detail and accuracy as possible while generating a consistent output across stakeholders, solutions, and geographies. The *Roadmap* methodology was structured around the following constraints:

1. **Existing Data**: The *Roadmap* analysis used existing research on generation rates, employment count, compost values, tip fees, and many other variables. This data is necessarily generalized at the municipal, county, state, regional, or national level, and does not reflect the full potential variation of food system costs and benefits throughout the system.
2. **Lack of ramp up phase**: The analysis does not estimate in detail the ramp up time required to finance, construct, and deploy each solution at scale. The models all assume 100% operation in year one to aid in making solutions comparable. Similarly, the exact timeframe to reach the 20% food waste reduction target was not estimated in detail, but was estimated to be feasible in a five to ten year period.
3. **Terminal Value**: The costs and benefits of all solutions are compared for a ten year period after deployment. The period after the ten years, or terminal value, is not accounted for, although the economics will have changed substantively as significant capital components will be paid off, increasing profit margins. Depreciation is generally excluded from the cost-benefit analysis.
4. **Lack of feedback effects**: ReFED's modeling assumes the baseline food waste generation to be constant – recycling solutions are based on the same amount of potential food waste as prevention solutions. However, prevention solutions will shrink the pool of available food waste for recovery and recycling solutions, and recovery will shrink the available waste for recycling. This constrained flow, or perturbation, is not accounted for in this analysis. Additionally, many of the solutions explored could have significant effects on the market dynamics for products, especially compost. ReFED's modeling assumes prices stay constant, regardless of an increase in supply.
5. **Value Chain Linkages**: Each *Roadmap* solution was analyzed discretely. However, many solutions will require an increase in capacity in another part of the value chain to be implemented. This is most evident in recovery, which requires a simultaneous increase in donations from businesses, transportation capacity, and storage and distribution capacity among food recovery organizations. Similarly, the growth of recycling processing infrastructure will need to occur in balance with an increase in food scrap feedstock availability, transportation capacity, and market demand for compost products.
6. **Multiplier Effects:** Some solutions may have additional benefits when implemented together that are not captured in the *Roadmap*. For example, a Consumer Education Campaign may also improve waste practices at businesses, since employees at food businesses who participate in the campaigns may also change their behavior.
7. **Geographic Variations**: Optimal or preferable solutions in one geographic area may not be feasible or attainable in another region based on a variety of factors. Many of these were embedded in the ReFED geospatial analysis, but solutions will be dependent on factors which are beyond the scope of this study such as regional variations in the economy, unique climatic

factors, existing infrastructure, regional historical events, supply and demand imbalances, local pricing, and others.

8. **Adoption Rate Uncertainty**: The *Roadmap* analysis began by accounting for existing market penetration rates of each solution. Next future adoption rates were modeled based on an estimate from industry experts of the portion of the market where it is feasible and economically rationale to adopt a solution under existing policy and technology constraints. These assumptions did not include the complexity of system dynamics, evolving technology and markets, and uncertainty related to political and business outcomes over the next decade. Expected changes in available financing, policy, innovation, and education will alter the feasibility and economic advantage of many of the recommended solutions over the next decade.
9. **Decreased Farm Production:** The *Roadmap* assumes that when downstream businesses or consumers achieve savings from waste reduction, farmers do not experience significant net decreases in demand. The analysis uses the assumption that any lost revenue is made up by shifting to higher value or less resource-intensive products, or by changing export behavior. One scenario excluded from the *Roadmap* is that prevention and recovery efforts at scale could reduce the total value of food produced in the United States.

Baseline Definition and Methodology

Overview of existing methodologies and *Roadmap* Baseline

The *Roadmap* U.S. food waste generation baseline of 62.5 million tons per year is the result of extensive research integrating primary and secondary data sources from specific industries. The baseline measures both food waste going to landfills (52.4 million tons per year), as well as cosmetically-imperfect produce left unused on-farm and in pack houses that can be repurposed for higher value use (10.1 million tons per year).

To generate this baseline, ReFED focused mainly on secondary research and synthesizing the results of previous studies on food waste. Whenever possible, data and assumptions were verified through interviews with professionals and academics. Efforts were made to find multiple sources for each modeling input, and where this was not possible assumptions were vetted with industry experts. These assumptions focused on capturing a middle ground between conservative and aggressive estimates. A list of sources can be found at the end of this appendix – although some data sources are unable to be listed publicly due to confidentiality agreements.

Source	U.S. Annual Food Waste Estimate (million tons)
ReFED 2016	63
FAO 2011	103
USDA 2016	67
EPA 2015	35

Figure 1: Comparison of Major Studies on U.S. Food Waste Baseline

There are several existing sources estimating national food waste quantities, as summarized in Figure 1. Three of the most commonly cited estimates of U.S. food waste are described below:

An overview of these three studies is described below:

<u>Food and Agriculture Organization of the United Nations (FAO) estimated U.S. food waste at 103 million tons per year.</u> FAO measures food waste per capita in terms of food intended for human consumption that goes uneaten, arriving at an annual figure of approximately 103 million tons for the United States, based on 295 kg of food loss per capita for North America and applied to the U.S. population of 319 million.[1] FAO's approach uses global food production volumes and applies conversion factors to estimate the edible mass of crop quantities intended for human consumption.

<u>U.S. Department of Agriculture (USDA) estimate of 67 million tons per year.</u> USDA estimates that 67 million tons of food (133 billion pounds) go uneaten per year at the retail and consumer levels.[2] This

[1] Gustavsson, Jenny; Cederber, Christel and Ulf Sonesson. "Global Food Losses and Food Waste." *Food and Agricultural Organization of the United Nations*. 2011. Available from http://www.fao.org/docrep/014/mb060e/mb060e00.htm

[2] Buzby, Jean; Wells, Hodan and Jeffrey Hyman. "The Estimated Amount, Value, and Calories of Postharvest Food Losses at the Retail and Consumer Levels in the United States." *United States Department of Agriculture*. 2014. Available from http://www.ers.usda.gov/media/1282296/eib121.pdf

figure, based on Economic Research Service data on loss-adjusted food availability and Nielsen Homescan datasets for residential food consumption, specifically excludes waste that occurs between farm and retail.

U.S. Environmental Protection Agency (EPA) estimate of over 35 million tons per year. EPA released a study on municipal solid waste that identified nearly 35 million tons of food waste disposed annually.[3] EPA methodology estimates food scraps in municipal solid waste by compiling data from a variety of waste sampling studies which are conducted at the point of disposal. EPA's materials flow method results in lower estimates because it does not fully account for the residential or commercial food loss to the sewer system, minor losses between generation and disposal, or the significant fraction of food residues that are disposed in containers. A 2015 study by J. Powell et al., in the journal Nature Climate Change found landfill disposal rates in the U.S. to be more than twice the previously reported national estimates including those published by EPA. Applying EPA's waste characterization to this greater total MSW quantity would considerably increase food waste estimates food waste.[4]

The ReFED *Roadmap* is the first major national study to incorporate regional economic variation, to calculate food waste quantities across sectors at the county level. This allowed for a unique spatial analytic approach and enabled the variation of food prices across the country to influence economic evaluations.

Aside from its use of county-level data, the ReFED *Roadmap* generation baseline differs from existing estimates for a number of reasons. Most studies are based on landfilled waste, where organic material breakdown and contaminated paper can distort totals by changing the weight of waste during transport and storage. Furthermore, the few existing national studies generally use statistical extrapolations to estimate the portion of landfill waste that comes from food or other organic material, resulting in wide variations between each study. Finally, ReFED took the approach of combining data points from a wider variety of sources. The *Roadmap* attempts to combine the most accurate data sources to estimate waste at each part of the value chain, including farms, manufacturers, consumer-facing businesses, and consumers.

---

[3] Advancing Sustainable Materials Management: Facts and Figures 2013. United States Environmental Protection Agency, Office of Resource Conservation and Recovery (5306P). EPA530-R-15-002US EPA, June 2015. https://www.epa.gov/sites/production/files/2015-09/documents/2013_advncng_smm_rpt.pdf

[4] Powell, Jon T et al. Nature Climate Change. Estimates of solid waste disposal rates and reduction targets for landfill gas emissions, Feb 2016. Available from http://www.nature.com/nclimate/journal/v6/n2/full/nclimate2804.html

Roadmap Waste Generation Model

Figure 2 below outlines a summary of the ReFED *Roadmap* Waste Generation model output broken out by key stakeholder:

Generation by Category	Landfill %	Total %	Total (tons/yr)
Residential	51%	42%	26,560,793
Restaurants	22%	*18%*	*11,443,712*
[Full Service Restaurants]	*[14%]*	*[12%]*	*[7,318,772]*
[Limited Service Restaurants]	*[8%]*	*[7%]*	*[4,124,942]*
Supermarket, Distribution and Grocery Stores	15%	13%	7,972,268
Institutional	9%	8%	4,912,908
Industrial / Manufacturing	2%	2%	1,065,000
Government	1%	1%	488,965
Total Landfill Losses	**100%**	**--**	**52,443,648**
On-farm losses	--	16%	10,100,000
Total U.S. Food Waste	--	**100%**	**62,543,648**

Figure 2: Generation by Category

ReFED identified four main stakeholder categories for use in the *Roadmap* to simplify the wide variety of waste generation sources. A summary of this information is listed below in Figure 3:

Category	Farms	Manufacturers	Consumer-Facing Businesses	Homes***
Stakeholders Included	-Fields -Pack houses -On farm processing -Fishing Boats*	-Food Processors -Food & Beverage Manufacturers -Other industrial -Manufactured byproduct converted to animal feed*	-Distributors** -Retail Grocers and Supermarkets -Restaurants -Food Service -Institutions (Universities, Schools, Hospitals, Hotels) -Government (Municipal, Federal, Prisons, Military) -Corporate cafeterias*	-Homes -Apartments -Other dwellings

Figure 3: Waste Generation Stakeholder Categories

*Excluded from the *Roadmap* baseline waste calculation

**Distributors can be described as their own category as they typically sell to other food businesses, but they were added to the "consumer-facing businesses" category in the *Roadmap* for simplification

***Excludes drain disposal, which is not considered waste; see explanation below for details

ReFED considered numerous potential methodologies for estimating the baseline of U.S. food waste. The final methodology was selected to meet three core goals:

- Provide county-level estimates of food waste to allow for an economic analysis that includes variations in regional pricing and policy constraints at the MSA level
- Use the best available data at each point in the value chain, recognizing that current research on food waste generation levels is highly varied

- Produce standardized data that can be compared across stakeholders and rolled up into a single analysis to create common outputs.

To reach these objectives, the core *Roadmap* methodology is based on a data set of per-employee waste generation rates for key industries and a per-capita generation rate for households. ReFED did not attempt to estimate the percent of edible vs. inedible food waste at the baseline level, but did include estimates on the overall f edible food available for prevention or recovery for specific solutions. An overview of the four key steps of the baseline generation modeling process is shown in Figure 4 below:

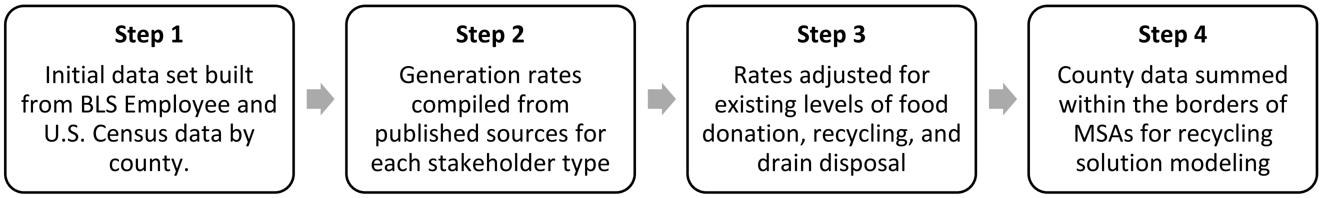

Figure 4: Roadmap Baseline Generation Process

Step 1 consisted of the basic step of sourcing employee counts from the Bureau of Labor Statistics and aggregating them in sub-categories appropriate to food waste research. U.S. Census County Business Patterns were used to select key NAICS codes.[5] Finally, U.S. Census data was used to compile the household population by county as a starting point for residential waste levels.

Steps 2 and 3 were a much more complex process. ReFED searched all of the available research literature to find the best data on waste generation rates on a per-employee basis for each stakeholder group and per-capita basis for households. For on farm losses, a different methodology was used. Instead of estimated waste rates per employee, rates of cosmetic imperfection – the main driver of waste – were estimated by food type.

A detailed table showing the results of this process can be found in Figure 5 below.

[5] County Business Patterns. *United States Census Bureau*. 2015. Available from http://www.census.gov/econ/cbp/

Farms						
Farms	Waste Generation Rate %	Total Annual Production	Total Waste Quantity (M tons/yr)	% Total		Reference
Fruits	11.7	30.8	3.6			*USDA, Tomorrow's Table*
Vegetables	13.1*	49.5	6.5			*USDA, Tomorrow's Table*
	Total (Adjusted):		**10.1**			
**13.1% average waste generation rate calculated from 11.1% average CI rate applied to roll-up category of 34 major USDA crop types (excl. potatoes) with a 15% CI rate applied to potato production.*						

Manufacturers					
Manufacturers	Generation T/Empl/Yr	Employees	Tons*	NAICS	Reference
Animal Food	6.75	8,435	8,777	3111	*University of Florida 1999*
Grain & Oilseed Milling	17.01	11,654	30,557	3112	*University of Florida 1999*
Sugar & Confectionery	3.38	21,579	11,226	3113	*University of Florida 1999*
Canning & Specialty	33.75	50,714	263,838	3114	*Energy Trust 2010*
Dairy	2.57	48,282	19,090	3115	*Energy Trust 2010*
Meat	6.75	105,233	109,494	3116	*University of Florida 1999*
Seafood	9.86	15,880	24,124	3117	*Energy Trust 2010*
Bakeries	6.75	175,354	182,455	3118	*University of Florida 1999*
Other	22.28	82,718	284,023	3119	*Energy Trust 2010*
Beverage & Tobacco	10.13	84,200	131,415	312	*University of Florida 1999*
	Total (Adjusted):		**1,065,000**		
**The resulting total tonnage, 6.9M tons, was then increased by 302% to align with FWRA survey extrapolations at 20.9M tons. FWRA also estimates 94.9% diversion rate, so total non-recovered manufacturing waste was estimated at 1.065M tons.*					

Consumer-Facing Businesses					
Retail and Restaurants	Generation T/Empl/Yr	Employees	Tons	NAICS	Reference
Grocery Store Distributors (Wholesale)*	11.2	501,295	3,233,303[6]	4244	*Energy Trust 2010*
Supercenters	0.5*	1,420,442	710,221	452910	Extrapolation from Grocery Interviews
Supermarkets and Grocery Stores	1.5	2,686,098	4,028,744	445	*Mercer 2013*
Full Service Restaurants	1.5	4,879,669	7,318,772	722511	*Mercer 2013*
Limited Service Restaurants	1.1	3,749,095	4,124,942	722513	*Mercer 2013*
	Total:		**19,415,981**		
**Wholesale waste if frequently diverted to food donation networks and distributors based on storage capacity. An assumed 42% diversion rate was applied to generation estimates. Does NOT account for current diversion including animal feed. *Supercenter generation measured at 0.5tons/employee, or 1/3 rate per employee relative to dedicated grocery & supermarkets which do not staff in other departments. Estimates verified based on RRS research & interviews.*					
Foodservice & Institutional	**Generation T/Empl/Yr**	**Employees**	**Tons**	**NAICS**	**Reference**
Colleges/Universities	*0.78*	1,203,164	938,829	6113	*Cascadia 2006*
Elementary and Secondary Schools	*0.28*	877,439	248,754	6111	*University of Florida 1999*

[6] Based on feedback from Advisory members and others, ReFED decided to apply an assumption that 42% of wholesale waste is currently diverted through recovery and recycling.

Large Hotels	*0.75*	1,806,734	1,356,135	721	*Mercer 2013*
Assisted Living and Nursing homes	*0.33*	3,186,153	1,036,615	623	*Mercer 2013*
Hospitals	*0.36*	3,655,901	1,332,576	622	*University of Florida 1999*
	Total:		**4,912,908**		
Governmental		**Persons**	**Tons**	NAICS	
Correctional Facilities	*0.18**	2,227,500[7]	406,519	NA	Florida DEP 2004
Military Bases	*0.07***	1,185,872[8]	82,447	NA	*Battelle 2015*
	Total:		**488,965**		
**Generation based on incarcerated individuals. **Military generation rates rely on extrapolation from 2015 Battelle study[9] which provided generation at SC military bases. Active military members on bases were multiplied by an estimated generation factor which was deemed conservative based on known diversion and composting practices at some bases today.*					
Homes					
Residential Waste	**Household Waste per Capita (LB)**	**2014 Population**	**Tons**	**NAICS**	**Source**
	238	318,857,056	37,943,989	NA	*WRAP 2012*
	Total (adjusted):		**26,560,793**		
**Assumed 70% Percent of residential solid food waste to landfill/incinerator. Other sent down drain, home compost, pets, etc. Does NOT account for current residential programs (impact minimal nationwide).*					

Figure 5: Food Waste Generation Rates as Calculated in Step 2

Each stakeholder group was approached differently based on the available data. The section below outlines the nuances in completing the Step 2 and 3 analysis for each of the four main stakeholder groups.

On-Farm Loss Baseline

On farm losses could not be simplified into a per employee waste generation rate. These losses instead were estimated based on waste generation rate for each food type.

While on-farm food waste may occur due to a myriad of reasons – from inclement weather and pests to overproduction or insufficient labor – the analysis focused on estimating on-farm losses of cosmetically imperfect (CI) produce that is undersized, blemished, misshapen, or otherwise unmarketable for sale. This cosmetically imperfect produce may be wasted in the form of crops left unharvested – to be tilled into the soil – or culled in on farm packing sheds, where discarded produce typically does not find a secondary purpose. Since on farm losses generally do not end up in landfills, they have often been excluded from past estimates of U.S. food waste, but they were included in the *Roadmap* based on the large opportunity to capture higher value from this unused edible source of food.

---

[7] Total Number in prison or local jail, 12/31/13. Source: Bureau of Justice Statistics, Annual Surveys of Probation and Parole, Deaths in Custody Reporting Program - Annual Summary on Inmates under Jail Jurisdiction, and National Prisoner Statistics Program, 2013.

[8] Active Military at US Bases. 2012 Demographics Profile of the Military Community. Office of the Deputy Assistant Secretary of Defense, 2012.
[9] Battelle for U.S. EPA Office of R&D. Feasibility Study on Food Waste Generated in Columbia, South Carolina, 2015.

Various studies were explored to estimate how many pounds of wasted cosmetically-imperfect fruits and vegetables are produced per pound of retail-standard fruits and vegetables. These CI rates were than applied to USDA datasets on agricultural production by product types to get an overall quantity of CI food wasted by food type.[10] Based on a study conducted by Tomorrow's Table on Minnesota produce growers, the project team extracted the following data on produce cosmetic imperfection rates across a variety of fruit and vegetable types.[11]

Cosmetic Imperfection Rates by Crop Type (Tomorrow's Table 2015)					
Apples	25%	Carrots	12%	Potatoes	15%
Asparagus	7%	Cauliflower	15%	Squash	12%
Beets	9%	Cucumbers	15%	Sweet Corn	11%
Berries	10%	Eggplant	12%	Tomatoes	20%
Broccoli	8%	Green Beans	8%	Turnips	7%
Brussel Sprouts	8%	Onions	10%	Watermelon	9%
Cabbage	8%	Parsnips	14%	Zucchini	9%
Cantaloupe	10%	Peppers	15%		

Figure 6: Cosmetic Imperfection Rates

ReFED developed an initial CI rate estimate by taking an unweighted average over this data, resulting in a vegetable CI rate of 13.1% and a fruit CI rate of 11.7%. Note that this data sample had a low sample size of fruit types and wide range of CI rates (e.g. 9-10% for watermelon and berries, 25% for apples). Future research efforts could assess actual CI losses for each crop type based on actual U.S. crop production quantities and it should include geographical differences, seasonal impacts, and non-CI causes of on farm losses in order to result in improved accuracy.

