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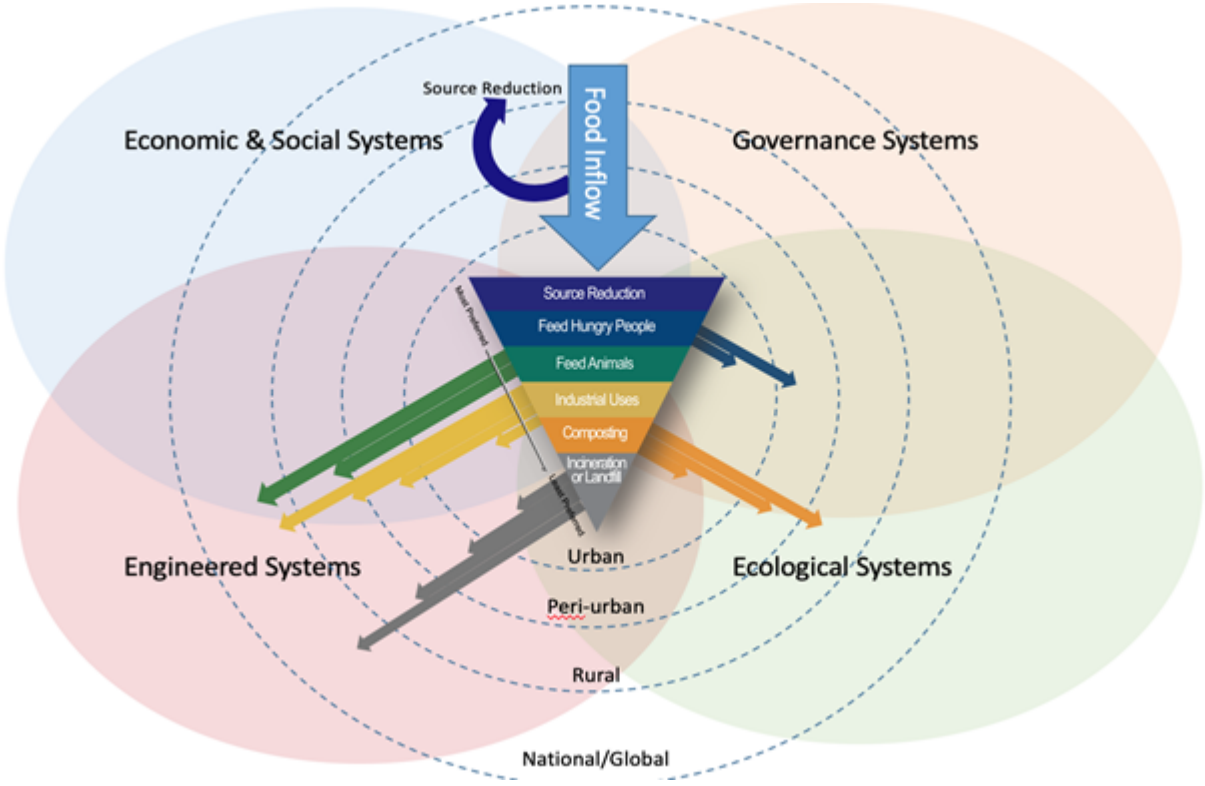
POST-EVENT REPORT

Wasted Food and Sustainable Urban Systems: Prioritizing Research Needs



Roni Neff (JHSPH), Brian E. Roe (OSU), & Sauleh Siddiqui (JHU)

Organizing Committee: Ava Richardson, Baltimore City Dept of Planning; Darby Hoover, NRDC; Kat Klosek, Center for Applied Research, JHU; Laura Moreno, UC Berkeley; Natasha Wedderburn, Coppin State University; Yvette Cabrera, NRDC

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Executive Summary

On September 9-10, 2019, our team convened 40 practitioners and researchers at the Johns Hopkins University in Baltimore to co-create a research agenda on wasted food as a sustainable urban systems opportunity. As envisioned in the cover figure, which was shared at the conference's opening session, urban systems represent a nexus in the food-to-waste process. Two leading indicators of an urban system's sustainability are the percent of food that goes uneaten and the percent of landfill occupied by food waste. Food systems and the other urban systems depicted in the figure influence one another, creating the potential for important synergies in addressing overall urban sustainability.