ReFED validated and refined these fruit and vegetable CI rates by reviewing additional studies on agricultural crop imperfections from Milepost Consulting, based on produce growers in California[12], and a University of Arizona study on farm food losses.[13] The University of Arizona study suggests a slightly lower 10% average on-farm loss rate across all crops. The Milepost Consulting study used a wider range of crops and concluded that the on-farm opportunity could be even higher, with a 2-30% overall harvest shrink for fruit crops such as pears and plums, which included in-situ culls ("edible crop left-over after harvesting due to cosmetic characteristics") and packing culls ("edible crop that leaves the field or orchard but does not enter commerce"). Additional research is needed to improve the understanding of this wide variation of on farm losses for certain specific fruit crops.

---

[10] National Agricultural Statistics Service; Quick Stats. *United States Department of Agriculture.* 2015. Available from http://quickstats.nass.usda.gov/

[11] Berkenkamp, JoAnne and Nennich, Terry. "Beyond Beauty: The Opportunities and Challenges of Cosmetically Imperfect Produce." *Tomorrow's Table.* 2015. Available from http://www.ngfn.org/resources/ngfn-database/Beyond_Beauty_Grower_Survey_Results_052615.pdf

[12] "Left-Out: An Investigation of the Causes & Quantities of Crop Shrink." *Milepost Consulting.* 2012. Available from http://docs.nrdc.org/health/files/hea_12121201a.pdf

[13] Jones, Timothy. "Using Contemporary Archaeology and Applied Anthropology to Understand Food Loss in the American Food System." *University of Arizona.* 2004. Available from http://www.ce.cmu.edu/~gdrg/readings/2006/12/19/Jones_UsingContemporaryArchaeologyAndAppliedAnthropologyToUnderstandFoodLossInAmericanFoodSystem.pdf

Finally, ReFED combined total U.S. annual production of vegetables and fruits with the best estimate of average rates of losses due to cosmetic imperfection to generate a total estimated on farm loss of over 10 million tons per year:

	Total Annual Production (USDA)	Avg % CI Loss	Estimated Weight of CI Loss
Vegetables	49.5M tons	13.1%	6.5M tons
Fruits	30.8M tons	11.7%	3.6M tons
Total	83.3M tons	12%	10.1M tons

Figure 7: Fruit and Vegetable Cosmetic Imperfection Losses

Note that the above annual production figures specifically include fresh vegetables only, and do not include vegetables sold for processing purposes such as juicing. Fruit production totals, based on USDA calculations of utilized production, do not distinguish between fresh fruit and fruit designated for processing or manufacturing.

Manufacturers

Available data sources for industrial generation rates are limited. The *Roadmap* relied on several sources, including UF 1999, Energy Trust 2010, FWRA/BSR 2014. While these studies may offer the best data available, the waste generation rates may not be representative of the entire industry.

The *Roadmap* utilized FWRA generation rates to develop the total baseline, calculating that manufacturing waste exceeds 21M tons annually. The *Roadmap* then added on an employee-based multiplier to calculate the country-level opportunity through the spatial analysis, given the strong regional focus of different parts of the food manufacturing sector. The discrepancy between the FWRA national extrapolation and employee-based geospatial analysis could account for a total difference of 700K tons per year, or approximately 1% of the national baseline. This difference does not make a material impact in assessing the overall opportunity across the largest MSAs.

For Step 3, data from the Food Waste Reduction Alliance was used to account for extremely high current diversion efforts of 95%. In other words, of the 21M tons of manufacturing waste generated today, almost 20M tons are already diverted from landfill for other beneficial purpose. Roughly 85% of diversion is estimated to come from animal feed, with the rest primarily used for food recovery and recycling.

Consumer-Facing Businesses

The consumer-facing business category encompasses a diverse mix of grocers, restaurants, food service providers, and other government and private institutions. Estimates were included for nearly all of these segments. Government sources (prisons and military bases) of food waste were calculated but not incorporated into the spatial component of the analysis due to insufficient availability of geospatial data. No data could be found on corporate cafeterias, particularly with any geographical breakdown, and this segment was excluded from the analysis. Additional research should be conducted to improve data on these segments for future studies.

A key 2013 study from Mercer County, NJ was referenced to provide generation rates for grocery stores and restaurants on a per-employee basis. Other sources included UF 1999, Energy Trust 2010, and Cascadia 2006.

For step 3, for all consumer-facing businesses, other than grocery distribution centers, it was assumed that current recovery rates were already accounted for, based on the various references used which measured the waste at the point of disposal. Due to a lack of data, existing food recovery or animal feed diversion efforts were not included in the dataset for grocery distribution centers, resulting in a likely small overestimation of the total waste generation baseline for this segment.

Homes

Residential generation rates vary widely between sources, primarily due to whether the study was conducted in the home or as a waste characterization at a landfill or transfer station. A significant portion of food wasted in the home is poured down the drain or disposed using an in-sink grinder, where it is eventually recovered as biosolids at a wastewater treatment plant. This portion of the household waste stream would not be captured in a landfill waste characterization.

The most detailed global analysis of consumer food waste behavior was conducted by Waste and Resources Action Programme (WRAP), a registered charity in the United Kingdom that has played a leading role in stimulating multi-stakeholder action to reduce food waste. WRAP conducted in depth consumer studies to better understand exactly how much food is disposed and the various causes. The *Roadmap* used WRAP's 2012 study for household generation *(238 lbs per person per year)* as the basis for its home waste baseline due to the extensive quantification of the waste stream.

After reviewing industry data, ReFED estimated *that 30% of that consumer food waste is currently poured or disposed of down the drain.* This fraction of existing waste was not included in the *Roadmap*. Consumer waste disposed down the drain consists of a high fraction of liquids that are processed with other wastewater and an estimated 50-60% already finds beneficial reuse nationally as a constituent of water resource recovery facilities (WRRF) biosolids. The remaining potential for WRRFs to increase their rate of beneficial reuse of biosolids was not explicitly modeled in the *Roadmap*, but is referenced in the WRRF with AD solution. The portion of waste that goes down the drain represents a future opportunity to increase prevention, but was excluded from this analysis.

There have recently emerged a small number of residential food waste collection programs in cities such as San Francisco. Due to a lack of data on the scope of these programs, and their relatively minor penetration nationwide, current residential food recovery or food scrap recycling programs were not included in the *Roadmap* baseline estimate.

To complete the *Roadmap* baseline, **Step 4** took the county level waste generation data after Step 3 and aggregated it into for the top 50 largest MSAs for each of the four stakeholder groups. This data MSA-level data provided the baseline for the recycling analysis, which combined it with MSA-level policy, input and market pricing, other constraints to model out the potential scalability and cost effectiveness of each solution.

Waste Generation Sources

The following table represents the references which supported many of the assumptions behind the ReFED Generation Model.

Reference	Study Focus
CA 2006	Waste disposal for industry groups, prepared by Cascadia Consulting for California Integrated Waste Management Board (CIWMB) in June 2006. 371 commercial sites belonging to 14 industry groups from LA, Sacramento, San Diego, and San Francisco area were surveyed. Samples of disposed waste from each site were gathered, weighing between 200 and 250 lbs per sample.
Mercer County, NJ 2013	3 categories of food waste generators: Business, Institutional, and Residential. When comparing total waste data to the other counties in NJ, Mercer is below average. Note food waste data is based on estimated 13.9% of total residential MSW is food waste, which is likely too low, and annual food waste tonnage based on CT study equations Source: Assessment of Food Waste Generation in Mercer County, New Jersey. Arnold G. Mercer, P.E. January 2013.
CT 2012	Health care, hospitals, residential and non-residential colleges, correctional facility, supermarket, and restaurant formulas originate in this study. Many other studies cite these, including Mercer County study and Massachusetts study. Source: Updated Mapping of Food Residual Generation in Connecticut, Prepared for Connecticut Department of Energy and Environmental Protection, Prepared by US EPA Region 1 Office of Administration and Resource Management. Jeri Weiss, Boston, MA. Spring 2012
CIWMB 2000 (updated in CA 2006 study)	Hotels number includes small hotels as well as large. Health care value (1560) is nursing homes + medical/health services. Source: Business Group Waste Compositions, Solid Waste Characterization Database, CIWMB www.ciwmb.ca.gov/WasteChar/BizGrpCp.asp (February 2000).
WRAP – UK 2008	UK household waste data from 2007. Household value derived from 70 kg of food waste per person per year. Source: The Food We Waste. Waste & Resources Action Programme (WRAP), United Kingdom. Project code: RBC405-0010 ISBN: 1-84405-383-0 April 2008
Thurston County, WA 2011	Survey of 16 kindergarten and elementary schools in Thurston County over a period of 1 week, and then total FW for the year was calculated. March 2011.
Food Waste Diversion Project	Food Waste Diversion in Florida Report, Center for Biomass Programs, University of Florida's Institute of Food and Agricultural Sciences, Gainesville, FL; as modified by RRSI for Tampa Electric Company (TECO).
Eureka, MN 2013	Highest and Best Use of Source Separated Organics: A Zero-Waste Perspective. RRS Study in May 2013. Household value derived from collected household tons of food waste, and assumption that there are 2.67 people per household.
Urban Waste Grease Resource Assessment	Source: An Assessment of the Recovery and Potential of Residuals and By-Products from the Food Processing and Institutional Food Sectors in Georgia, University of Georgia, College of Agricultural and Environmental Science , Ben Magbunua, September 2000

Figure 8: Baseline Generation References

Waste Characterization

Food waste was characterized by five major food categories, including Grain Products, Meat, Fruits & Vegetables, Seafood, and Milk / Dairy. This characterization information is modeled using USDA loss-adjusted food availability data, measuring food loss specifically at retail and consumer levels[14]. This USDA study uses supermarket supplier shipment and retailer point-of-sale data for retail-level losses, and relies on Nielsen data for consumer-level information – the resulting waste characterizations are shown below:

	Grain Products	Meat	Fruits & Vegetables	Seafood	Milk and Dairy
Retail	22.4%	7.1%	40.4%	1.2%	28.9%
Consumer	16%	15.7%	43.4%	2.1%	22.9%

Figure 9: Waste Characterization by Food Category

An alternative method of modeling waste characteristics was also explored using data from an FAO report on global food waste and losses[15]. This approach resulted in waste generation data by food type at each stage of the food supply chain. However, a significant discrepancy was identified between the two data sources (USDA / FAO) that could not be clarified. The project team used the USDA data as it focuses on the United States and more accurately measures and characterizes retail and consumer-driven waste, where the majority of the solution analysis focused.

Recovery Potential Baseline

A unique element of the *Roadmap* relative to existing research was a bottoms-up estimate of the current levels and total feasible potential increase of food recovery occurring across each of the four major stakeholder groups: farms, manufacturers, restaurants and foodservice providers, and retailers. Distributors were excluded from this analysis due to a lack of data. The baseline of current recovery efforts as well as the incremental food recovery potential within each of these stakeholder groups provided the key data to model the expected increase in food recovery from each of the seven solutions detailed in the *Roadmap*.

---

[14] Buzby, Jean; Wells, Hodan and Jeffrey Hyman. *United States Department of Agriculture*. 2014. Available from http://www.ers.usda.gov/media/1282296/eib121.pdf

[15] Gustavsson, Jenny; Cederber, Christel and Ulf Sonesson. "Global Food Losses and Food Waste." *Food and Agricultural Organization of the United Nations*. 2011. Available from http://www.fao.org/docrep/014/mb060e/mb060e00.htm

Figure 10 below outlines the current levels of food recovery and feasible additional food donation opportunity for each of the four main stakeholder groups:

	Farms	Manufacturers	Restaurant / Foodservice	Grocery Retail
1) Current annual total food waste baseline (post-recovery)	10M tons	1M tons	16M tons	4M tons
2) Current annual food donation levels	300K tons	525K tons	100K tons	700K tons
3) Growth ratio from current to maximum food recovery levels	15x	--	10x	2x
4) Maximum potential food donation opportunity	4.5M tons	525K tons	1M tons	1.4M tons
5) Feasible additional food donation opportunity above current levels	**4.2M tons**	**--**	**900K tons**	**700K tons**

Figure 10: Food Recovery Baseline and Feasible Additional Recovery Opportunity

Current food donation quantities across farms, restaurants/foodservice, and retailers above are based on an aggregation of secondary research on existing food recovery efforts around the country.

- For farm food donations, estimates of total produce donations from farmers in AZ, CA, ID, MI, MN, ND, NY, FL, OR, PA, WA, and WI were compared to total USDA agricultural production in those states to triangulate a net food recovery total of 300K tons per year.

- For restaurant/foodservice food donations, Food Donation Connection reports that close to 20K tons are recovered annually.[16] The ReFED Advisory Council estimated that this data accounts for roughly 20% of total food recovery efforts, for a total estimate of 100K tons per year.

- For retail food donations, publicly released data and annual reports from 7 of the largest 9 grocery retailers nationwide show that 450K tons are donated annually,[17] with a collective 60% grocery retail market share by sales.[18] Assuming that larger retailers have the scale and operational efficiency to donate more pounds of food per dollars of sales than smaller retailers, 700K tons per year represents a conservative industry-wide recovery total.

---

[16] "Restaurants donate unused food to help feed hungry." *Orlando Sentinel.* 2014. Available from http://www.orlandosentinel.com/features/os-donating-restaurant-food-20140726-story.html

[17] Includes Walmart, Kroger/Harris Teeter, Safeway, Publix, H-E-B, Whole Foods, and Target

[18] "Market share of the leading grocery retailers in the United States in 2014." *Statista.* 2014. Available from http://www.statista.com/statistics/240481/food-market-share-of-the-leading-food-retailers-of-north-america/

- For food manufacturing donations, Feeding America estimated that it receives approximately 3 lbs of donations from manufacturers for every 4 lbs received from retailers. This data was extrapolated into a national estimate of roughly 525K tons per year.[19]

The *Roadmap* Recovery Potential Baseline across the four stakeholders estimates that 1.6M tons of food donations are collected today nationwide. This aggregate numbers was then validated against estimates of total food recovered annually through Feeding America's network of food banks, which rescued 2.5 billion pounds of food in 2014 (1.25M tons). A realistic assumption that Feeding America's network of food banks handle 75% of all food donations in the U.S. results in a comparable total recovery estimate of 1.67M tons, a good triangulation of the *Roadmap* Recovery Baseline of 1.6M tons.

Through additional stakeholder and Advisory Council interviews, it was estimated what the maximum feasible size of food recovery levels could be relatively to current efforts. It was estimated that farm food recovery could grow to be 15x larger than current levels on farms, 10x larger within restaurant / food service, and 2x large within grocery retail. This reflects the relative maturity of existing food recovery efforts within these sectors. For food manufacturers, given the low levels of remaining waste and well established recovery programs, it was conservatively assumed that no additional food could be recovered from *Roadmap* solutions.

The final step of the *Roadmap* Recovery Baseline Potential was to subtract the current recovery levels from the maximum feasible levels to calculate the *additional* recovery potential for each stakeholder group. For example, 100K tons of food are donated from restaurant/foodservice today, with an estimated maximum potential of 1M tons. The difference, or 900M tons, is the additional recovery potential. These additional recovery potential estimates indicate the net pool of possible food donations across the recovery solutions analyzed. Roughly 20% (1.1M tons) of this theoretical feasible potential (5.8M tons) is estimated to be captured from implementing the *Roadmap.*

Figure 11 below compares the current and additional food recover levels by stakeholder (excluding manufacturers). While retailers dominate existing food recovery efforts today, the bulk of incremental future donation opportunity lies with farms.

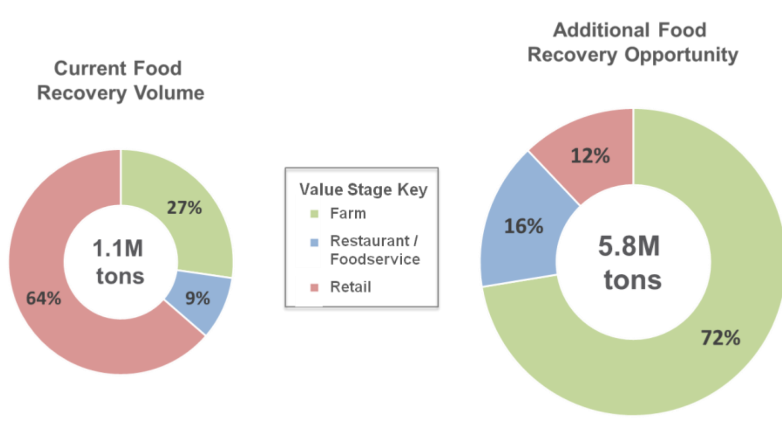

Figure 11: Food Recovery – Feasible Additional Opportunity

[19] "2014 Annual Report." *Feeding America*. 2014. Available from http://www.feedingamerica.org/about-us/about-feeding-america/annual-report/2014-annual-report.pdf (see chart on page 5)

Economic Methodology

After establishing all aspects of the Waste Generation Baseline, the core analysis conducted in the *Roadmap* focused on an economic analysis from implementing each of the 27 solutions. This economic analysis included the following calculations and output variables:

CALCULATIONS	OUTPUT VARIABLES
• Potential to reduce waste by food product category and stakeholder • Upfront and ongoing implementation costs • Cost savings • New revenue opportunities	• Economic Value • Annual waste diversion • Business Profit Potential • Jobs created • Greenhouse gas reductions • Water savings • Meals recovered

Figure 12: Roadmap Calculations and Output Variables

A 10 year timeline was used for all solution modeling, as a realistic timeline for decision makers to consider the cost-benefits of solutions including the depreciation of equipment. Throughout the *Roadmap* and within this technical appendix, any reported numbers on Economic Value, Business Profit Potential, or consumer food cost savings are calculated as an annualized NPV based on a 10 year timeline and a 4% discount rate (see Financing section below for further detail on financing and cost of capital rates).

Calculating the "Value" of Food Waste

To calculate the financial and economic value of food waste as well as food waste diverted, the *Roadmap* analysis used 2015 data from the Bureau of Labor Statistics on monthly average food prices to estimate retail food value[20]. This BLS source offered the most comprehensive list of all food types needed to calculate average prices for all food categories. To improve the accuracy of value calculations, an Advisory Council member provided additional data on wholesale prices for restaurants and foodservice. Food waste from on-farm losses also relies on these wholesale prices, which may overstate the economic value of this waste, but an alternative data source could not be found. Both retail and wholesale price data are shown in the table below:

	Grain Products	Meat	Fruits & Vegetables	Seafood	Milk and Dairy
Retail	$1.21	$5.73	$1.51	$8.04	$1.21
Wholesale	$0.97	$3.24	$0.74	$4.88	$1.17

Figure 13: The Value of Food by Category

A weighted average of these prices results in a rough $2.50 per pound average across all retail food prices, and wholesale prices between $1.00 - $1.25 per pound. For recovery solutions, "Food Costs Avoided" were calculated using a flat $1.71 per pound value, based on latest Feeding America auditing

---

[20] "Average Retail Food and Energy Prices, U.S. and Midwest Region." *United States Department of Labor, Bureau of Labor Statistics.* 2015. Available from http://www.bls.gov/regions/mid-atlantic/data/AverageRetailFoodAndEnergyPrices_USandMidwest_Table.htm

standards for valuing donated food[21]. Each individual solution methodology may include notes on whether other adjustments were made to estimate food value, or if alternative data was used.

Market Values for Recycled Food Waste

Recycling solutions assumed no retail or wholesale value to the food, but instead evaluated the value of finished compost, energy, or feed that could be created from the waste stream. Different data sources and assumptions were used for these inputs and additional detail is provided below in the Recycling Solutions Methodology section.

1) Compost values were sourced from industry publications[22] and ranged from $7 - $25/cubic yard, and were discounted by 5% to account for potential compost donations or incentive programs. These values were segmented by 14 separate geographic markets. Wholesale food waste compost values were used wherever possible – in cases where there was no specific food waste compost value, wholesale yard waste compost values were used instead.
2) Electricity and gas prices were sourced from proprietary databases. Gas prices were segmented into nine markets, and electricity prices were broken down on a state by state basis. A blend of commercial and industrial rates was used. No incentive pricing due to renewable portfolio standards was utilized due to a lack of clearly reported data at the state/MSA level.
3) For animal feed, cost offsets were calculated using spot prices for commodity corn in mid-December 2015.

Economic Value

A solution's Economic Value reflects the annualized NPV of all one-time and recurring costs and benefits over a 10-year period.

The food waste value methodologies outlined above served as inputs into calculations of net Economic Value and Business Profit Potential for each solution. Across all prevention, recovery, and recycling solutions, Economic Value captures the full spectrum of financial benefits (including food costs avoided and revenue generated) and financial costs (including initial capital expenditures and annual operating expenses).

Food costs avoided and revenue generated were modeled on a 10 year time-frame, assuming a constant annual average benefit – no solution ramp-ups or ramp-downs were incorporated due to lack of data and also to simplify solution methodologies.

Initial investment expenses were modeled to fully impact Year 1 financials, while recurring operating expenses (variable and/or fixed) were modeled over the 10 year period. Initial investment expenses and ongoing cots were modeled based on custom estimates calculated for each solution based on the specifics of the solution, with assumptions validated by a sub-group of the Advisory Council. For example, estimated investment and costs for Secondary Resellers was based on publically available data of the upfront cost and long-term profit margins of existing businesses in this sector. Conversely, the

[21] "Feeding America Financial Statements." *KPMG.* 2015. Available from http://www.feedingamerica.org/about-us/about-feeding-america/annual-report/FA-FY2015-financial-statements.pdf
[22] Composting News, January 2015.

estimated cost for Donation Tax Incentives was based on the maximum government tax subsidy required based on the formula existing under current legislation.

All ongoing cost savings, revenues, and additional costs were modeled using a standard 4% discount rate representing the social cost of capital. The 4% social cost of capital rate was selected after sampling a number of other marginal abatement cost curve studies, based on the expected long-term cost of borrowing for the U.S. government.

Business Profit Potential

"Business Profit Potential" is defined as the expected annual profits that the private sector can earn by investing in solutions, after adjusting for initial investment required, differentiated costs of capital, and benefits that accrue to non-business stakeholders. The calculation focused on actual business profits, after subtracting all costs, and not simply revenues, which would potentially be a 10x larger amount.

To determine the Business Profit Potential, solutions were considered as having either consumer and public benefits, business benefits, or mixed benefits. Business Profit Potential opportunities were calculated for a subset of business benefit and mixed benefit solutions that had significant potential.

Solution Benefits	Included Solutions	Funding Source	Beneficiary	Business Profit?
Consumer & Public Benefits	Date Labeling, Consumer Education Campaigns, Donation Storage and Handling, Donation Matching Software, Donation Transportation, Value-Added Processing, Donation Liability Education, Safe Donation Regulation, Donation Tax Incentives, Home Composting, Community Composting, WRRF with AD	Mix of Business and other Sources	Consumer	None
Business Benefits	Improved Inventory Management, Manufacturing Line Optimization, Smaller Plates, Trayless Dining, Waste Tracking & Analytics, Cold Chain Management, Produce Specifications, Onsite Greywater, Animal Feed, Secondary Resellers	Business	Business	All
Mixed Benefits	Spoilage Prevention Packaging, Packaging Adjustments, Centralized Composting, Centralized Anaerobic Digestion, In-Vessel Composting	Business and other Sources	Business and Consumer	Some – only that accrue to business

Figure 14: Solutions Categorized by Benefit Type

The Business Profit Potential analysis likely underestimates the true potential by focusing only on food businesses and recycling processing developers; the impact on other technology and service providers was not included. Some business and mixed benefit solutions were excluded from the analysis due to a lack of data and low estimated profit levels for any single stakeholder. Excluded solutions in need of additional research include Packaging Adjustments, Animal Feed, Onsite Greywater, and In-Vessel Composting. Similarly, some solutions with consumer & public benefits have potential for business profit, but actual use cases are breakeven or very low profit: WRRF with AD, Value-Added Processing, Donation Matching Software, Donation Transportation, Community Composting, and Donation Tax Incentives.

For prevention solutions that generate pure business benefits, the calculation of Business Profit Potential was relatively simple. The initial corporate investment and ongoing costs was subtracted from sustained cost reductions and new revenue streams. For these solutions, nearly all of the Economic

Value created is in the form of business profit. The only adjustment that was made is that Business Profit Potential used a higher discount rate to reflect realistic costs of capital for corporate investors.

For recycling processing facilities and other mixed benefit solutions, a more complex calculation was required to separate the business profit out from Economic Value accruing to consumers, government, or other stakeholders. The other main adjustment from Economic Value was to use apply solution-specific discount rates based on a realistic estimate of the sources of funding – see Financing section below for additional detail.

Recycling processing facilities were the hardest solution to model for Business Profit Potential. Recycling facilities can be highly profitable under the right conditions where costs are managed, and sufficient revenues are derived through tip fees and sale of product. However, often recycling facilities operate with low levels of profit margin when market conditions are not attractive. Therefore, a conservative approach was taken to estimate profit margins including both highly profitable and less profitable facilities. Recycling Business Profit Potential excluded all collection and transportation impacts – in other words, the profit margin of haulers is not included.

Financing

Throughout the *Roadmap*, Economic Value and cost-benefit financial modeling used a standard 4% discount rate representing the social cost of capital. However, more realistic differentiated costs of capital were used for two analyses: Business Profit Potential, and total financing needs as summarized in the Path Ahead Financing section.

The *Roadmap* calculated the total financing for each solution across seven sources of financing. Figure 15 presents the output table of this analysis. This data was used to generate the $17.8 billion total financing need over the ten year period as highlighted in the *Roadmap*, as well as the breakout by solution category and funder type as shown in the charts in the Path Ahead Financing Section.

	Total Financing Need (over ten years)						
Solution Name	**Government Tax Incentives**	**Public Project Finance**	**Grants**	**Impact Investments**	**Private Equity**	**Corporate Finance**	**Private Project Finance**
Produce Specifications	-	-	$6.7 M	$6.7 M	-	$119.8 M	-
Cold Chain Management	-	-	-	-	-	$4.2 M	-
Inventory Management	-	-	-	-	$14.0 M	$126.0 M	-
Manufacturing Line Optimization	-	-	-	-	-	$3.9 M	-
Smaller Plates	-	-	-	$24.6 M	-	$221.8 M	-
Secondary Resellers	-	-	-	-	$225.0 M	$2,025.0 M	-
Trayless Dining	-	-	-	$2.7 M	-	$24.7 M	-
Waste Tracking & Analytics	-	-	-	$8.9 M	$35.7 M	$44.6 M	-
Packaging Adjustments	-	-	-	-	-	$1,591.0 M	$280.8 M
Spoilage Prevention Packaging	-	-	-	-	$397.1 M	$697.6 M	-
Consumer Education Campaigns	-	-	$247.0 M	-	-	-	-
Standardized Date Labeling	-	-	$47.8 M	-	-	$33.8 M	-
Donation Storage and Handling	-	-	$237.0 M	$343.0 M	-	-	-
Donation Matching Software	-	-	$4.9 M	$4.8 M	-	-	-
Standardized Donation Regulation	-	-	$47.8 M	-	-	-	-
Donation Liability Education	-	-	$47.8 M	-	-	-	-
Donation Tax Incentives	$7,178.6 M	-	-	-	-	-	-
Donation Transportation	-	-	$552.3 M	$176.3 M	-	-	-
Value-Added Processing	-	-	$43.6 M	$64.5 M	-	-	-
Centralized Compost	-	$239 M	$239 M	$96 M	$48 M	$287 M	$48 M
Centralized AD	-	$196 M	$196 M	$294 M	$98 M	-	$196 M
WRRF with AD	-	$576 M	$247 M	-	-	-	-
Commercial Greywater	-	-	$26 M	$13 M	$13 M	$35 M	-
In-vessel Compost	-	-	$3 M	-	-	$5 M	-
Community Compost	-	$36 M	$18 M	$18 M	-	-	-
Backyard Compost	-	$6 M	$1 M	-	-	-	-
Animal Feed	-	-	$0 M	$3 M	-	$5 M	-

Figure 15: Total Financing Need by Solution

The methodology for estimating the financing need sought to answer this question: "How much new funding will be required across stakeholders to implement the solution over ten years?" The financing need includes all types of capital (grants, equity, debt, tax subsidies), under the assumption that this financing must be marshalled across stakeholders to provide the capital required to scale up the solution. The financing need includes three types of costs:

- All upfront investment costs in new equipment, facilities, or programs
- All Year 1 operating costs

- Year 2-10 operating costs, *only for solutions where these cannot be funded out of cost savings or new revenues achieved from the solution*, because any financial benefits accrue to a different stakeholder than that which funds the ongoing cost of the solution (e.g. Consumer Education Campaign).

Once the aggregate finance amount was calculated for each solution, two other pieces of data were needed. First, an average cost of capital was estimated for each funding source, as reflected in Figure 16. ReFED estimated an appropriate cost of capital for seven private, government, and philanthropic sources of financing. For grants and tax incentives, the cost of capital used in other analyses can range from 0% to 4% -- the 1% assumption reflected a balanced approach that accounts for administrative costs and a limited time value of money.

Grants	Tax Incentives	Impact Investments	Private Equity	Corporate Finance	Private Project Finance	Public Project Finance
1%	1%	2%	15%	10%	10%	4%

Figure 16: Financing Rates by Funding Source

Second, in order to estimate how much financing is required from each source, a ReFED panel of experts estimated the percent breakdown of likely financing across the seven potential sources. This was not meant to be prescriptive, as the actual financing is highly dependent on funder interest and relative costs of capital. As external market and environmental factors change – a national spotlight on food waste, for example – funding availability may shift to favor more or less expensive forms of financing. However, given current market conditions, this exercise provided a rough estimate of the total amount of funding required for each solution, by each funding source, and in aggregate. This is an essential part of the *Roadmap*, which was designed to highlight the need to galvanize the formation of new funding sources required to achieve the benefits highlighted in the report.

Figures 17-18 represent the results of this exercise, including the financing mix for each solution, and the assumptions that underlined this analysis.

Solution Name	Grants / Tax Incentives	Impact Investments	Private Equity	Corporate Finance	Private Project Finance	Public Project Finance	Blended Rate
PREVENTION							
Produce Specifications	5%	5%	-	90%	-	-	9.2%
Cold Chain Management	-	-	-	100%	-	-	10.0%
Improve Inventory Management	-	-	10%	90%	-	-	10.5%
Manufacturing Line Optimization	-	-	-	100%	-	-	10.0%
Smaller Plates	-	10%	-	90%	-	-	9.2%
Secondary Resellers	-	-	10%	90%	-	-	10.5%
Trayless Dining	-	10%	-	90%	-	-	9.2%
Waste Tracking & Analytics	-	10%	40%	50%	-	-	11.2%
Packaging Adjustments	-	-	-	85%	15%	-	10.0%
Spoilage Prevention Packaging	-	-	40%	60%	-	-	12.0%

Consumer Education Campaign	100%	-	-	-	-	-	1.0%
Date Labeling	50%	-	-	50%	-	-	5.5%
RECOVERY							
Donation Storage and Handling	40%	60%	-	-	-	-	1.6%
Donation Matching Software	50%	50%	-	-	-	-	1.5%
Safe Donation Regulation	100%	-	-	-	-	-	1.0%
Donation Liability Education	100%	-	-	-	-	-	1.0%
Donation Tax Incentives	100%		-	-	-	-	1.0%
Donation Transportation	75%	25%	-	-	-	-	1.3%
Value-Added Processing	40%	60%	-	-	-	-	1.6%
RECYCLING							
Centralized Composting	25%	10%	5%	30%	5%	25%	5.7%
Centralized AD	20%	30%	10%	-	20%	20%	5.1%
WRRF with AD	30%	-	-	-	-	70%	3.1%
Commercial Greywater	30%	15%	15%	40%	-	-	6.9%
In-Vessel Composting	40%	-	-	60%	-	-	6.4%
Community Composting	25%	25%	-	-	-	50%	2.8%
Home Composting	25%	-	-	-	-	75%	3.3%
Animal Feed	5%	40%	-	55%	-	-	6.4%

Figure 17: Financing Mix

Solution Name	Rationale for Funding Allocation
PREVENTION	
Produce Specifications	Businesses will directly invest in new market channels, but Grants and Impact Investments will also play a role for technical assistance, pilots, and social entrepreneurs targeting this market
Cold Chain Management	Businesses will directly invest in cold chain improvements. There are likely entrepreneurial opportunities which will require Private Equity or Impact Investments, but few examples exist today
Inventory Management	Businesses will directly invest in inventory management systems. The development of new platforms to enable easier tracking of food waste will require some Private Equity.
Manufacturing Line Optimization	Businesses will invest in line changes and process optimization within their manufacturing plants. Grants, Impact Investments, and Project Finance may play a role in the future for companies who do not have upfront capital available for facility improvements, but few examples exist today
Smaller Plates	Businesses will directly invest in smaller plates. For institutions or other businesses which may lack upfront funding, impact investments could play an important role in unlocking capital for this solution
Secondary Resellers	Secondary resellers will likely need internal financing combined with alternate, more expensive forms of capital (e.g. Private Equity) to fund growth. Grocery Outlet, a leading secondary reseller, is owned by Hellman & Friedman LLC, a private equity fund
Trayless Dining	Businesses will invest in trayless dining. For institutions or other businesses which may lack upfront funding, impact investments could play an important role in unlocking capital for this solution
Waste Tracking & Analytics	Businesses will invest in waste tracking and analytics solutions, but there is equally a need for scaling the existing companies providing services in this area. Impact Investments can play an

	important role in unlocking capital for institutions or non-profits who would benefit from this technology but lack initial funding
Packaging Adjustments	Businesses will fund packaging adjustments through Corporate Finance. In some cases, Project Finance or Private Equity may be available for investing in turn-key upgrades
Spoilage Prevention Packaging	Businesses will invest in spoilage prevention packaging, but Private Equity is also needed for developing and scaling new innovations
Consumer Education Campaign	Consumer education requires all philanthropic funding. Some businesses may invest as well, contributing to a minimal portion of overall funding
Date Labeling	Business investment is needed for changes to labeling machinery and process changes, but this will need to be equally matches with philanthropic funding for education and research
RECOVERY	
Donation Storage and Handling	Grants will provide primary funding, and in cases where social enterprises are developing solutions, Impact Investments may also be involved
Donation Matching Software	Grants and Impact Investments will support the development and expansion of platforms. Depending on whether a company is a non-profit or for-profit, the funding needs will shift. There may be limited opportunity for Private Equity funding, but few examples exist today
Safe Donation Regulation	Safe donation regulation will require all philanthropic funding
Donation Liability Education	Donation liability education will require all philanthropic funding
Donation Tax Incentives	Government tax credits will fund donation tax incentives, with additional philanthropic funding for policy advocacy
Donation Transportation	Grants will provide primary funding, and in cases where social enterprises are developing solutions, Impact Investments may also be involved. Limited opportunities for Private Equity are possible, though few examples today
Value-Added Processing	Grants will provide primary funding, and in cases where social enterprises are developing solutions, impact investments may be involved. Limited opportunities for Private Equity are possible, though few examples today
RECYCLING	
Centralized Composting	Large waste and recycling players will invest in large composting facilities, while a significant number of facilities are projected to be launched and operated by municipal programs. Federal and state grants will be available to project developers in addition to private and corporate grants.
AD	Large players in the waste industry, food manufacturing and retail will invest in AD facilities as will municipalities who will build centralized and small-scale units, and install infrastructure at WRRFs. Federal and state grants in the form of capital and tax subsidies will be made more widely available to independent project developers. Additionally, Impact Investments in the form of low interest loans are expected to play a significant role in this industry.
WRRF AD	WRRFs in large, municipal areas are generally public facilities under control of the regional city or local government. Public finance in the form of loans or bonds are anticipated to play the most significant role in financing AD development at WRRFs.
Commercial Greywater	Businesses will directly invest in on-site waste treatment systems including greywater aerobic digesters. Grants will be made available to incentivize adoption.
In-Vessel Composting	Some businesses, including institutional food services and large institutions such as schools and universities that can take advantage of compost produced on-site will invest in in-vessel composting. Grants from government or educational institutions will support the development.
Community Composting	Community composting is expected to be mostly developed and financed by local governments or even more locally at the neighborhood level, supported by public finance or grants, or low-interest impact investment.
Home Composting	Investments in home-composting are expected to be small, with most actual costs falling on the resident. Public financing will come in the way of municipal program funding to provide equipment to residents such as kitchen-counter containers or bins.
Animal Feed	Animal feed heating and pelletizing equipment is largely treated as a business investment, with opportunity for impact funding from farms/feeding facilities.

Figure 18: Financing Mix Assumptions

Prevention Solutions Methodology

All prevention solutions shared a similar framework for analysis. Core data calculations are defined below, followed by a description of the data for all 12 solutions.

Three steps were taken to initially calculate diversion potential for each solution:

1) **Net waste** - The quantity of food waste currently being sent to landfill is identified for each stakeholder impacted by a solution, representing the net opportunity drawn from the baseline generation model.
2) **Addressable waste** - Based on assumptions gathered from the research process, this is the maximum amount of food waste that can be potentially diverted from landfill, based on the constraints of the solution, including specific food types and stakeholders that each solution impacts.
3) **Diversion potential** – Within existing policy and technology constraints, an estimates was made of the diversional potential that a solution can feasibly achieve if appropriate resources are provided to scale up implementation.

Once diversion potential was estimated, an additional set of calculations was made to derive the economic analysis:

4) **Diversion characterization** - The approximate composition of food waste being diverted is estimated. For example, a solution such as Produce Specifications that specifically addresses only fruit and vegetable waste has a waste characterization that is 100% produce. The waste characterization is then converted into an equivalent value of food costs avoided using price data outlined in the Cost Methodology section above, and including any solution-specific discounts as noted below.
5) **Financial Costs** - The costs associated with each solution include the initial investment capital, ongoing implementation and operating costs, advocacy costs, and other general expenses. Although cost figures are listed here in nominal terms for clarity, they are modeled using discount rates and incorporated into annualized NPV terms for the food costs avoided below.
6) **Financial Benefits –** Financial benefits from prevention solutions include direct cost savings to food business and consumers, and additional revenues generated by food businesses. The financial benefits were then calculated as an annualized NPV based on a 10 year timeline.

Using Standardized Date Labeling as an example, the methodology follows this process: Standardized Date Labeling will primarily impact consumers. There is 26.5 million tons of current residential waste that represents the **net waste** opportunity. Of this waste, an estimated 20% occurs due to confusion over expiration dates. This leads to a total **addressable waste** of 8 million tons. Of the 8 million tons of addressable waste, it is estimated that 5-10% of consumers will modify their behavior as a result of a change in the labels and associated education. Taking the conservative 5% assumption, this leads to a **diversion potential** of 400,000 tons of food waste annually from this solution.

Below is a summary of the diversion potential and economic modeling conducted for each solution, with sources where appropriate.