The meeting followed a "double-diamond design" process. We gathered preliminary input with a pre-conference survey of nearly 300 practitioners and researchers. We then engaged in expansive idea generation through a sequence of group sessions and Baltimore city field visits presenting challenges and solutions at different scales. Our process led the assembled group to identify top urban food waste challenges, to select key approaches to address them, and finally, to identify the research most needed to inform and advance those approaches. The interdisciplinary and community-engaged conversations produced the groundwork for a convergent research agenda addressing six core knowledge gaps:

I. Tools and Typologies for Systems Modeling and Evaluation
II. Understanding Intervention Spillovers Across the Supply Chain & the Food Waste Hierarchy
III. The Potential for Leveraging Front-line Workers in Cities
IV. Preventing Consumer-level Waste of Food in Cities
V. Equity
VI. Data on Wasted Food and Connected Systems

We map each knowledge gap to key elements of convergence science in sustainable urban systems as articulated by NSF. If followed, the resulting research agenda will provide much-needed data, frameworks, and knowledge to support city efforts to address waste of food while creating generalizable insights across urban systems of diverse scales and types. Co-creation of knowledge will build buy-in and assure research projects are designed so as to yield actionable findings.

Our convening and its outputs support the national goal of halving waste of food by 2030—a goal also adopted by many cities. To date, little urban-oriented research supports city efforts to address waste of food. Yet, cities are rapidly scaling efforts to increase the retention of food's value, while strengthening co-benefits for food security, economies, environments, and employment, urban system sustainability, and equity. The pace of development in this sector contributes to the urgency for research findings to shape efforts, including investments in infrastructure likely to last decades or more. We envision food waste as a test case for addressing sustainability across multiple urban systems. We are energized by the participants at our conference and by our interactions with the organizers of the related NSF SUS conference at the Rochester Institute of Technology and look forward to collaborating with these and other research and practitioner groups to co-generate the knowledge required to advance sustainability science and address this opportunity for cities across the globe.

Table of Contents

Figures

Tables

A. Introduction

On September 9-10, 2019, our team convened practitioners and researchers on the campus of the Johns Hopkins University in Baltimore, MD to co-create a research agenda on wasted food as a sustainable urban systems opportunity. Food is among the most essential and interdependent flows between rural and urban areas within an urban system. "Wasted food" refers to "…discard[ed] or alternative (non-food) use of food that is safe and nutritious for human consumption along the entire food supply chain, from primary production to end household consumer level."[1] Wasted food is a critical topic of study for sustainable urban systems (SUS) research, representing not only a vast resource loss for cities and a source of ecosystem damage, but also a powerful test bed centrally located at the intersection of numerous SUS systems and concepts.

Wasted food and sustainable urban systems

Urban systems represent a nexus in the food-to-waste process, as visualized in Figure 1, which was shared with participants in the opening session. The dotted concentric circles represent the outward scoping of activities from the urban core in the center circle through the urban to rural gradient, which is then encompassed by connections to national and global systems. The urban system emerges from overlapping and interlinking economic and social systems, governance systems, engineered systems, and ecological systems. The majority of food flows from outer circles toward the center and meets one of several fates as depicted by the EPA food recovery hierarchy.

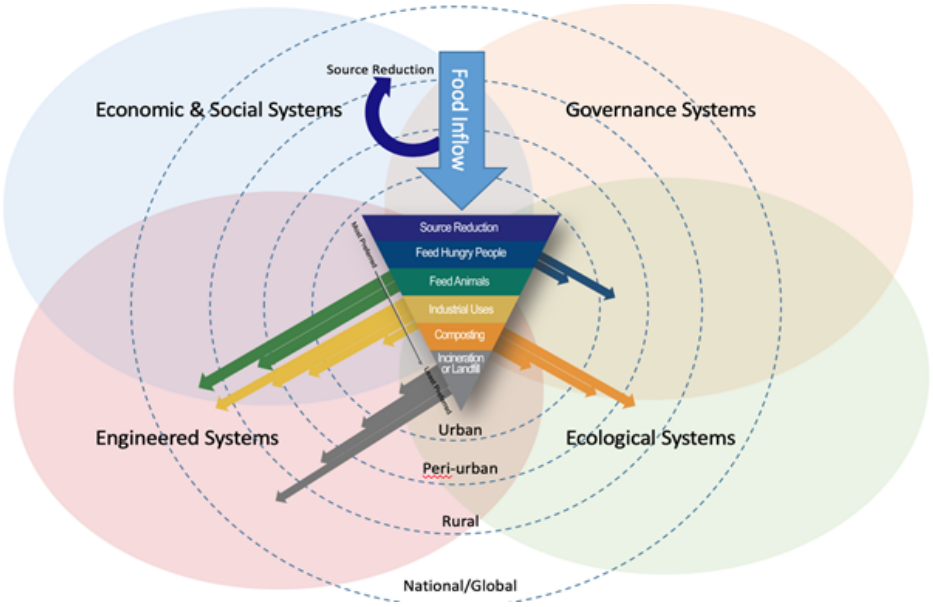

Figure 1: Wasted Food and Sustainable Urban Systems Concept Model

The food recovery hierarchy's widely-invoked normative framework for the disposition

[1] United Nations Food & Agricultural Organization. Available online at: http://www.fao.org/platform-food-loss-

of food prioritizes bars higher on the inverted pyramid for edible, rescuable (safe and good quality) food. While alternative prioritizations are possible, the pyramid's categorization of activity types remains useful regardless: a) source reduction (herein "reduction" or "prevention"); b) feeding hungry people (herein: "rescue"); c) feeding animals, industrial uses, composting (herein, "recycling"); and d) incineration or landfill.