Category 1: Packaging, Product, and Portions

Solution	Standardized Date Labeling
Description	Standardizing food label dates and instructions, including eliminating "sell by" dates, to reduce consumer confusion
Modeling Assumptions	
Diversion Potential	**Net waste**: 26.5M tons residential (ReFED generation model) • 20% of residential waste occurs due to confusion over expiration dates (NRDC[23])
	Addressable waste: 8M tons (calculation) • 5-10% of consumers will react to label changes and modify behaviors (using private study on consumer cold-water wash habits as a proxy for consumer reaction)
	Diversion potential: 400K tons (calculation)
Diversion Characterization	**Food types included**: all (assumption) 16% grain, 16% meat, 43% produce, 23% milk/dairy, 2% seafood (USDA[24] calculation)
Financial Costs	**Operating costs**: $10M per year for educating consumers about date label changes; actual changing of labels is a low-cost/no-cost effort for manufacturers (assumption validated with Advisory Council members)
Financial Benefits	**Food costs avoided**: potential * characterization * food type retail value = $1.8B per year (calculation)

Solution	Packaging Adjustments
Description	Optimizing food packaging size and design to ensure complete consumption by consumers and avoid residual container waste
Modeling Assumptions	
Diversion Potential	**Net waste**: 26.5M tons residential (ReFED generation model) • 20-25% of residential waste is attributed to either package size or design (Journal of Cleaner Production[25]) • Percent of food product not optimally packaged: o 90% of grains, 50% of meat, 10% of fruits and vegetables, 50% of seafood, 80% of milk/dairy products (validated with Advisory Council)
	Addressable waste: 2.75M tons (860K tons grain, 470K tons meat, 285K tons fruit and vegetables, 65K tons seafood, 1.1M tons milk/dairy (calculation) • 5-10% of all packaged foods could be optimized through offering additional size options and packaging design improvements, e.g.through smaller containers, pre-portioned servings, etc. (validated with Advisory Council)
	Diversion potential: 210K tons (calculation)

[23] "The Dating Game." *Natural Resources Defense Council.* 2013. Available from http://www.nrdc.org/food/files/dating-game-IB.pdf

[24] Buzby, Jean; Wells, Hodan and Jeffrey Hyman. "The Estimated Amount, Value, and Calories of Postharvest Food Losses at the Retail and Consumer Levels in the United States." *United States Department of Agriculture*. 2014. Available from http://www.ers.usda.gov/media/1282296/eib121.pdf

[25] Williams, Helen; Wikstrom, Fredrik; Otterbring, Tobias et. al. "Reasons for household food waste with special attention to packaging." *Journal of Cleaner Production*. 2012. Available from http://brage.bibsys.no/xmlui/bitstream/handle/11250/93524/Gustafsson_JCP_2012.pdf

Diversion Characterization	**Food types included**: all (assumption) 16% grain, 16% meat, 43% produce, 2% seafood, 23% milk/dairy (USDA / calculation)
Financial Costs	**Operating costs**: $275M per year from increased costs of food packaging, based on total addressable waste quantity of 2.75M tons and $.05/lb incremental average cost of food packaging modifications (based on studies of consumer food packaging costs and dairy product packaging costs[26,27]), such as additional material or small container sizes.
Financial Benefits	**Food costs avoided**: potential * characterization * food type retail value = $950M per year (calculation)

Solution	**Spoilage Prevention Packaging**
Description	Using active intelligent packaging, such as ethylene absorbing packaging inserts, to prolong product freshness and slow down spoilage of perishable fruits and meat
Modeling Assumptions	
Diversion Potential	**Net waste**: 4M tons retail, 26.5M tons residential (ReFED generation model) • 43% of retail and residential food waste is fruits and vegetables, 11% of this is packaged fresh fruit and addressable by solution (USDA "Postharvest Food Losses", FAO[28]) • 15% of retail and residential food waste is meat, 50% of this is addressable by solution (USDA, validated with Advisory Council)
	Addressable waste: 2M tons fruit, 3.3M tons meat (calculation) • 10-33% of addressable fresh fruit and meat waste can be reduced at the retail level (assumption based on interview with spoilage prevention packaging vendor) • 5-10% of addressable fresh fruit and meat waste can be reduced at the residential level (assumption based on interview with spoilage prevention packaging vendor) • 15% adoption rate for fruit (validated with Advisory Council) • 25% adoption rate for meat (validated with Advisory Council)
	Diversion potential: 70K tons (calculation)
Diversion Characterization	**Food types included**: packaged fresh fruit, meat 75% fresh fruit, 25% meat (calculation)
Financial Costs	**Operating costs**: Assume one spoilage prevention packaging unit needed per 1lb of fruit and 2lbs of meat (validated with Advisory Council), and adoption rates described above: • $170M per year, based on $.04 per unit spoilage prevention packaging cost (based on interview with spoilage prevention packaging vendor) • Retailers and consumers assumed will split cost of packaging technology, so retailers and consumers each incur $85M costs per year
Financial Benefits	**Food costs avoided**: potential * characterization * food type retail value = $312M per year (calculation) with an estimated $219M accrued to consumers and $94M accrued to retailers

[26] Kendall, P and Payton, L. "Cost of Preserving and Storing Food." *Colorado State University*. Available from http://extension.colostate.edu/docs/pubs/foodnut/08704.pdf
[27] "Cheddar Manufacturing Cost Increased More Than 1 Cent Per Pound in California Last Year." *Cheese Reporter*. Available from http://npaper-wehaa.com/cheese-reporter/2013/11/s1/?g=print#?article=2069556
[28] Manalili, Nerlita; Dorado, Moises and Robert van Otterdijk. "Appropriate Food Packaging Solutions for Developing Countries." *Food and Agriculture Organization of the United Nations.* 2014. Available from http://www.fao.org/docrep/015/mb061e/mb061e00.pdf

***Note**: Produce Specifications captures the combined benefits of Retail and Restaurant components; this solution was modeled separately by stakeholder to enable separate sets of assumptions and implementation nuances, but impacts are aggregated and reported at the solution level.*

Solution	Produce Specifications (Restaurant and Foodservice)
Description	Accepting and integrating the sale of off-grade produce (short shelf life, different size/ shape/ color), also known as "ugly" produce, for use in foodservice and restaurant preparation and for retail sale
Modeling Assumptions	
Diversion Potential	**Net opportunity**: 10.1M tons of cosmetically-imperfect (CI) on-farm losses (ReFED analysis) • 60% of CI on-farm losses are fit for foodservice and restaurant applications as cosmetically imperfect produce (validated with Advisory Council) • 35% of this quantity could be captured in a safe, feasible, and cost-effective manner for foodservice applications (regardless of whether loss occurs due to pre-harvest shrink, in-situ culls, or packinghouse culls) (validated with Advisory Council)
	Addressable opportunity: 2.1M tons of on-farm loss (calculation) • 5-10% of this addressable opportunity represents the net reduction in CI food waste from imperfect produce that restaurants substitute for standard existing produce (assumption and substitutive based on ReFED team discussions)
	Diversion potential: 160K tons (calculation)
Diversion Characterization	**Food types included**: 100% fruits and vegetables (calculation)
Financial Costs	**Operating costs**: $80M per year based on $0.25 / lb average purchase price for cosmetically imperfect produce in foodservice (validated with Advisory Council)
Financial Benefits	**Food costs avoided**: potential * characterization * wholesale price = $200M per year (calculation) ▪ Wholesale average price of produce = $0.74 / lb (data from Advisory Council)

Solution	Produce Specifications (Retail)
Description	Accepting and integrating the sale of off-grade produce (short shelf life, different size/ shape/ color), also known as "ugly" produce, for use in foodservice and restaurant preparation and for retail sale
Modeling Assumptions	
Diversion Potential	**Net opportunity**: 10.1M tons of cosmetically-imperfect (CI) on-farm losses (ReFED analysis) • 40% of CI on-farm losses are fit for retail sale as cosmetically imperfect produce (validated with Advisory Council); NOTE: within retail, 40% assumes that retailers put forth effort to build consumer demand and market CI produce (e.g. see Intermarche's "Inglorious Fruits and Vegetables" campaign[29]) – while those costs are not explicitly modeled in the Roadmap analysis, they could be incorporated into existing retail branding and marketing efforts) • 35% of this quantity could be captured in a safe, feasible, and cost-effective manner for retail use (regardless of whether loss occurs due to pre-harvest shrink, in-situ culls, or

[29] Godoy, Maria. "In Europe, Ugly Sells In The Produce Aisle." *National Public Radio*. 2014. Available from http://www.npr.org/sections/thesalt/2014/12/09/369613561/in-europe-ugly-sells-in-the-produce-aisle

	packinghouse culls) (validated with Advisory Council)
	Addressable opportunity: 1.5M tons of on-farm loss (calculation) • 5-10% of this addressable opportunity represents the net reduction in CI food waste from imperfect produce that restaurants add to existing retail stores as additional inventory (assumption and additive effect based on ReFED estimates)
	Diversion potential: 105K tons (calculation)
Diversion Characterization	**Food types included**: 100% fruits and vegetables (calculation)
Financial Costs	**Operating costs**: $53M per year based on $0.25 / lb average purchase price for cosmetically imperfect produce in retail (validated with Advisory Council); this low per-pound price floor, compared to average retail prices, is needed to ensure profitability to retailers and address overall sourcing, merchandising, and branding/marketing costs for new CI produce inventory – it also assumes that growers and producers can find cost-effective ways to get this produce to market as part of existing business operations)
Financial Benefits	**Revenue Generated**: potential * characterization * discounted retail price = $190M per year (calculation) ▪ Discounted retail price of produce = $1.05 / lb = average retail price ($1.51/lb) * 30% discount

Solution	**Smaller Plates**
Description	Providing consumers with smaller plates in self-serve all-you-can-eat (AYCE) dining settings to reduce portion sizes
Modeling Assumptions	
Diversion Potential	**Net waste**: 7.3M tons restaurant, full-service + 0.9M tons institutional, college / university (ReFED generation model) • 10% of full-service restaurant waste comes from all-you-can-eat (AYCE) buffets (validated with Advisory Council) • 80% of institutional (college / university) waste comes from dining halls with AYCE buffets, especially through student meal plans (validated with Advisory Council) • 80% of all self-serve, AYCE dining establishments – both restaurant and institutional – could reduce plate sizes (validated with Advisory Council)
	Addressable waste (from plate size): 585K tons restaurant + 600K tons institutional, college / university only (calculation) • Using smaller plate sizes in self-service settings results in smaller consumer portion sizes and can reduce waste by 10-20% (NIH[30])
	Diversion potential: 180K tons (calculation)
Diversion Characterization	**Food types included**: all (assumption) 16% grain, 16% meat, 43% produce, 23% milk/dairy, 2% seafood (USDA / calculation)
Financial Costs	**Investment costs**: $250M for replacement of dinnerware for smaller plate sizes in AYCE dining settings • $50M for smaller plates in institutional AYCE dining settings, $200M in restaurants (calculation)

[30] Freedman, MR and Brochado, C. "Reducing portion size reduces food intake and plate waste." *Obesity*. 2012. Available from http://www.ncbi.nlm.nih.gov/pubmed/20035274

	• Based on $10,000 dinnerware replacement costs in 20,000 restaurants and 4,640 institutions (facility and cost assumptions validated with Advisory Council) **Operating costs**: Minimal; policy / process changes and consumer education (e.g. signage) may be needed (validated with Advisory Council)
Financial Benefits	**Food costs avoided**: potential * characterization * food type retail value = $407M per year (calculation)

Solution	**Trayless Dining**
Description	Eliminating tray dining in all-you-can-eat dining (AYCE) establishments to reduce consumer portion sizes
Modeling Assumptions	
Diversion Potential	**Net waste**: 7.3M tons restaurant, full-service + 0.9M tons institutional, college / university (ReFED generation model) • 10% of full-service restaurant waste comes from all-you-can-eat (AYCE) buffets (validated with Advisory Council) • 10% of AYCE restaurants still use tray dining (validated with Advisory Council) • 70% of institutional (college / university) waste comes from dining halls with AYCE meal plans (validated with Advisory Council) • 40% of AYCE dining halls still use trays (interview with Advisory Council)
	Addressable waste: 73K tons restaurant + 260K tons institutional, college / university only (calculation) • 90% of AYCE establishments still using trays can go trayless with simple retrofits to tray return system, other facilities are design- or cost-prohibitive (interview with Advisory Council) • Eliminating trays reduces net waste by 25-30% (Aramark[31])
	Diversion potential: 85K tons (calculation)
Diversion Characterization	**Food types included**: all (assumption) 16% grain, 16% meat, 43% produce, 23% milk/dairy, 2% seafood (USDA / calculation)
Financial Costs	**Investment costs**: $30M for retrofit of tray return systems in institutions (no cost in restaurant settings except policy change) • $30M for retrofitting tray return systems in college / university AYCE dining settings, using $15,000 installation cost in 1,830 institutions (installation cost based on interview with Advisory Council) • Based on 7250 postsecondary education institutions * 70% with AYCE meal plans * 40% with trays * 90% can go trayless (IES[32] / assumption validated with Advisory Council) **Operating costs**: Minimal; policy / process changes and consumer education (e.g. signage) may be needed (validated with Advisory Council)
Financial Benefits	**Food costs avoided**: potential * characterization * food type retail value = $190M per year (calculation)

[31] "The Business and Cultural Acceptance Case for Trayless Dining." *Aramark Higher Education*. 2008. Available from http://www.elon.edu/docs/e-web/bft/sustainability/ARAMARK%20Trayless%20Dining%20July%202008%20FINAL.pdf

[32] "Fast Facts." *National Center for Education Statistics*. 2013. Available from https://nces.ed.gov/fastfacts/display.asp?id=84

Category 2: Operational and Supply Chain Efficiency

Solution	Waste Tracking & Analytics
Description	Providing restaurants and prepared-food providers with data on wasteful practices to inform behavior and operational changes
Modeling Assumptions	
Diversion Potential	**Net waste**: 7.3M tons restaurant, full-service only + 4.9M tons institutional (ReFED generation model) • 15% of full-service restaurant waste is from restaurants with sufficient business requirements for waste tracking (Advisory Council) • 25% of full-service restaurant waste is pre-consumer / kitchen waste (Advisory Council) • 80% of institutional waste is from institutions with sufficient business requirements for waste tracking (Advisory Council) • 25-50% of institutional waste is pre-consumer / kitchen waste (Advisory Council)
	Addressable waste: 430K tons restaurant + 1,475K tons institutional (calculation) • Implementing waste tracking & analytics reduces pre-consumer / kitchen waste by 20-40% (UC Berkeley[33], Advisory Council)
	Diversion potential: 570K tons (calculation)
Diversion Characterization	**Food types included**: all (assumption) 25% grain, 20% meat, 50% fruits and vegetables, 3.5% seafood, 1.5% milk/dairy (Advisory Council / USDA)
Financial Costs	**Operating costs**: $90M for both institutions and restaurants (calculation) • Total institutional foodservice cost: $36M, based on 25K facilities * 80% adoption rate * $1800/year average product cost (Advisory Council member data and assumptions validated with ReFED team) • Total restaurant cost: $53M, based on 500K facilities * 15% adoption rate * $700/year average product cost (Advisory Council member data and assumptions validated with ReFED team); some existing waste tracking and analytics products are priced higher, but expected to fall with additional products and viable free options • Due to waste quantities, institutional waste tracking costs are higher than those for restaurants
Financial Benefits	**Food costs avoided**: potential * characterization * food type retail value = $1.38B per year (calculation)

Solution	Cold Chain Management
Description	Reducing product loss during shipment to retail distribution centers by using direct shipments and cold chain certified carriers
Modeling Assumptions	
Diversion Potential	**Net waste**: 3.2M tons retail distribution centers (ReFED generation model) • 70% of retail distribution center food waste is perishable (validated with Advisory Council)

[33]"2012-2013 FY Sustainability Rankings, Ratings, and Awards." *University of California*. 2013. Available from http://ucop.edu/sustainability/_files/2013-uc-awards.pdf

	Addressable waste (perishable only): 2.3M tons (estimation of *all perishable food sold, incl. food not wasted*) • 10% of food waste at point of delivery to retail distribution centers is driven by temperature/cold chain issues during transport; other 90% of distribution center waste is due to quality control, product spoilage, culling, etc. (validated through interview with major food retailer; most delivery rejections fall under a myriad of QC-related reasons) • 5-15% of perishables loss from transport to DCs can be reduced through improved cold chain management involving temperature monitoring technologies, certified cold chain carriers, and minimizing shipment stops (conservative assumption based on interviews with transport providers; hard data is unavailable)
	Diversion potential: 18K tons (calculation)
Diversion Characterization	**Food types included**: all except grains (assumption) 9% meat, 52% produce, 37% milk/dairy, 2% seafood (USDA / calculation)
Financial Costs	**Operating costs**: $4.2M per year from use of more expensive transport vendors with additional cold chain technology investments (market assumption based on 10% of value of food costs avoided, validated with Advisory Council)
Financial Benefits	**Food costs avoided**: potential * characterization * food type retail value = $36M per year (calculation)

Solution	**Improved Inventory Management**
Description	Improvements in the ability of retail inventory management systems to track an average product's remaining shelf-life (time left to sell an item) and inform efforts to reduce days on hand (how long an item has gone unsold)
Modeling Assumptions	
Diversion Potential	**Net waste**: 4M tons retail (ReFED generation model) • 70% of retail waste is perishable food waste (validated with Advisory Council, and triangulated through interviews with food retailers) • 28% of perishable waste is due to ineffective ordering (Retail Profit Solutions[34])
	Addressable waste: 800K tons (calculation) • 5-10% of ordering-related perishable shrink can be reduced through store-level inventory planning (conservative assumption based on past Deloitte analyses for retail inventory projects)
	Diversion potential: 60K tons (calculation)
Diversion Characterization	**Food types included**: all (assumption) 22% grain, 7% meat, 40% produce, 30% milk/dairy, 1% seafood (USDA / calculation)

[34] "Perishable Shrink." *Retail Profit Solutions.* Available from http://wheresmyshrink.com/perishableshrink.html

Financial Costs	**Investment costs**: $100M one-time to upgrade retailer inventory software systems (market assumption) • 50% of 40,000 retailers nationwide need to upgrade inventory systems; others do not (FMI[35] / validated with Advisory Council and past Deloitte work with food retailers) • Inventory system upgrade costs $5000 per store (validated with internal stakeholders) **Operating costs**: $40M to conduct inventory analyses (market assumption) • All 40,000 retailers nationwide to conduct annual inventory analyses, at $1000 per store (FMI / assumption validated with Advisory Council and food retail experts)
Financial Benefits	**Food costs avoided**: potential * characterization * food type retail value = $115M (calculation)

Solution	**Secondary Resellers**
Description	Businesses that purchase processed foods and produce directly from manufacturers and distributors for discounted retail sale to consumers
Modeling Assumptions	
Diversion Potential	**Net waste diverted:** • Grocery Outlet nets $1B in annual sales across its 200+ stores (Grocery Outlet) • At $2.4 / lb average food price this equals 280K tons sold per year (calculated from ReFED food cost data) • 40% of product sold would otherwise go to waste; other 60% is made-to-order, not "diverted" from waste (validated with Advisory Council) • 40% * 280K tons = 110K tons of food diverted from going to waste
	Growth in existing food recovery channels: • Existing secondary resellers could double to triple in current market size (Grocery Outlet)
	Diversion potential: 165K tons diverted (calculation)
Diversion Characterization	**Food types included**: all (assumption) 22% grain, 7% meat, 40% produce, 30% milk/dairy, 1% seafood (USDA / calculation)
Financial Costs	**Investment costs**: $900M to open 300 additional stores nationwide at a per-store opening cost of $3M (assumption based on current discount grocery market and Deloitte retail expert) • $3M per-store construction cost based on comparison of discount grocer retail square footage[36] to standard food retail store area[37] and typical grocery store costs of $5M[38]
	Operating costs: $1.12B per year based on 90% of annual revenue (10% overall profit margin assumed based on industry standards) • Variable costs: $375M based on $1.6 / lb average selling price of food sold in secondary reseller stores and 17% average food profit margin store-wide (based on data from ReFED team and industry experts) • Fixed costs: $750M (calculation based on total operating costs minus variable food costs)

[35] "Supermarket Facts." *Food Marketing Institute*. 2015. Available from http://www.fmi.org/research-resources/supermarket-facts

[36] Smith, Kevin. "Grocery Outlet Bargain Market to open 14 Southern California locations." *San Gabriel Valley Tribune*. 15 September 2015. Available from http://www.sgvtribune.com/business/20150915/grocery-outlet-bargain-market-to-open-14-southern-california-locations

[37] Tuttle, Brad. "Your Grocery Store May Soon Be Cut in Half." Money. 2 June 2014. Available from http://time.com/money/136330/why-your-grocery-store-may-soon-be-cut-in-half/

[38] "The 50 Fastest Growing Supermarket Chains." Chain Store Guide. 2010. Available from https://www.chainstoreguide.com/static_content/pdf/50-Fastest-Growing-Grocery-Stores-2010.pdf

Financial Benefits	**Revenue generated**: potential * characterization * food type retail value = $1.27B (calculation)

Solution	**Manufacturing Line Optimization**
Description	Identifying opportunities to reduce food waste from manufacturing / processing operations and product line changeovers
Modeling Assumptions	
Diversion Potential	**Net opportunity**: 345K tons of food waste sent to landfills annually (ReFED analysis) • ConAgra diverted 1,500 tons of waste from landfill last year, and believes this quantity could be sustainable year over year (interview with ConAgra[39],[40]) • ConAgra is assumed to represent 5-15% of industry-wide waste reduction opportunity (proxy for market share, based on ReFED team assumptions) • Overall opportunity for waste reduction through line optimization across all food manufacturers is proportional to ConAgra's efforts, i.e. industry-wide diversion potential is between 1.5M tons / 15% and 1.5M tons / 5% per year (validated with Advisory Council, but limited data available on manufacturing waste prevention through line optimization)
	Diversion potential: 20K tons (calculation)
Diversion Characterization	**Food types included**: all food types included (assumption) 22% grain, 7% meat, 40% produce, 30% milk/dairy, 1% seafood (USDA / calculation)
Financial Costs	**Operating costs**: $3.9M per year based on average cost of $0.10 per wholesale dollar value of reclaimed food, regardless of method of optimization (interview with Advisory Council)
Financial Benefits	**Food costs avoided**: potential * characterization * wholesale price = $39M per year (calculation)

Category 3: Consumer Education Campaigns

Solution	**Consumer Education Campaigns**
Description	Conducting large-scale consumer advocacy campaigns to raise awareness of food waste and educate consumers about ways to save money and reduce wasted food
Modeling Assumptions	
Diversion Potential	**Net waste**: 26.5M tons residential (ReFED generation model)
	Addressable waste: 26.5M tons (assumes all households can be targeted) • 5-15% reductions in household waste generation can be achieved through various forms of consumer education, including media and other outreach methods (WRAP[41], assumptions based on ReFED interviews) • 1/3 of total household waste reduction impact due to consumer education can be attributable to media (interview with NRDC[42])

[39] ConAgra Foods, interview by Robert Bui, 13 October 2015.
[40] "2015 Citizenship Report." *ConAgra Foods*. September 2015. Available from http://media.corporate-ir.net/media_files/IROL/97/97518/ConAgra_Foods_Citizenship_Report_2015.pdf
[41] Quested, Tom; Ingle, Robert and Andrew Parry. "Household Food and Drink Waste in the United Kingdom 2012." *Waste & Resources Action Programme*. November 2013. Available from http://www.wrap.org.uk/sites/files/wrap/hhfdw-2012-main.pdf.pdf

	• Of this media-attributable consumer waste reduction impact, 2/3 is specifically driven by consumer campaigns (other 1/3 occurs due to other sources of consumer information) (validated with Advisory Council)
	Diversion potential: 585K tons (calculation)
Diversion Characterization	**Food types included**: all (assumption) 16% grain, 16% meat, 43% produce, 23% milk/dairy, 2% seafood (USDA / calculation)
Financial Costs	**Operating costs**: $260M for various media campaigns, distributed over 10 years (assumptions below validated with Advisory Council and ReFED team) • 50 large and 50 smaller metropolitan areas running campaigns costing $100K / $50K each • 25K institutions within foodservice conducting campaigns costing $10K each • 15 NGOs funding educational campaigns costing $50K each
Financial Benefits	**Food costs avoided**: potential * characterization * food type retail value = $2.67B per year (calculation)

Recovery Solutions Methodology

The recovery solution methodologies below adhere to the same overall analysis framework used for the prevention solutions. For each solution, the total potential and addressable waste by stakeholder is initially quantified, leading to the calculation of the quantity that is feasible to divert.

Manufacturers are excluded from the recovery section due to limited opportunities to increase existing food recovery efforts. Although food processors and producers handle an enormous quantity of food and generate significant amounts of waste, these outputs already have extremely high rates of reuse (95%), either being sold through secondary retail channels or to animal feed buyers. Food manufacturers also typically have long-standing relationships with food recovery agencies, further limiting incremental food donation opportunities.

For most of the recovery solutions, the key input variables are the **addressable food recovery rate** and the **adoption rate**. For all recovery solutions outside of Donation Matching Software, addressable food recovery rate reflects a percentage of total potential quantity that could be addressed by that solution. For example, out of 900K tons of restaurant/foodservice recovery opportunity, Donation Storage and Handling specifically could help address 23% of that quantity. These percentages are based on a BSR study for the Food Waste Reduction Alliance that surveyed manufacturers, retailers, and restaurants on their perceived barriers to food donation, such as “transportation constraints” or “liability concerns”[43] – each barrier aligns with one of the *Roadmap’s* recovery solutions.

A solution’s adoption rate indicates the theoretical market penetration or prevalence of each solution, once implemented. Food policy solutions for instance, once fully-implemented, will have a 100% solution adoption rate as legislation can be enacted at the federal level and apply to all businesses and

[42] Natural Resources Defense Council, interview by Robert Bui, 17 August 2015.

[43] Business for Social Responsibility. “Analysis of Food Waste Among Food Manufacturers, Retailers, and Restaurants.” *Food Waste Reduction Alliance.* 2014. Available from http://www.foodwastealliance.org/wp-content/uploads/2014/11/FWRA_BSR_Tier3_FINAL.pdf

recovery organizations nationwide. Food infrastructure solutions, which are costlier and may have geographical and regional dependencies, have lower adoption rates. These infrastructure solutions assume that implementation will apply to more densely populated areas for retail/foodservice donations, and higher-producing regions for farm/producer donations.

For the recovery solutions, "Food Costs Avoided" were calculated using a flat $1.71 per pound value, based on latest Feeding America auditing standards for valuing donated food[44]. The financial benefits were then calculated as an annualized NPV based on a 10 year timeline.

Category 4: Donation Infrastructure

<table>
<tr><th>Solution</th><th colspan="4">Donation Matching Software</th></tr>
<tr><td>Description</td><td colspan="4">Using a technology platform to connect individual food donors with recipient organizations and reach smaller scale food donations</td></tr>
<tr><td colspan="5">Modeling Assumptions</td></tr>
<tr><td rowspan="6">Diversion Potential</td><td></td><td>Farm</td><td>Restaurant / Foodservice</td><td>Retail</td></tr>
<tr><td>Total potential food recovery:</td><td>• N/A</td><td>• 240K tons (Feeding America[45])</td><td>• 60K tons (Feeding America[46]</td></tr>
<tr><td>Addressable food recovery: % recovery potential</td><td>• N/A</td><td>• 100% (total potential food recovery represents incremental opportunity)</td><td>• 100% (total potential food recovery represents incremental opportunity)</td></tr>
<tr><td colspan="4">• Adoption rate of 100% nationwide, based on Feeding America's Online Marketplace platform
• 50% of the food recovery potential estimated by Feeding America is attributable directly to the donation matching software platform; the other 50% relies on additional labor, transportation, or storage and handling outside solution scope (Advisory Council and expert interviews)</td></tr>
<tr><td>Diversion potential:</td><td>N/A</td><td>120K tons</td><td>30K tons</td></tr>
<tr><td colspan="4"></td></tr>
<tr><td>Diversion Characterization</td><td colspan="4">Food types included: all (validated with Advisory Council)
24% grain, 15% meat, 48% produce, 10% milk, 3% seafood (calculation / assumption)</td></tr>
<tr><td>Financial Costs</td><td colspan="4">Investment costs: $5M for development of software platform, employee/staff training and education (based on Google.org's $1.6M investment in Online Marketplace[47], $5M enables a variety of platforms to be developed and could be allocated to unanticipated costs)</td></tr>
</table>

[44] "Feeding America Financial Statements." *KPMG.* 2015. Available from http://www.feedingamerica.org/about-us/about-feeding-america/annual-report/FA-FY2015-financial-statements.pdf

[45] Feeding America, interview by Robert Bui. 3 August 2015.

[46] Ibid.

	Operating costs: $500K per year for system maintenance and ongoing training and support (validated with Advisory Council)
Financial Benefits	**Food costs avoided**: diversion potential * $1.71 / lb (Feeding America standard value of donated food) = $433M per year (calculation)

Solution	**Donation Storage and Handling**			
Description	Expanding temperature-controlled food distribution infrastructure (e.g. refrigeration, warehouses) and labor availability to handle (e.g. process, package) additional donation volumes			
Modeling Assumptions				
Diversion Potential		**Farm**	**Restaurant / Foodservice**	**Retail**
	Total potential food recovery:	• N/A	• 900K tons (Roadmap analysis)	• 700K tons (Roadmap analysis)
	Addressable food recovery: % recovery potential not donated due to *food bank storage / refrigeration constraints* (ReFED / BSR)	• N/A	• 23% of restaurant total recovery potential (BSR[48]) • 210K tons could be donated if storage / refrigeration is addressed	• 27% of retail total recovery potential (BSR[49]) • 190K tons could be donated if storage / refrigeration is addressed
	• Adoption rate of 40% nationwide (assumption of top MSAs only, validated with Advisory Council) • 50-80% addressable quantity can be captured across all value stages (validated with Advisory Council)			
	Diversion potential:	N/A	50K tons	50K tons
Diversion Characterization	**Food types included**: all (validated with Advisory Council) 24% grain, 15% meat, 48% produce, 10% milk, 3% seafood (calculation / assumed adjustment from retail waste characterization based on food type values)			
Financial Costs	**Investment costs**: $100M one-time for physical facility construction **Operating costs**: $500 per ton of food stored / handled = $105M per year (validated with Advisory Council)			

[47] "Feeding America to Use New Technology for Local Food Rescue with $1.6M Google Global Impact Award." *Feeding America*. 2014. Available from http://www.feedingamerica.org/hunger-in-america/news-and-updates/press-room/press-releases/feeding-america-wins-google-impact-award.html

[48] Business for Social Responsibility. "Analysis of Food Waste Among Food Manufacturers, Retailers, and Restaurants." *Food Waste Reduction Alliance.* 2014. Available from http://www.foodwastealliance.org/wp-content/uploads/2014/11/FWRA_BSR_Tier3_FINAL.pdf

[49] Ibid.

Financial Benefits	**Food costs avoided**: diversion potential * $1.71 / lb (Feeding America standard value of donated food) = $297M per year (calculation)

Solution	**Donation Transportation**			
Description	Providing small-scale transportation infrastructure for local recovery as well as long-haul transport capabilities			
Modeling Assumptions				
Diversion Potential		**Farm**	**Restaurant / Foodservice**	**Retail**
	Total potential food recovery:	• 20K tons (*Roadmap* assumption)	• 900K tons (*Roadmap* analysis)	• 700K tons (*Roadmap* analysis)
	Addressable food recovery: % recovery potential not donated due to *transportation constraints* (ReFED / BSR)	• 100% of above recovery potential equals a doubling of food currently recovered by Borderlands Food Bank (*Roadmap* assumption)	• 26% of restaurant total recovery potential (BSR) • 235K tons could be donated if transportation is addressed	• 27% of retail total recovery potential (BSR) • 190K tons could be donated if transportation is addressed
	• Adoption rate of 40% nationwide (assumption of top MSAs only, validated with external stakeholders) • 50-80% addressable volume can be captured across all value stages (validated with Advisory Council)			
	Diversion potential:	20K tons	50K tons	40K tons
Diversion Characterization	**Food types included**: all (validated with Advisory Council) 24% grain, 15% meat, 48% produce, 10% milk, 3% seafood (calculation / assumed adjustment from retail waste characterization based on food type values)			
Financial Costs	**Operating costs**: $700 per ton of food picked up or transported, or $0.35/lb = $46M per year, based on Feeding America costs of foodservice vs. retail donations (calculated from related Advisory Council data; these costs are based on associated labor operating costs, and assumes usage of existing physical transportation infrastructure – additional costs to purchase physical capital, e.g. trucks, are not explicitly modeled here)			
Financial Benefits	**Food costs avoided**: diversion potential * $1.71 / lb (Feeding America standard value of donated food) = $317M per year (calculation)			

Solution	**Value-Added Processing**			
Description	Extending the usable life of donated foods through processing methods such as making soups, sauces, or other value-added products			
Modeling Assumptions				
Diversion Potential		**Farm**	**Restaurant / Foodservice**	**Retail**
	Total potential	• 4,200K tons	• 900K tons	• 700K tons

		Farm	Restaurant / Foodservice	Retail
	food recovery:	(Roadmap analysis)	(Roadmap analysis)	(Roadmap analysis)
	Addressable food recovery: % recovery potential not donated due to *on-site storage / refrigeration constraints* (ReFED / BSR)	• 20% of farm total recovery potential (Roadmap assumption) • 840K tons could be donated if storage / refrigeration is addressed	• 19% of restaurant total recovery potential (BSR) • 170K tons could be donated if storage / refrigeration is addressed	• 18% of retail total recovery potential (BSR) • 125K tons could be donated if storage / refrigeration is addressed
	• Adoption rate of 60% nationwide (assumption of top MSAs only and high-volume farm / food production regions, validated with Advisory Council) • 10-20% addressable volume can be captured across all value stages (validated with Advisory Council)			
	Diversion potential:	75K tons	15K tons	12K tons
Diversion Characterization	**Food types included**: all (validated with Advisory Council) 18% grain, 10% meat, 65% produce, 6% milk, 1% seafood (calculation / assumed adjustment from retail waste characterization based on food type values)			
Financial Costs	**Investment costs:** $75M upfront for capital investments and machinery (primary interview, based on $3.6M initial investment by a leading state-wide food bank to handle 10M pounds / 5K tons of donated per year) **Operating costs**: $4M per year based on operation, maintenance, and other costs estimated at 5% of initial investment cost (ReFED assumption)			
Financial Benefits	**Food costs avoided**: diversion potential * $1.71 / lb (Feeding America standard value of donated food) = $295M per year (calculation)			

Category 5: Donation Policy

Solution	**Donation Liability Education**			
Description	Educating potential food donors on donation liability laws			
Modeling Assumptions				
Diversion Potential		**Farm**	**Restaurant / Foodservice**	**Retail**
	Total potential food recovery:	• 4,200K tons (*Roadmap* analysis)	• 900K tons (*Roadmap* analysis)	• 700K tons (*Roadmap* analysis)
	Addressable food recovery: % recovery potential not donated due to *liability concerns* (ReFED / BSR)	• 10% of farm total recovery potential (Roadmap assumption) • 420K tons could be donated if liability concerns are addressed	• 21% of restaurant total recovery potential (BSR) • 190K tons could be donated if liability concerns are addressed	• 21% of retail total recovery potential (BSR) • 145K tons could be donated if liability concerns are addressed

	• Adoption rate of 100% nationwide (assuming sweeping education effort, validated with Advisory Council) • Removing liability concern barrier will only address 50% of donation potential; reported liability concerns are overstated as businesses over-attribute reasons for not donating food to liability (assumption validated with Advisory Council and industry experts) • 10-20% addressable volume can be captured across all value stages (validated with Advisory Council)			
	Diversion potential:	30K tons	15K tons	12K tons
Diversion Characterization	**Food types included**: all (validated with Advisory Council) 24% grain, 15% meat, 48% produce, 10% milk, 3% seafood (calculation / assumption)			
Financial Costs	**Operating costs**: $5M per year for a mix of ongoing policy advocacy and lobbying, employee education and training, and awareness campaign costs (extrapolated from historic policy lobbying costs per Food Policy Action)			
Financial Benefits	**Food costs avoided**: diversion potential * $1.71 / lb (Feeding America standard value of donated food) = $164M per year (calculation)			

Solution	**Standardized Donation Regulation**			
Description	Standardizing local and state health department regulations for safe handling and donation of food through federal policy			
Modeling Assumptions				
Diversion Potential		**Farm**	**Restaurant / Foodservice**	**Retail**
	Total potential food recovery:	• 4,200K tons (*Roadmap* analysis)	• 900K tons (*Roadmap* analysis)	• 700K tons (*Roadmap* analysis)
	Addressable food recovery: % recovery potential not donated due to *regulation concerns* (ReFED / BSR)	• 5% of farm total recovery potential (Roadmap assumption) • 285K tons could be donated if regulation is addressed	• 11% of restaurant total recovery potential (BSR) • 100K tons could be donated if regulation is addressed	• 6% of retail total recovery potential (BSR) • 42K tons could be donated if regulation is addressed
	• Adoption rate of 100% nationwide (assuming sweeping policy effort based on federal policy) • 50-60% addressable volume can be captured across all value stages (validated with Advisory Council)			
	Diversion potential:	115K tons	55K tons	25K tons
Diversion Characterization	**Food types included**: all (validated with Advisory Council) 24% grain, 15% meat, 48% produce, 10% milk, 3% seafood (calculation / assumption)			
Financial Costs	**Operating costs**: $5M per year for a mix of ongoing policy advocacy and lobbying costs for legislators (extrapolated from historic policy lobbying costs per Food Policy Action)			
Financial Benefits	**Food costs avoided**: diversion potential * $1.71 / lb (Feeding America standard value of donated			

	food) = $557M per year (calculation)

Solution	**Donation Tax Incentives**			
Description	Expanding federal tax benefits for food donations to all corporations and improving ease of donation reporting processes for tax deductions			
Modeling Assumptions				
Diversion Potential		**Farm**	**Restaurant / Foodservice**	**Retail**
	Total potential food recovery:	• 4,200K tons (Roadmap analysis)	• 900K tons (Roadmap analysis)	• N/A
	Addressable food recovery: % recovery potential that could be **influenced by tax incentives**	• 100% of farm total recovery potential (*Roadmap* assumption) • 4,200K tons are influenced by tax incentives	• 100% of restaurant total recovery potential (*Roadmap* assumption) • 900K tons are influenced by tax incentives	• N/A
	• Adoption rate of 100% nationwide (federal tax incentive benefits all businesses) • 5-10% addressable volume can be captured across all value stages (validated with Advisory Council)			
	Diversion potential:	315K tons	65K tons	N/A
Diversion Characterization	**Food types included**: all (validated with Advisory Council) 20% grain, 5% meat, 70% produce, 4% milk, 1% seafood (calculation / assumption)			
Financial Costs	**Operating costs**: $5M per year for a mix of ongoing policy advocacy and lobbying and subsequent employee awareness and training efforts (extrapolated from historic policy lobbying costs per Food Policy Action)			
Financial Benefits	**Food costs avoided**: diversion potential * $1.71 / lb (Feeding America standard value of donated food) = $1.1B per year (calculation)			

Recycling Solutions Methodology

The economics of food waste recycling are complex and sensitive to local variation. ReFED modeled these variations for the 50 largest metropolitan areas (using Combined Statistical Area data), since they generate roughly of all food waste nationwide. Once tonnage was generated for each county, this data was imported into a GIS and summed at the CBSA level, and then combined with datasets for statewide policies, tip fees, labor rates, energy prices, relative land values, and the value of finished compost.

Economic modeling was done in three stages:

1. Determine baseline cost model structure for each solution.

2. Determine amounts of food waste able to be diverted to each solution.
3. Assign food waste to key solutions on an individual MSA basis based on favorable economics.

Recycling Cost Model Structure

Detailed operational models were constructed for windrow composting, aerated static pile composting, anaerobic digestion and WRRF with AD. Facilities were assumed to have an avergage processing capacity of 40k tons per year. While most operations are significantly smaller today, reaching these economies of scale is important to demonstrate cost effectiveness on a per-ton basis. The economic modeling accounted for all facility and equipment costs, operations and maintenance, labor expenses, expected revenues, and other avoided costs, using both public and proprietary datasets. Capital expenditures were fixed across all locations, but operational costs varied according to local prices. Properties were assumed to be leased, and leasing rates were varied by a cost of land index at the state level. A separate model was constructed for the capital and operational costs of collection for both residential and business generators.

For on-site solutions, community and home composting, and animal feed, a nation-wide approach was used to model the economic potential, costs, and benefits, as the local complexities are significantly fewer.

The figure below outlines the results of the *Roadmap* MSA-level estimate of food waste currently wasted by landfilling, and the amount of food waste diverted through recycling in those cities. This estimate was built by first estimating existing waste at the county level for each of the main stakeholder groups, and then aggregating to the MSA level. It is important to note that given that local environments vary drastically, the Roadmap did not attempt to analyze how individual cities adoption rates of different technologies would roll out and each technology was analyzed independently. A capture rate of 100% indicates that a city has multiple recycling technologies that could be very successful in the local environment. The capture rate v. baseline shows the amount of additional food waste diverted through the *Roadmap* versus the current waste levels sent to landfill.

Note: This analysis can be assumed to be illustrative of what may occur. However, it was completed at a macro level and uses national datasets (versus in-depth regional assessments), and as a result local roll-out realities are likely to differ.

Metro Area	Annual Food Scraps Sent to Landfill (tons per year)	Roadmap Waste Diverted from Landfill (tons per year)	Additional Capture v. Baseline
New York-Newark-Jersey City, NY-NJ-PA	3,048,559	1,066,996	35%
Los Angeles-Long Beach-Anaheim, CA	2,104,863	947,188	45%
Chicago-Naperville-Elgin, IL-IN-WI	1,524,136	533,448	35%
Dallas-Fort Worth-Arlington, TX	1,011,780	20,236	2%
Philadelphia-Camden-Wilmington, PA-NJ-DE-MD	979,703	538,837	55%
Houston-The Woodlands-Sugar Land, TX	932,624	18,652	2%
Washington-Arlington-Alexandria, DC-VA-MD-WV	910,779	273,231	30%
Miami-Fort Lauderdale-West Palm Beach, FL	905,243	18,105	2%
Boston-Cambridge-Newton, MA-NH	882,397	882,397	100%
Atlanta-Sandy Springs-Roswell, GA	830,888	16,618	2%
Phoenix-Mesa-Scottsdale, AZ	676,929	13,539	2%
Detroit-Warren-Dearborn, MI	649,130	12,983	2%
San Francisco-Oakland-Hayward, CA	625,799	312,899	50%
Riverside-San Bernardino-Ontario, CA	610,839	335,962	55%
Minneapolis-St. Paul-Bloomington, MN-WI	556,357	250,361	50%
Seattle-Tacoma-Bellevue, WA	541,367	541,367	100%
San Diego-Carlsbad, CA	509,917	254,958	50%

Baltimore-Columbia-Towson, MD	466,174	186,470	40%
Tampa-St. Petersburg-Clearwater, FL	442,807	8,856	2%
St. Louis, MO-IL	427,454	136,785	32%
Top 20 Cities TOTAL	**18,637,745**	**6,369,888**	**34% (wght avg)**

Figure 19: Top 20 Metropolitan Regions by Existing Annual Food Waste Levels and Roadmap Diversion Potential

Determining Regional Recycling Diversion Potential

In order to calculate the diversion potential for each solution, a matrix was designed to assign portions of the waste stream to different technologies based on the presence of significant policy drivers and likelihood, feasibility, and cost effectiveness of adoption. A weighted average of the uptake rate was determined based on local categorization by general policy categories – for instance does the state have a landfill ban on yard waste or recycling mandates. An overall recycling rate projection was assigned to each MSA, providing an estimate of the total amount of waste expected to be captured.

For each solution, regional factors were considered including labor rates and operating cost drivers, variations in end market material value, collection costs, and avoided disposal costs. MSA's were ranked from lowest to highest total system cost per ton of waste diverted. There were five main variables that fed into the total system cost calculation: (i) avoided disposal costs, (ii) cost of collection/logistics, (iii) processing capital cost, (iv) processing operational costs, and (v) processing revenue streams. Figures 20 and 21 below show the top 20 MSAs by projected system benefit/cost on a per-ton basis for composting systems and AD, respectively.

Each MSA was assigned a separate percentage of food waste diversion for each of the major solutions (Centralized Compost, AD, and WRRF) in a way that maximized total benefit and minimized cost. Then weighted averages of each cost and benefit stream were calculated from the chosen MSAs and applied to the captured tonnage. These values were then utilized in a 10-year financial model to calculate the net present value and the environmental impacts of each solution.

Metro Area	Total Benefit (Cost) $ Per Ton ASP Composting	Total Benefit (Cost) $ Per Ton Windrow Composting
Hartford-West Hartford-East Hartford, CT	$29	$49
Portland-Vancouver-Hillsboro, OR-WA	$25	$44
Providence-Warwick, RI-MA	$16	$36
Boston-Cambridge-Newton, MA-NH	$16	$35
Seattle-Tacoma-Bellevue, WA	$16	$35
New York-Newark-Jersey City, NY-NJ-PA	$12	$32
Minneapolis-St. Paul-Bloomington, MN-WI	($4)	$16
Philadelphia-Camden-Wilmington, PA-NJ-DE-MD	($9)	$11
Pittsburgh, PA	($11)	$9
Milwaukee-Waukesha-West Allis, WI	($16)	$3
Chicago-Naperville-Elgin, IL-IN-WI	($17)	$3
Buffalo-Cheektowaga-Niagara Falls, NY	($19)	$0
Indianapolis-Carmel-Anderson, IN	($19)	$0
Baltimore-Columbia-Towson, MD	($24)	($5)
San Francisco-Oakland-Hayward, CA	($25)	($5)
Rochester, NY	($25)	($6)
San Jose-Sunnyvale-Santa Clara, CA	($26)	($7)
Los Angeles-Long Beach-Anaheim, CA	($28)	($9)
Tampa-St. Petersburg-Clearwater, FL	($29)	($10)
Orlando-Kissimmee-Sanford, FL	($30)	($11)

Figure 20: Top 20 Metropolitan Regions by Highest Total Benefit per Ton Waste Diverted for Centralized Composting

Composting systems were modeled based on regional economics of windrow and ASP systems, and tonnage was attributed to each technology based on the metropolitan regions where system economics were either positive or very near breakeven. The overall split was 79% windrow and 21% ASP. On average, the modeling showed that windrow technologies have a $20 per ton higher system net economic benefit than ASP. This data was then aggregated in order to generate the overall Centralized Composting solution results.

Metro Area	Total Benefit (Cost) $ Per Ton
	Anaerobic Digestion
New York-Newark-Jersey City, NY-NJ-PA	$44
Buffalo-Cheektowaga-Niagara Falls, NY	$40
Rochester, NY	$36
Philadelphia-Camden-Wilmington, PA-NJ-DE-MD	$22
Portland-Vancouver-Hillsboro, OR-WA	$20
Hartford-West Hartford-East Hartford, CT	$19
Seattle-Tacoma-Bellevue, WA	$12
Providence-Warwick, RI-MA	$7
Boston-Cambridge-Newton, MA-NH	$7
Washington-Arlington-Alexandria, DC-VA-MD-WV	($4)
Minneapolis-St. Paul-Bloomington, MN-WI	($19)
Las Vegas-Henderson-Paradise, NV	($22)
Pittsburgh, PA	($26)
Tampa-St. Petersburg-Clearwater, FL	($26)
Louisville/Jefferson County, KY-IN	($30)
Milwaukee-Waukesha-West Allis, WI	($31)
Chicago-Naperville-Elgin, IL-IN-WI	($32)
Phoenix-Mesa-Scottsdale, AZ	($33)
Indianapolis-Carmel-Anderson, IN	($34)
Baltimore-Columbia-Towson, MD	($37)

Figure 21: Top 20 Metropolitan Regions by Highest Total Benefit per Ton Waste Diverted for AD

For anaerobic digestion, the main driver of total system cost-benefit is the cost of disposal, or tipping fee. Other key drivers included natural gas prices, compost prices, and labor costs.

Figure 22 below shows the top 50 recycling-MSA pairings with the highest system benefit per ton is listed (out of window composting, ASP composting, anaerobic digestion, and WRRF with AD). The top 5 most cost effective solutions are all modeled to be an expansion of AD at WRRFs in the Northeast, due to high value of energy, high value of compost, high value of avoided disposal costs, and relatively low incremental capital and operating cost.

Top Solution	MSA	System Benefit (Cost) per ton
WRRF	Hartford-West Hartford-East Hartford, CT	$65.98
WRRF	Rochester, NY	$60.28
WRRF	Boston-Cambridge-Newton, MA-NH	$59.55
WRRF	Providence-Warwick, RI-MA	$59.46
WRRF	Buffalo-Cheektowaga-Niagara Falls, NY	$58.77
WRRF	Portland-Vancouver-Hillsboro, OR-WA	$55.26
Windrow	Hartford-West Hartford-East Hartford, CT	$48.98
WRRF	Seattle-Tacoma-Bellevue, WA	$45.01
Windrow	Portland-Vancouver-Hillsboro, OR-WA	$44.12
AD	New York-Newark-Jersey City, NY-NJ-PA	$43.52
WRRF	New York-Newark-Jersey City, NY-NJ-PA	$42.92
AD	Buffalo-Cheektowaga-Niagara Falls, NY	$39.59
AD	Rochester, NY	$36.49
Windrow	Providence-Warwick, RI-MA	$35.70
Windrow	Boston-Cambridge-Newton, MA-NH	$35.51
Windrow	Seattle-Tacoma-Bellevue, WA	$35.25
WRRF	Pittsburgh, PA	$35.21
WRRF	Minneapolis-St. Paul-Bloomington, MN-WI	$34.13
WRRF	Philadelphia-Camden-Wilmington, PA-NJ-DE-MD	$33.85
Windrow	New York-Newark-Jersey City, NY-NJ-PA	$31.69
ASP	Hartford-West Hartford-East Hartford, CT	$29.39
WRRF	Sacramento--Roseville--Arden-Arcade, CA	$25.69

ASP	Portland-Vancouver-Hillsboro, OR-WA	$25.05
WRRF	San Jose-Sunnyvale-Santa Clara, CA	$23.46
WRRF	Riverside-San Bernardino-Ontario, CA	$22.40
AD	Philadelphia-Camden-Wilmington, PA-NJ-DE-MD	$21.69
AD	Portland-Vancouver-Hillsboro, OR-WA	$19.89
AD	Hartford-West Hartford-East Hartford, CT	$18.98
WRRF	Richmond, VA	$18.96
ASP	Seattle-Tacoma-Bellevue, WA	$16.18
ASP	Providence-Warwick, RI-MA	$16.08
ASP	Boston-Cambridge-Newton, MA-NH	$15.89
WRRF	Indianapolis-Carmel-Anderson, IN	$15.83
Windrow	Minneapolis-St. Paul-Bloomington, MN-WI	$15.72
WRRF	Orlando-Kissimmee-Sanford, FL	$14.72
WRRF	Washington-Arlington-Alexandria, DC-VA-MD-WV	$13.52
ASP	New York-Newark-Jersey City, NY-NJ-PA	$12.48
AD	Seattle-Tacoma-Bellevue, WA	$11.58
WRRF	Milwaukee-Waukesha-West Allis, WI	$11.47
Windrow	Philadelphia-Camden-Wilmington, PA-NJ-DE-MD	$10.57
WRRF	San Francisco-Oakland-Hayward, CA	$8.85
WRRF	Baltimore-Columbia-Towson, MD	$8.61
Windrow	Pittsburgh, PA	$8.58
WRRF	San Diego-Carlsbad, CA	$8.54
WRRF	Los Angeles-Long Beach-Anaheim, CA	$7.23
AD	Providence-Warwick, RI-MA	$7.20
WRRF	Chicago-Naperville-Elgin, IL-IN-WI	$7.17
AD	Boston-Cambridge-Newton, MA-NH	$7.02
WRRF	Tampa-St. Petersburg-Clearwater, FL	$6.57
WRRF	Detroit-Warren-Dearborn, MI	$5.98

Figure 22: Top 50 Metropolitan Regions by Highest Total Benefit - Compost, AD, WRRF

Recycling Solution Economic Modeling Details

The detailed assumptions and outputs for the eight recycling solutions are detailed below. Unlike the prevention and recovery sections, where the Advisory Council validated many specific assumptions, the MSA-level data that drove the assumptions was mainly collected from public and private datasets. The Advisory Council validated the overall methodology, the sources of data, and provided validation of the model results as roughly approximating findings in specific MSAs where there is empirical data.

Category 6: Energy and Digestate

Solution	**Centralized Anaerobic Digestion**
Description	A series of biological processes in which microorganisms break down biodegradable material in the absence of oxygen resulting in two end products: biogas and digestate. There are many different AD technologies, including wet and dry versions, the latter being generally better suited for food waste mixed with yard waste.
Modeling Assumptions	
Diversion Potential	**Addressable waste**: 3.5M tons commercial/industrial in areas with strong policies, 9.6M tons commercial in non-policy areas (ReFED generation model)
	Diversion Potential: 1.9M tons • 25% uptake in areas where policy and other economic drivers are strong (assumption)

Financial Costs	**Capital costs**: $848M total across 9 metro areas • $59 per annual ton of capacity in amortized annual costs at a WACC of 5.1% **Operating costs**: $109M per year across 9 metro areas • $57 to $61 per ton **Indirect costs**: $145M per year in collection costs • $71 to $89 per ton **Annual Capital Payments:** $83M
Financial Benefits	**Direct revenues**: tip fees + energy sales + composted digestate sales = $251M per year (calculation) **Avoided disposal costs**: avoided trash collection + avoided landfill tip fees = $162M per year (calculation)
New Businesses Served	3,000+

Solution	**WRRF with AD**
Description	Delivering waste by truck or through existing sink disposal pipes to a municipal WRRF, where it is treated with anaerobic digestion; the biosolids can be applied to land for beneficial reuse
Modeling Assumptions	
Diversion Potential	**Addressable waste**: 13.4M tons residential (ReFED generation model)
	Diversion Potential: 1.6M tons • 10% to 15% residential uptake in strong policy and yard waste ban areas (assumption) • 15% residential uptake in multifamily buildings
Financial Costs	**Capital costs**: $736M total across 50 metro areas • $89 per ton in amortized annual costs at a WACC of 3.1% **Operating costs**: $97M per year across 50 metro areas • $55 to $67 per ton **Utilization of existing infrastructure**: 18 MSAs have excess capacity and material processed up to the current capacity is discounted 25% **Annual Capital Payments**: $61M
Financial Benefits	**Direct revenues**: energy sales = $53M per year (calculation) **Avoided disposal costs**: avoided trash collection + avoided landfill tip fees = $171M per year (calculation)
New Businesses Served	500+
New Homes Served	25M

Category 7: On-Site Business Processing Solutions

Solution	**In-Vessel Composting**
Description	Composting at small scale at institutions or businesses with heat and mechanical power to compost relatively quickly (less than one month versus more than two months for windrow

	composting)
Modeling Assumptions	
Diversion Potential	**Addressable waste**: 2.3M tons commercial in strong policy areas (ReFED generation model)
	Diversion Potential: 11.7K tons • 0.5% commercial uptake (assumption)
Financial Costs	**Capital costs**: $7.7M total across all areas • $157 per ton in amortized annual costs at a WACC of 6.4% **Operating costs**: $262K per year across all areas • $22 per ton
Financial Benefits	**Avoided disposal costs**: avoided collection and landfill tip fees = $798K per year (calculation)

Solution	**Commercial Greywater**
Description	An on-site treatment technology, greywater aerobic digesters use combinations of nutrients or enzymes and bacteria to break food organics down until soluble, where it is flushed into the sewage system.
Modeling Assumptions	
Diversion Potential	**Addressable waste**: 12.8M tons commercial (ReFED generation model)
	Diversion Potential: 595K tons • 2% to 5% commercial uptake (assumption)
Financial Costs	**Capital costs**: $83M total across all areas • $33 per ton in amortized annual costs at a WACC of 6.9% **Operating costs**: $5.4M per year across all areas • $9 per ton
Financial Benefits	**Indirect revenues**: reduced collection costs = $9M per year (calculation) **Avoided disposal costs**: avoided landfill tip fees = $36M per year (calculation)

Category 8: Agricultural Products

Solution	**Community Composting**
Description	Transporting food from homes by truck, car, or bicycle to small, community, or neighborhood-level compost facilities that process 2,500 tons per year on average
Modeling Assumptions	
Diversion Potential	**Addressable waste**: 8.3M tons residential in all areas (ReFED generation model)
	Diversion Potential: 167K tons • 2% residential uptake (assumption)
Financial Costs	**Capital costs**: $63.7M total across all areas • $82 per ton in amortized annual costs at a WACC of 2.8% **Operating costs**: $8.6M per year across all areas • $52 per ton

Financial Benefits	**Direct Revenues**: subscription fees + sale of compost + gate fees = $7M per year (calculation) **Avoided disposal costs**: avoided collection costs = $9M per year (calculation)

Solution	Centralized Composting
Description	Transporting waste to a centralized facility where it decomposes into compost
Modeling Assumptions	
Diversion Potential	**Addressable waste**: 7.8M tons commercial/residential in areas with strong policies or yard waste bans, 13.6M tons commercial in non-policy areas, 5.3M tons outside key MSAs (ReFED generation model)
	Diversion Potential: 5.0M tons • 10% to 40% commercial uptake in strong policy areas (assumption) • 20% residential uptake in strong policy and yard waste ban areas (assumption) • 5% to 20% commercial uptake in other areas (assumption) • 21% of sites are expected to be ASP, the remainder windrow (calculation)
Financial Costs	**Capital costs**: $878 total across 20 metro areas • $23 per annual ton capacity at a WACC of 5.7% for windrow • $38 per annual ton capacity in amortized annual costs at a WACC of 5.7% for ASP • Weighted average of $26.13 per ton in amortized annual costs **Operating costs**: $91M per year across 20 metro areas • $17 to $24 per ton for windrow • $24 to $27 per ton for ASP **Indirect costs**: $319M per year in collection costs • $67 to $115 per ton **Annual Capital Payments:** $123M
Financial Benefits	**Direct revenues**: tip fees + compost sales = $270M per year (calculation) **Avoided disposal costs**: avoided trash collection + avoided landfill tip fees = $346M per year (calculation)
New Businesses Served	15,000+
New Homes Served	15M

Solution	Animal Feed
Description	Feeding food waste to animals after it is heat-treated and dehydrated and either mixed with dry feed or directly fed
Modeling Assumptions	
Diversion Potential	**Addressable waste**: 3.6M tons retail/wholesale/industrial waste (ReFED generation model)
	Diversion Potential: 49K tons • 2% retail/wholesale uptake in high policy environments (assumption) • 1% retail/wholesale uptake in other environments (assumption) • 3% industrial uptake (assumption)

Financial Costs	**Capital costs**: $5.8M total across all areas • $16 per ton **Operating costs**: $859K per year across all areas • $18 per ton **Indirect costs**: $3.6M in collection costs • $74 per ton
Financial Benefits	**Indirect Revenues:** $1.1M in avoided grain purchasing annually (calculation) **Avoided disposal costs**: avoided collection costs and landfill tip fees = $3.5M per year (calculation)

Solution	**Home Composting**
Description	Keeping a small bin or pile for on-site waste at residential buildings to be managed locally; also known as "backyard composting"
Modeling Assumptions	
Diversion Potential	**Addressable waste**: Targeted 3.9M tons residential in all non-policy or yard waste ban areas – although potentially applicable to all 26M tons residential food waste (ReFED generation model)
	Diversion Potential: 97K tons • 2.5% residential uptake (assumption)
Financial Costs	**Capital costs**: $486K total across all areas • $5 per ton for simple equipment **Operating costs**: $3.5M per year across all areas for education and outreach • $36 per ton
Financial Benefits	**Avoided disposal costs**: avoided collection costs = $4M per year (calculation)

Detailed Recycling Model Components

Collection Model

Capital costs for trucks and containers were amortized at 8 and 10 years, respectively, at an 8% interest rate. Operational costs include labor, benefits, insurance, maintenance, administration, and a profit margin. Route efficiencies are calculated using the average density numbers for a well-developed suburb, and the size and average fill levels of containers.

The collection cost model was run for each local labor rate to determine the costs for three scenarios: creating a new dedicated residential food waste program, adding food waste to an existing yard waste collection program, and collecting commercial material from large generators.

Assumptions were made around the potential cost savings to retailers and restaurants who could potentially realize significant savings in trash costs if their organics were diverted. Additionally, raw costs to the hauler for collection were discounted slightly to account for the potential use of depreciated equipment and route efficiency improvements from smaller trash loads at grocery stores, restaurants, cafeterias, and single family homes.

Additionally, 20% of commercial waste being sent to centralized compost or AD was assumed to employ a form of on-site pretreatment, such as a dehydrator or pulper. These technologies both reduce the volume of food waste and extend storage time. The adoption rate is limited by the significant capital expense ($50k+), requirement of valuable dock space, and need for ongoing maintenance.

Centralized Composting Model

Capital costs for a 40k ton compost facility were broken into three categories: site, buildings, and equipment. Site costs were calculated to be $3m, including pad engineering, utility hook ups, and road construction. Buildings include a scale house and maintenance hangar, and was calculated to be $500,000. Equipment costs for a windrow facility are expected to be $1.9 million and include a high end depackager and screener to reduce contamination, in addition to turners, loaders, and trucks. Equipment costs for an ASP facility are expected to be nearly $5.5 million, including the same depackager and screener, as well as costly aeration equipment and waterproof breathable tarps. Site costs are expected to be slightly lower for ASP due to a smaller footprint.

Operational costs include labor, maintenance, equipment operating costs, and site lease. Electricity, labor and lease costs vary regionally. Maintenance costs covered basic equipment, site, and building maintenance as well as ongoing utility costs. Equipment operating costs primarily accounted for the energy costs incurred in running the primary equipment.

Revenues were calculated by assuming that 50% of the local tip fee is collected per incoming wet ton of food waste, and that 80% of the finished compost would be sold at wholesale rates. The remaining 20% of finished compost was assumed to be donated and/or used on site. The *Roadmap* assumed facility capacity utilization rate of 80%.

Centralized Anaerobic Digestion Model

Capital costs for a 40k ton AD facility include the anaerobic digestion equipment itself, as well as equipment for odor control, gas treatment, and internal combustion engines. Additionally, costs for engineering and contingency were accounted for, as well as the capital costs for a smaller compost facility to manage the digestate. The total capital expenditure for a new facility is expected to be $36 million.

Operational costs include equipment maintenance, labor, utilities, and the operation of the compost facility, as well as purchase of bulking agents and the site lease.

Revenues were calculated by assuming 50% of the local tip fee, and assuming that the composted digestate is sold at 75% of wholesale pricing. The revenue generated from biogas was calculated differently depending on whether natural gas or electricity are more valuable locally. If electricity values are low, such as in the Seattle area, it was assumed that biogas is primarily used for CNG powered vehicles. If electricity values are high, such as in New England, it was assumed that the biogas is used to generate electricity and heat.

WRRF with AD Model

Capital costs for WRRF with AD are related specifically to the installation and use of AD technology to manage food waste in the wastewater stream, not to the total design and construction of a WRRF. The capital costs include the AD system and buildings, a portion of the settling tanks and separation equipment, odor control, gas treatment, and biosolids management, as well as contingency and engineering costs.

Operational costs include equipment maintenance, labor, utilities, and the operation of the biosolids processing facility, as well as purchase of polymers and the site lease. Additionally, additional operational costs from additional biological oxygen demand and suspended solids are estimated, although these costs can vary widely depending on the layout and age of the water treatment facility.

Revenues are only assumed from electricity and gas sales, using the same methodology as centralized AD. There is no tip fee – while sending trucks to WRRF AD facilities and injecting the food waste directly into the digester is a viable strategy, the cost profile is more closely related to the modeling of centralized AD. Additionally, no revenue is assumed from the reuse of the biosolids – it is assumed that they are sufficiently contaminated to have no value, although they can potentially still be land applied or beneficially reused.

This solution has potential for managing a portion of the residential food waste stream, but there are concerns about the impact to the public works infrastructure such as clogs from fats and oils, especially in warmer climates where drainage is slower.

Non-Financial Impacts Methodology

Meals Recovered

When food waste is "recovered" through the seven recovery solutions, it is assumed that all of the tons of food recovered end up feeding people in need through nonprofits and other organizations. Therefore, the *Roadmap* adopts a straight conversion of tons of wasted food avoided into meals saved. The *Roadmap* uses Feeding America's standard methodology that one average adult meal weighs 1.2lbs.[50] While the *Roadmap also* reports diversion potential figures in tons for overall consistency, food waste in a recovery context is almost always described in meals or pounds.

Food recovery is a complex ecosystem where food donations themselves are not all created equal. Depending on the donor organization, donated food may vary widely in nutritional value. Manufacturing donors tend to offer more processed goods, while farm donations offer healthy produce. Restaurant and foodservice donations may offer pre-prepared or higher-value meals ready for immediate consumption. Though the *Roadmap* does not differentiate among types of donated food in calculating social benefit, both food donors and recovery organizations must understand the various unique challenges of safely donating food.

Greenhouse Gas Emissions (GHGs) Reduced

To quantify the environmental benefits of each solution on greenhouse gas emissions (reported in tons of carbon dioxide equivalent, or CO_2e), the *Roadmap* analysis relies on a recent 2014 study published in the Journal of Industrial Ecology on "greenhouse gas emission estimates of U.S. dietary choices and food

[50] http://www.feedingamericaky.org/truth-about-hunger/nationwide-statistics

loss."[51] This report examines the underlying GHG impacts from production and transport of nearly 100 different food types across grain, produce, meat, seafood, and milk/dairy categories. This GHG emissions data (reported in kg CO2e per kg of food) is weighted against per capita retail availability of each food type, to obtain weighted average GHG emissions for each of the Roadmap's five food categories.

Diverting food waste for human consumption additionally avoids the greenhouse gas impacts of organic waste disposal. As food waste rots and decomposes in landfills it releases methane gases into the atmosphere. In carbon equivalents, this adds 0.355 kg CO2e / lb across all food types according to the EPA's Waste Reduction Model (WARM Model). The table below captures full lifecycle carbon impacts of wasted food, from production through disposal – these numbers feed into the various GHG calculations discussed throughout the Roadmap.

	Grain Products	Meat	Fruits & Vegetables	Seafood	Milk and Dairy
Production & Transport	0.30	5.73	0.36	2.96	1.27
Disposal	0.36	0.36	0.36	0.36	0.36
TOTAL	**.65**	**6.09**	**0.72**	**3.32**	**1.63**

Figure 23: Weighted GHG Emissions (kg CO2e / lb) by Food Category

The two primary sources used both utilize WARM as a foundation, but also account for transportation, emissions incurred by composting and AD equipment, fugitive emissions in sewer conveyance, and displaced use of fertilizers. Commercial greywater does not directly offset any fertilizers or other impacts, and incurs significant fugitive emissions as well as impacts from the electricity used to operate the machine. Figure 24 below shows the GHG reduction impact for each recycling solution:

Solution	**kg CO2e / lb Food Waste**	**Source**
AD	0.31	Morris 2014
Compost	0.26	Morris 2014
WWTP	0.22	Morris 2014
Onsite Greywater	0.00	Eureka 2013
Onsite Compost	0.47	Eureka 2013
Community Compost	0.49	Eureka 2013
Backyard Compost	0.21	Eureka 2013
Animal Feed	0.34	Eureka 2013

Figure 24: Recycling Solution GHG Emissions Factors

[51] http://onlinelibrary.wiley.com/doi/10.1111/jiec.12174/abstract

Water Conserved

Crop and animal water footprint data from the Water Footprint Network feeds into the Roadmap calculations of water conservation impacts across all solutions.[52] For a wide variety of different food types, the Water Footprint Network reports the amount of water used to produce a certain quantity of food (given in liters per kg of food). The Roadmap reports water impacts from waste diversion as a "water conserved" figure. While the water inputs to produce an amount of food is a sunk environmental cost, this volume still represents a water savings in terms of gallons that would otherwise have gone to waste with zero benefit to society. Prevention and recovery solutions are assumed to avoid water use embedded in wasted crops, while recycling solutions do not avoid water use.

By calculating an un-weighted average of the global average water footprint of animal and crop products across food categories defined by the Roadmap, the following water impacts can be obtained:

	Grain Products	Meat	Fruits & Vegetables	Seafood	Milk and Dairy
Water Footprint	1644	8205	604	452	796

Figure 25: Weighted Water Footprint (L / kg) by Food Category

Jobs Created

Food waste recovery solutions that create job opportunities include Donation Storage and Handling, Donation Transportation, and Value-Added Processing. For these solutions, the costs due to additional labor needed to handle food for donation, transport donated food, or process into value-added goods translate into jobs created. Assuming an average living wage of $12/hr, and 40 hours worked per year for 50 weeks, a single salaried employee costs $24,000 a year. The recovery solutions with job creation potential assume that total labor costs convert to jobs created at this $24K annual rate. Higher wage rates can also be modeled, and will result in a slightly lower net number of jobs.

For recycling solutions, job creation was measured by the number of employees needed for each facility (5-10) and the projected job creation due to expanded use of compost. For every million tons of organic matter composted, nearly 1,400 new jobs can be sustained using the finished compost in green infrastructure.[53] This translates to 9,000 jobs related to composting, over 1,900 jobs through AD facilities (excluding potentially hundreds of additional jobs related to composting digestate from these facilities), 230 jobs related to community composting and 100 jobs at WRRF facilities.

Across recovery and recycling solutions, approximately 15,165 new permanent jobs could collectively be created and sustained.

---

[52] http://waterfootprint.org/media/downloads/Report-48-WaterFootprint-AnimalProducts-Vol1_1.pdf
[53] State of Composting in the US. ILSR. B. Platt, N. Goldstein, C. Coker, S. Brown. July 2014.

Data Validation and Sensitivity Analysis

The *Roadmap* data and assumptions were generated from four sources: (i) the baseline data set described above, (ii) a secondary research literature review, (iii) advisory board and other expert interviews, and (iv) the *Roadmap* Economic Analysis calculations.

The *Roadmap* went through two stages of data validation. First, cross-stakeholder advisory board groups were convened for each chapter to analyze the methodology and flag areas of concern. For areas of concern, ReFED conducted additional research across multiple sources to triangulate a best estimate for each assumption. Topics were excluded from the analysis if there was no credible source to support an assumption. Over time, as food waste data becomes more readily available, this methodology will be refined.

The *Roadmap* also includes a sensitivity analysis to evaluate how data uncertainties for each solution and the baseline data could impact the study's recommendations.

Prevention and Recovery Sensitivity Analyses

Given the breadth of solutions and the challenges of obtaining food waste-related data, ReFED conducted sensitivity analyses across all solutions, identifying low, medium, and high confidence variables to assess the sensitivity of diversion and NPV impacts to data variable inputs.

For each variable analyzed, an absolute 10% change (increase or decrease) in the value was modeled for the sensitivity, and the resulting changes in net diversion potential and solution NPV were measured. The resulting sensitivity ratios indicate the relative percentage change in solution impacts – for example, a solution variable with a 5 to 1 sensitivity ratio will see a 50% increase in overall solution diversion potential and NPV from a 10% absolute increase in the input variable. Put another way, for every 1% increase in the variable (e.g. 5% diversion rate → 6% diversion rate) there is a 5% increase in the diversion potential and NPV. This approach assumes every variable is linear in nature, and an increase or decrease have mirrored effects. Solution costs were not examined in the prevention and recovery sensitivity analyses due to higher overall confidence and that fact that the costs are significantly lower than benefits.

Overall, prevention and recovery sensitivity analyses indicate real opportunities for additional future research into the specific diversion potentials of ReFED's various food waste solutions. While prevention solutions in particular are generally higher in data confidence than recovery, they are particularly sensitive to input assumptions around diversion rates. These diversion rates, while based on both primary interviews with business stakeholders and secondary research, could greatly benefit from further validation. For recovery, solutions are generally less sensitive to data input variables, but demonstrate consistently lower data confidence levels that would benefit from additional data validation.

High Confidence Data validated with high degree of accuracy	**Medium Confidence** Data validated but true value could be different	**Low Confidence** Data not validated or could be significantly different

Prevention Solution	Solution Variable	Impact on Diversion Potential & NPV	Data Confidence

Produce Specifications (Restaurant)	Applicability Rate (20% = 40% of on-farm CI losses could be fit for foodservice x 50% could be recovered cost effectively)	5 to 1	Medium
	Diversion Rate (5-10%)	13.3 to 1	Medium
Produce Specifications (Retail)	Applicability Rate (15% = 30% of on-farm CI losses could be fit for retail x 50% could be recovered cost effectively)	6.7 to 1	Medium
	Diversion Rate (5-10%)	13.3 to 1	Medium
Cold Chain Management	50% of perishable retail DC waste is due to temperature	2 to 1	Medium
	Diversion Rate (5-15%)	6.7 to 1	Low*
Date Labeling	Applicability Rate (20% of household waste due to date labeling confusion)	5 to 1	High
	Diversion Rate (5-10%)	13 to 1	Medium
Packaging Adjustments	Applicability Rate (20-25% consumer waste due to package size or design)	4.4 to 1	High
Spoilage Prevention Packaging	Applicability Rate (15% fruit, 25% meat can adopt tech)	4.7 to 1 (Diversion) 6.2 to 1 (NPV)	Medium
Improved Inventory Management	28% of perishable retail shrink is due to ineffective ordering	3.6 to 1	High
	Diversion Rate (5-10%)	13.3 to 1	Low*
Waste Tracking & Analytics	Diversion Rate (20-40% of pre-consumer waste)	3.3 to 1	High
Smaller Plates	Diversion Rate (10-20%)	6.7 to 1 (Diversion) 7.1 to 1 (NPV)	Medium
Trayless Dining	Diversion Rate (25-30%)	3.6 to 1	High
Secondary Resellers	Solution Growth Potential (100-200%)	1.3 to 1 (NPV) 0.67 to 1 (Diversion)	Medium
	40% of food sold through secondary resellers would have gone to waste	2.5 to 1 (Diversion) 4.8 to 1 (NPV)	Medium
Manufacturing Line Optimization	ConAgra market share (10-20%)	-3.9 to 1	Low**

Figure 26: Sensitivity Analysis for Prevention Solutions

** due to variation in current cold chain management and inventory management practices across different retailers, and uncertainties around quantities of waste generation in retail DCs and retail stores*
*** due to lack of publicly-available information on food manufacturers market share*
Note: some variables may have changed in final version of solution modeling.

Recovery Solution	Solution Variable	Impact on Diversion Potential & NPV	Data Confidence*
Donation Storage and Handling	Diversion Rate (50-80%)	1.57 to 1 (NPV) 1.54 to 1 (Diversion)	Low
Safe Donation Regulation	Diversion Rate (50-75%)	1.6 to 1	Low
Donation Transportation	Diversion Rate (50-80%)	1.54 to 1	Low
Value-Added Processing	Applicability Rate (60% of farm / retail / manufacturing waste)	1.72 to 1 (NPV) 1.67 to 1 (Diversion)	Low

Figure 27: Sensitivity Analysis for Recovery Solutions

** due to lack of available data or precedent for the effectiveness of these recovery solutions at-scale*

To understand the sensitivity of prevention solution diversion potentials and NPV calculations to baseline waste inputs, each baseline variable was analyzed individually and incrementally increased to determine the net impact on solution impacts. An adjustment was similarly made to all baseline variables simultaneously. The results below indicate that prevention solution impacts are not particularly sensitive to the food waste generation baseline, with 10% input increases resulting in 6-6.5% increases in diversion potential and economic impact.

Prevention Baseline Variable	Baseline Value	Baseline Increase	Net Diversion Potential Change (all solutions)	Net NPV Change (all solutions)
Consumer Waste	26.6 M tons	+ 10%	+ 1.6%	+ 2.9%
Restaurant Waste	11.4 M tons	+ 10%	+ 1.4%	+ 1.4%
Institutional Waste	4.9 M tons	+ 10%	+ 1.1%	+ 1.0%
Retail Waste	8.0 M tons	+ 10%	+ 1.1%	+ 0.9%
Manufacturing Waste	0.35 M tons	+ 10%	+ 0.0%	+ 0.0%
Farm Waste	10.1 M tons	+ 10%	+ 0.7%	+ 0.3%
ALL Waste Inputs	**63 M tons**	**+ 10%**	**+ 5.9%**	**+ 6.5%**

Figure 28: Waste Generation Sensitivity Analysis for Prevention Solutions

Similarly, for recovery solutions, each food recovery potential baseline was analyzed individually and simultaneously to measure the sensitivity of solution waste diversion and NPV impacts to baseline inputs. The results below indicate recovery solutions are far less sensitive than prevention solutions, with a 10% across-the-board increase in food recovery potential results in a 2-2.5% increase in solution impacts.

Recovery Baseline Variable	Baseline Value	Baseline Increase	Net Diversion Potential Change (all solutions)	Net NPV Change (all solutions)
Retail Donation Potential	0.7 M tons	+ 10%	+ 1.4%	+ 1.1%
Restaurant / Foodservice Donation Potential	0.9 M tons	+ 10%	+ 0.7%	+ 0.6%
Farm Donation Potential	4.2 M tons	+ 10%	+ 0.4%	+ 0.4%
ALL Donation Inputs	**5.8 M tons**	**+ 10%**	**+ 2.4%**	**+ 2.1%**

Figure 29: Waste Generation Sensitivity Analysis for Recovery Solutions

Recycling Sensitivity Analysis

The complexity of the recycling model methodology does not lend itself to a traditional sensitivity analysis, primarily due to the tonnage assignment phase. As input variables, such as tip fees, change, certain MSAs may become more or less suitable for a given solution. This would require nearly 750 separate evaluations to determine the sensitivity of each variable for each solution in each MSA. For the purposes of this analysis, the current tonnage assignment across MSAs used in the base *Roadmap* model remained constant and was not optimized with each adjustment to the underlying variables.

The following table shows the baseline recycling model results.

Solution	Diversion Potential (K tons / year)	Economic Value ($M)
Centralized Anaerobic Digestion (AD)	1,884	$40
Animal Feed	49	-$3
Residential Composting	97	$14
Community Composting	167	-$6
Centralized Composting	5,037	$18
Commercial Greywater	595	$19
In-vessel Composting	12	-$1
Drain Disposal to WRRF with AD	1,637	$38

Figure 30: Recycling Solution Baseline Results

As many of the recycling solutions have a net Economic Value considerably closer to zero than the prevention and recovery solutions, displaying impact as percentile or ratio change is less insightful. Instead, the results of an isolated 10% change in each key variable is shown in absolute terms ($M).

Figure 31 illustrates the sensitivity of each solution to a 10% change in key drivers including disposal fees, energy prices, end market material prices and others. It can be seen that a 10% increase in disposal fees on a per-ton basis will have the greatest impact on centralized composting, and then on Centralized AD. Small changes to collection costs will have large impacts especially for centralized composting, primarily because these costs are already high to begin with heavy influence on Economic Value.

Solution Name	+10% Tip Fees	+10% Compost Price	+10% Electricity Price	+10% Natural Gas Price	+10% Collection Costs	+10% Financing Rates
Centralized Anaerobic Digestion (AD)	**$13**	**$11**	$0.81M	**$10**	($7.1)	($3.6)
Animal Feed	$0.23	-	-	-	($0.57)	($0.13)
Residential Composting	$0.44	-	-	-	$1.8	$0.34
Community Composting	$0.75	-	-	-	-	($0.09)
Centralized Composting	**$28**	$9.2	($0.06M)	-	**($20)**	($6.1)
Commercial Greywater	$5.7	-	-	-	-	($0.52)
In-vessel Composting	$0.05	$0.10	-	-	-	($0.03)
WRRF with AD	$9.3	-	$2.7	$1.8	$6.9	$0.33

Figure 31: 10% Input Increase Sensitivity Analysis ($M Economic Value)

Compost price variations will have an impact on composting and Centralized AD, as much of he solution value is derived from sale of this end product. Below, Figure 32 shows sensitivity of solutions to similar changes in variable factors, but results are shown on a per-ton basis.

Solution Name	+10% Tip Fees	+10% Compost Price	+10% Electricity Price	+10% Natural Gas Price	+10% Collection Costs	+10% Financing Rates
Centralized Anaerobic Digestion (AD)	**$7.2**	$5.8	$0.43	$5.3	($3.8)	($1.9)
Animal Feed	$4.5	-	-	-	**($12)**	($2.7)
Residential Composting	$4.5	-	-	-	**$18**	$3.5
Community Composting	$4.5	-	-	-	-	($0.50)
Centralized Composting	$5.6	$1.8	($0.01)	-	($4.0)	($1.2)
Commercial Greywater	**$9.6**	-	-	-	-	($0.89)
In-vessel Composting	$4.5	$1.3	-	-	-	($2.4)
WRRF with AD	$5.7	-	$1.6	$1.1	$4.2	$0.20

Figure 32: 10% Input Increase Sensitivity Analysis ($/ton)

The following chart in Figure 33 illustrates the financial impacts of an incoming ton of wet food waste on the solution models. The median values are shown, as well as the variance found across different areas of the country.

Driver (per ton incoming food waste)	Mean	Range
Residential Collection Cost (Food Only)	($207)	+/- $35
Commercial Collection Cost	($93)	+/- $17
Residential Collection Cost (Yard Waste)	($86)	+/- $14
Base Tip Fee	($50)	+/- $33
Labor	($7)	+/- $3
Natural Gas Value	$13	+/- $3
Compost Value	$25	+/- $17
Electricity Value	$27	+/- $18

Figure 33: Key Drivers for Recycling Solutions

In many places, a reduction in the cost of collection can make AD systems viable. For example, here are three metro areas where a reduction in collection costs of 15% results in a positive system cost on a per-on basis. As can be seen in the MSAs shown in Figure 34, the total benefit on a per-ton basis will increase significantly as collection costs are lowered. Here, a 10% drop in collection costs can deliver total system benefits as high as $12/ton.

Metro Area	Collection Costs (Status Quo)	Total Status Quo Benefit (Cost)	Collection Costs (-10%)	New Total Benefit
Buffalo-Cheektowaga-Niagara Falls, NY	($174)	$0.53	$151	$12
Indianapolis-Carmel-Anderson, IN	($65)	($0.17)	$56	$4
Rochester, NY	($184)	($5.7)	$159	$7

Figure 34: Sensitivity of Collection for Centralized AD ($/ton)

Importance of Eliminating Transportation Through Local Processing

As waste must travel long distances from some cities to landfill, siting recycling facilities such as digesters in the closest proximity possible to metro areas may take advantage of significant transportation savings and unlock significant value under the right circumstances. Municipalities should seek excess space in current infrastructure such as:

- MRFs
- transfer stations,
- food manufacturing facilities and
- water resource recovery facilities

While digesters have been growing rapidly in rural settings, siting AD facilities near cities has been challenging. Utilizing dedicated digesters for source-separated organics at WRRFs could circumvent many of these barriers, and excess capacity, if available, could significantly lower construction capital costs. The *Roadmap* accounted for the cost of organics collection, but did not model the potential long-distance transportation savings that may be possible to achieve in some geographies. Local economics will vary, but consider a situation where the average collection truck carries 12 tons of organics at a cost of $4/mile. The transportation cost per ton to deliver that material directly to a disposal site 20 miles away would be $13. If the tip fee at that facility were $70, and factoring in a slight vehicle depreciation cost of $0.075/mi, the total cost would be $86.

Generally, if the disposal site is farther than 15 to 20 miles away, it becomes economically advantageous to aggregate materials locally at a transfer station then ship the material on larger long-haul trucks which carry the material at nearly half the cost per mile or much less by rail or barge. However, this approach incurs a small additional cost of transfer that may add $10/ton. The table below illustrates how direct hauling may be more economical within 20 miles, and transfer and long-hauling would become preferable at farther distances.

Distance to Landfill in Miles	10	20	30	40	50	100	150	200
Direct Haul + Dispose	**$78**	**$86**	$95	$103	$111	$152	$193	$233
Long Haul Truck + Dispose:	$84	$88	**$91**	**$95**	$99	$118	$137	$156
Local Facility:	$95	$95	$95	**$95**	**$95**	**$95**	**$95**	**$95**

Figure 35: Per-Ton Costs of Transportation to Remote Processing Facilities

A locally sited facility such as AD may require a higher tip fee to cover costs, but may produce transportation savings to offset higher tip fees and become competitive with lower disposal alternatives sited far away. In this example, a digester with a $95 tip fee would become more economical if alternative tipping sites at $70/ton were more than 40 miles away. Project economics will be very situation-specific and change with fuel prices, transfer station distance, and as landfill tip fees frequently decline farther from urban centers and become more competitive. The required tip fee for an anaerobic digester will be impacted by many additional factors beyond transportation, the cost of processing, digestate transport to composting or post-treatment alternative, availability and proximity of end markets for the product, and its value.

In addition to the cost of collection, compost economics are highly sensitive to landfill tipping fees. In an example facility where wholesale compost prices are relatively high ($24/CY) and collection costs are average ($85/ton), landfill tipping fees need to cross $60 per ton in order for net economic value to be positive. The following table below shows how profit potential for a facility and the system economic value are influenced by changes in disposal rates on a per-ton basis.

Landfill Tip Fee ($/ton)	Net Profit Potential ($/ton)	Total Economic Value ($/ton)
($40.00)	$47.86	($17.14)
($50.00)	$52.86	($7.14)
($60.00)	$57.86	$2.86
($70.00)	$62.86	$12.86
($80.00)	$67.86	$22.86

Figure 36: Landfill Tip Fee Sensitivity

Similarly, cost of capital can have a significant impact on the feasibility of a project, especially capital intensive AD projects. Shown here is the impact of changing interest rates on the capital payments and the total economic value of AD in Providence, RI. It should be noted that the *Roadmap* model shows Providence as being one of the most favorable environments for AD, along with Boston and Hartford, primarily due to high electricity rates and landfill tipping fees in New England.

Interest Rate	Amortized Capital Cost ($/ton)	Total Economic Value ($/ton)
2%	($44.08)	$18.91
3%	($48.45)	$14.54
4%	($53.04)	$9.95
5%	($57.84)	$5.15
6%	($62.85)	$0.15
7%	($68.04)	($5.05)
8%	($73.42)	($10.43)

Figure 37: Sensitivity to Cost of Capital (AD)

Additional Roadmap Report Analyses

> *<u>Roadmap data:</u> "This mountain of waste grows up to two times if you add in other food fit for people that doesn't get eaten for one reason or another, leading to up to 40% of all food grown being wasted."*

<u>Explanation</u>: The extent to which food is produced and not consumed has been studied in the past, with different total food waste estimates varying depending on specific methodologies and approaches. The Roadmap opening statistic below is based on a collection of reported figures and Roadmap analysis, including NRDC's *Wasted* report (2012) and Food and Agriculture Organization's Global Food Loss and Waste study (2011).

At the upper end of this range, NRDC's *Wasted* report states that 40% of food produced goes uneaten – this figure is based on a peer-reviewed study in the Public Library of Science, which compared food calories consumed to food calories produced for human consumption. The FAO study on global food waste estimates that approximately 33% of edible food mass goes to waste, based on total food production of 900 kg per capita and 300 kg going to waste. Using ReFED's own analysis and estimate of 62.5M tons of food waste sent to landfill and left on farms due to cosmetic imperfections – which does not allocate for edible vs. inedible mass – this represents 20% of the total weight of edible food produced (900 kg per capita production ≈ 315M tons based on latest U.S. population statistics).

> *<u>Roadmap Data:</u> "Put another way, if all of our country's wasted food was grown in one place, this mega-farm would cover roughly 80 million acres, over three-quarters of the state of California. Growing the food on this wasteful farm would consume all the water used in California, Texas, and Ohio today combined. The farm would harvest enough food to fill a 40-ton tractor every 20 seconds. Many of those trailers would travel thousands of miles, and much of that food would be kept cold in refrigerators and grocery stores for weeks. But instead of being purchased, prepared and eaten, this perfectly good food would be loaded onto another truck and hauled to a landfill where it would emit a stream of harmful greenhouse gases as it decomposes."*

<u>Explanation</u>: This calculation is based off of several underlying statistics. As noted below, 18% of cropland is consumed environmentally by food waste and total cropland is 442 million.[54] 18% of this is 79.5 million and California has approximately 101 million acres of land. Food waste uses 21% of freshwater withdrawals, which is equivalent to the use in California, Texas and Ohio.[55] Using the 63 million tons of waste as the baseline and dividing by the number of seconds in year (31,536,000 seconds), we waste 2 tons per second.

---

[54] Lubowski, Ruben et. al. "Major Uses of Land in the United States, 2002. *USDA Economic Research Service*. May 2006. Available from http://www.ers.usda.gov/publications/eib-economic-information-bulletin/eib14.aspx

[55] Maupin, M.A. et. al. "Total Water Use." *U.S. Geological Survey*. 2010. Available from http://water.usgs.gov/watuse/wuto.html

Roadmap Data: *"The U.S. spends $218B a year--1.3% of GDP--growing, processing, transporting, and disposing of food that is never eaten"*

Explanation: The *Roadmap* total value of food waste estimate was calculated using a collection of ReFED-derived datasets and external research, linking food waste generation volumes, waste compositions, and waste value conversions. A summary table of this calculation is shown below.

Stakeholders	% of Waste (volume)	Total Annual U.S. Food Waste	Annual Waste Value
Farm	16.2%	10,142,665 tons	$ 15,011,144,806
Manufacturing	1.7%	1,065,000 tons	$ 2,440,172,981
Retail / Restaurant / Foodservice / Government	39.7%	24,817,855 tons	$ 56,863,717,583
Residential	42.4%	26,560,793 tons	$ 143,840,435,351
			$ 216,506,802,789

Figure 38: Overview of Roadmap Waste Volumes and Values

Using the *Roadmap* waste generation baseline and estimate of on-farm losses, the Total Waste figures above encapsulate the total volume of food waste analyzed and addressed by the Roadmap analysis. Within these supply chain segments, USDA data on food waste composition at the retail and consumer levels was applied to characterize each waste stream. While farm waste was treated as 100% produce, and residential waste characterized according to USDA data on consumer food waste, all business and institutional segments were characterized uniformly based on USDA retail food waste composition data. Additional foodservice-specific data on food waste composition was available and used for ReFED solution analysis, but cannot be shared publicly.

To quantify the financial impacts of these waste streams, based on food types, retail average food price data from the Bureau of Labor Statistics and wholesale food prices from the Advisory Council were used to calculate the resulting Waste Value figures shown above.

Roadmap Data: *"Environmentally, food waste consumes 21% of all freshwater, 19% of all fertilizer, 18% of cropland, and 21% of landfill volume and is a leading cause of climate change."*

Explanation: The statistic above is based on the application of ReFED's waste generation baseline to FAO's Global Food Loss and Waste study and a report from M. Kummu et. al. on food loss and resource waste. Kummu's report estimates that per capita food waste rates for North America / Oceania contributes to 35% of overall freshwater consumption, 31% of cropland use, and 30% of fertilizer use[56]. These rates are based on FAO data, which estimates per capita food waste in North America at around 295 kg / year, per capita[57]. Using a total U.S. population of 320M, this represents 103M tons annually of

[56] Kummu, M. et. al. "Lost food, wasted resources: Global food supply chain losses and their impacts on freshwater, cropland, and fertiliser use." *Science of The Total Environment*. 1 November 2012. Available from http://www.sciencedirect.com/science/article/pii/S0048969712011862#t0010

[57] Gustavsson, Jenny; Cederber, Christel and Ulf Sonesson. "Global Food Losses and Food Waste." *Food and Agricultural Organization of the United Nations*. 2011. Available from http://www.fao.org/docrep/014/mb060e/mb060e00.htm

food loss and waste – defined by FAO as food intended for human consumption that ultimately does not get consumed.

Applying the Roadmap's 62M ton food waste estimate to the above methodology, approximately 60% of the food waste quantity estimated by FAO and driving the Kummu report's resource utilization estimates, the analysis arrived at 21% of freshwater / 19% of fertilizer / 18% of cropland as the net resource impact from food waste sent to landfill and occurring on farms. The cited statistic on food waste as a percentage of U.S. landfill volume remains constant, and is based on recent EPA data[58].

> Roadmap Data: *"Recovering [1.8B meals annually] would also prevent 3.45M tons of GHG emissions annually, equivalent to the savings of 100M U.S. households replacing a single incandescent lightbulb with a compact fluorescent lightbulb"*

Explanation: According to Green America, if every household in the United States were to replace one existing incandescent lightbulb with a compact fluorescent lightbulb (CFL), the energy saved would "prevent greenhouse gas emissions equivalent to 800,000 cars[59]." The total number of households in the U.S. needed to achieve this impact is approximate 120M based on recent Census data[60].

The EPA estimates that the average passenger vehicle emits 4.7 metric tons or 5.18 tons of CO2e per year[61]. Given that 800K cars is then equivalent to 4.14M tons of greenhouse gas emissions, 3.45M tons of GHG emissions reduced through food recovery corresponds to the 100M household statistic referenced in the ReFED report.

---

58 "Sustainable Management of Food Basics." *U.S. Environmental Protection Agency*. 14 September 2015. Available from http://www.epa.gov/sustainable-management-food/sustainable-management-food-basics

59 "Real Green Living." *Green America*. 2010. Available from http://www.greenamerica.org/livinggreen/CFLs.cfm

60 "Number of Households in the U.S. from 1960 to 2015." *Statista*. 2016. Available from http://www.statista.com/statistics/183635/number-of-households-in-the-us/

61 "Greenhouse Gas Emissions from a Typical Passenger Vehicle." U.S. Environmental Protection Agency. May 2014. Available from http://www3.epa.gov/otaq/climate/documents/420f14040a.pdf

Excluded Solutions

Initially, over 50 solutions were considered for analysis within the ReFED *Roadmap.* Ultimately, 27 solutions were selected for detailed analysis. Roughly two dozen other solutions were excluded from the economic analysis because they were out of scope, not economical, or likely limited in scale. Further analysis of these solutions, plus other solutions, would likely result in additional waste reduction opportunities, and is recommended for future research.

Category	Solution Not Analyzed	Definition
Producers	Gleaning	A second smaller harvest of crops that were not originally economical to harvest, often completed by volunteers
	Immigration Laws	Labor constraints are one reason fields are left unharvested
	Seed Traits	Seeds can be optimized to be drought and pest resistant
	Farm Bill Subsidies	The Farm Bill provides important support to our food system, but also includes incentives and subsidies which may mask true supply and demand signals which could reduce food waste.
	Farm Pest Management	This can include agroecological practices or the application of different fertilizers and pesticides to reduce pests.
	Farm Planning Tools	Better supply forecasting and management of agricultural production
	Indoor Agriculture	Growing food in a controlled environment
	Local Agriculture	Growing food close to where it will be consumed
	Direct Animal Feed	Serving food scraps directly to animals without processing the food scraps
Consumer Facing Businesses	Training & Management Practices	Training store employees on ways to reduce, recover and recycle food through proper storage, food handling and food separation.
	SKU Rationalization	Reducing the number of unique products stocked and sold in retail stores to enhance inventory planning and reduce product expiry
	Smaller Menu Size	Reducing consumer menu options in restaurants to facilitate better inventory planning and management
	Smart Labels	Using low-cost RFID devices to detect and monitor spoilage rate of fruits, meats, and seafood during shipment to retailers
	Dynamic Store Merchandising	Integrating retail POS/inventory systems with dynamic pricing capabilities and electronic shelf labels in retail settings
	Case Size Optimization	Optimizing cases for distribution, similar to packaging adjustments but at the case level
	Catering Contracts	Caterers currently overestimate the amount of food they will need to ensure they do not run out of anything – clients can sign a waiver stating they understand if a food item runs out
	Price Markdowns	Marking down products at a discount to encourage sale of products before they go bad, such as baked goods
Consumer	Online Grocery Shopping	Consumer shopping online, a potential way to reduce waste due to more just in time stocking and less floor shrink
	Consumer Food Recovery	Recovering food from homes, similar to business food recovery
	Dumpster Diving / Foraging	The practice of raiding dumpsters to find discarded food that is still edible
	Garbage Disposal Education	Encouraging consumers to utilize garbage disposals as a tool for recycling in cities where there
	Subscription Meal Services	Pre-packaged meals to reduce consumer prep and plate waste

	Food Saving Containers	Containers to properly store food and reduce exposure to oxygen to extend shelf life
	Smart Refrigerators	Providing reminders to consumers on products that are near expiration to encourage better meal planning
	Meal and Shopping Planning Apps	Tools to help consumers better plan and shop for meals to reduce accidental excess purchase
End of Life	Biofuels	Expanding food fats and grease as biodiesel input

Figure 39: Excluded Solutions

Sources

The following data sources have served to inform and corroborate the values and assumptions made to date in the project analysis.

Advancing Sustainable Materials Management: Facts and Figures 2013. United States Environmental Protection Agency, Office of Resource Conservation and Recovery (5306P). EPA530-R-15-002US EPA, June 2015. https://www.epa.gov/sites/production/files/2015-09/documents/2013_advncng_smm_rpt.pdf

Analysis Of Biodigesters And Dehydrators To Manage Organics On-Site. Zoe Neale. October 2013, Vol 54, No. 10, p.20

Analysis of U.S. Food Waste Among Food Manufacturers, Retailers, and Restaurants. BSR. 2014

Assessment of Food Waste Generation in Mercer County, New Jersey. Expands on 2007 Assessment of Biomass Energy Potential in New Jersey. Arnold G. Mercer. January 2013.

Average Retail food and energy prices, U.S. and Midwest Region. U.S. Bureau of Labor Statistics. April 2015.

Best Practices and Emerging Solutions Toolkit. Food Waste Reduction Alliance. Spring 2014.

CO-DIGESTION OF ORGANIC WASTE PRODUCTS WITH WASTEWATER SOLIDS: FINAL REPORT WITH ECONOMIC MODEL. Lauren Fillmore, Water Environment Research Foundation. David L. Parry, Ph.D., P.E., BCEE, CH2M HILL. January 2014.

Commercial Food Waste Disposal Study, New York City. Department of Environmental Protection, Steven W. Lawitts, Acting Commissioner, 2008.

Estimated Fish consumption rates for the U.S. population and selected subpopulations. EPA. J. Bigler, J. Birch, J. Rogers. April 2014.

FAOSTAT Production Quantities by Country. Food and Agriculture Organization of the United Nations. Retrieved 2015.

Food Waste Diversion in Florida Report. Center for Biomass Programs, University of Florida's Institute of Food and Agricultural Sciences. Gainesville, FL; as modified by RRS for Tampa Electric Company (TECO). 1998.

Food Waste Diversion Study. Prepared for Mecklenburg County Solid Waste. Prepared by Kessler Consulting, Inc.. Mecklenburg County NC . March 2012.

Food Waste in Canada. Opportunities to increase the competitiveness of Canada’s agri-food sector, while simultaneously improving the environment. M. Gooch, A. Felfel, N. Marenick. November 2010.

Food Waste Separation. Project Memorandum No. 10B in Water Pollution Control Plant Master Plan. San Jose, CA. August 2009.

Highest and Best Use of Source Separated Organics: A Zero-Waste Perspective. Eureka Recycling. May 2013.

Household Food and Drink Waste in the United Kingdom 2012. WRAP. Project code: CFP102 ISBN: 978-1-84405-458-9. Research date: May 2012 – July 2013 Date: November 2013.

Household Food Waste to Wastewater or to Solid Waste? That is the Question. C. Diggelman, R. Ham. October 2003.

Global food losses and food waste. Food and Agriculture Organization of the United Nations. J. Gustavsson, C. Cederberg, U. Sonesson. 2011.

Identification, Characterization, and Mapping of Food Waste and Food Waste Generators in MA. Prepared for MA Department of Environmental Protection by Draper/Lennon, Inc.. Boston, MA. Sept 2002.

Land Application and Composting of Biosolids. Water Environment Federation. 2010.

Metro's Organic Waste Management Program. Comprehensive overview of region's organic waste management. Portland, OR. Jennifer Erickson. January 2004.

North Carolina 2012 Food Waste Generation Study. State of North Carolina, N.C. Department of Environment and Natural Resources – Dee Freeman, Secretary. August 2012.

On-Site Systems for Processing Food Waste. A report to the MA Department of Environmental Protection. Northeastern University. I. Griffith-Onnen, Z. Patten, J. Wong. April 2013.

Preparatory Study on Food Waste Across EU 27. European Commission. V. Monier, V. Escalon, C. O'Connor. October 2010.

Reducing Food Loss and Waste (Working Paper). World Resources Institute. B. Lipinski, C. Hanson, J. Lomax, et. al.. May 2013.

State of Composting in the US. ILSR. B. Platt, N. Goldstein, C. Coker, S. Brown. July 2014.

State Indicator Report on Fruits and Vegetables 2013. U.S. Center for Disease Control. 2013.

Statistics of U.S. Businesses: County Business Patterns. United States Census Bureau. April 2015.

Strategies to achieve economic and environmental gains by reducing food waste. WRAP. A. Parry, K. James, S. LeRoux. Research date: February 2014 – August 2014 Date: February 2015.

Summary of Research Regarding the Environmental Efficacy of Food Waste Disposers. InSinkerator. M. Glitter. October 2006.

Survey of the Potential Environmental Impact of Food Waste Disposal Regulations in the Northeastern United States. EPA and Energy Star. A. Schnitzer. March 2015.

Sustainable Food Waste Evaluation. Water Environment Research Foundation (WERF). 2012

The Estimated Amount, Value, and Calories of Postharvest Food Losses at the Retail and Consumer Levels in the United States. United States Department of Agriculture. J. Buzby, H. Wells, J. Hyman. February 2014.

The food we waste, Food waste report v2. WRAP UK. ISBN: 1-84405-383-0. April 2008.

The Green, blue, and grey water footprint of Farm Animals and animal products. UNESCO Institute for Water Education. M. Mekonnen, A. Hoekstra. December 2010.

The Progressive Increase of Food Waste in America and Its Environmental Impact. Bethesda, MD. K. Hall, M. Dore, C. Chow. November 2009.

Updated Mapping of Food Residual Generation in Connecticut. Prepared for Connecticut Department of Energy and Environmental Protection. Prepared by US EPA Region 1 Office of Administration and Resource Management. Jeri Weiss, Boston, MA. Spring 2012.

U.S. Energy price projections (Short-term Outlook and Annual Energy Outlook). U.S. Energy Information Administration. 2015.

Utilities of the Future Energy Findings. Steve Tarallo, Black & Veatch. 2014.

Waste Disposal and Diversion Findings for Selected Industry Group. Targeted state-wide characterization study for CA. Prepared by Cascadia Consulting Group. June, 2006.

Wasted: How America Is Losing Up to 40% of Its Food from Farm to Fork to Landfill. NRDC. Dana Gunders . August 2012.

Water footprint of crop and animal production: a comparison. Water Footprint Network. Retrieved 2015.