In short, city food systems import vast quantities of food for their populations and businesses to purchase, then rescue some of the surplus for human consumption; generate some value from other parts of the surplus and from scraps; and export the rest. As less food is wasted (source reduction), it means less food flows to the outcomes depicted at the bottom of the inverted pyramid, and that less food needs to be imported to cities to meet the nutritional needs demanded by the metabolism of the urban system. Food that continues to flow below the top rung of the figure may flow back out of the center, representing circular material flows. The exact size and velocity of the arrows in the figure will be influenced by components in the systems undergirding the figure such as energy, infrastructure, transportation, and health.

Two leading indicators of an urban system's sustainability are the percent of food that goes uneaten and the percent of landfill occupied by food waste. The food system and other urban systems influence one another, creating the potential for important synergies in addressing urban sustainability. To provide a few examples, better utilization of food that would otherwise be wasted can: improve diets, particularly among those who face food insecurity; reduce unnecessary resource use and costs for food production, processing, storage, and distribution; reduce stress on waste treatment systems through less garbage disposal volume; support development of urban and peri-urban agriculture through compost and animal feed production; advance technologies, infrastructure and output for renewable energy production; and reduce asthma attacks triggered by air emissions from waste incineration.

Why wasted food?

Across the United States, an estimated 31-40% of the food supply may be wasted[2,3] representing a loss of an estimated 30 million acres of cropland, 4.2 trillion gallons of irrigation water, 780 million pounds of pesticides, 1.8 billion pounds of nitrogen fertilizer -- and over 1,250 calories and nearly 1 pound of food per capita per day.[4] The loss of under-consumed nutrients is also considerable; e.g., our research estimates that the U.S. discards enough dietary fiber each day to meet the Recommended Dietary Allowance for 74 million adult women.[5] Higher diet quality can

[2] Gustavsson J, Cederberg C, Sonesson U, van Otterdijk R, Meybeck A. Global food losses and food waste – Extent, causes and prevention, Save Food! at Interpack 2011, Dusseldorf, Germany, 2011. Rome: FAO.

[3] Buzby, Jean C., Hodan F. Wells, and Jeffrey Hyman. The Estimated Amount, Value, and Calories of Postharvest Food Losses at the Retail and Consumer Levels in the United States, EIB-121, U.S. Department of Agriculture, Economic Research Service, February 2014.

[4] Conrad Z, Niles MT, Neher DA, Roy ED, Tichenor NE, et al. (2018) Relationship between food waste, diet quality, and environmental sustainability. PLOS ONE 13(4): e0195405. https://doi.org/10.1371/journal.pone.0195405

[5] Marie L. Spiker, Hazel A.B. Hiza, Sameer M. Siddiqi, Roni A. Neff, Wasted Food, Wasted Nutri-ents: Nutrient Loss from Wasted Food in the United States and Comparison to Gaps in Dietary Intake, Journal of the Academy of Nutrition and Dietetics, Volume 117, Issue 7, 2017, Pages 1031-1040.e22, ISSN 2212-2672, https://doi.org/10.1016/j.jand.2017.03.015.

result in higher waste, due to perishability of items including produce and seafood.[6,7] One study finds that approximately ⅔ of food system greenhouse gas emissions may be considered directly influenced by cities, and further, that city action to halve post-distribution waste of food and improve waste management can cut food sector greenhouse gas emissions by 11% and 5% each.[8] The emissions from wasted food include both those "embedded" through processes of production, processing, transport, heating and cooling; and emissions of methane during decomposition.

Our conference and its outputs support the national goal of halving wasted food by 2030—a goal also adopted by many cities. To date, little urban-oriented research supports city efforts to address waste of food. Yet, cities are rapidly scaling efforts to increase the retention of food's value, while strengthening co-benefits for food security, economies, environments, and employment, urban system sustainability, and equity. The pace of development in this sector contributes to the urgency for research findings to shape efforts, including investments in infrastructure likely to last decades or more.

The agenda emerging from the conference identifies much-needed data, frameworks, and approaches for knowledge co-generation to support city efforts to reduce waste of food while creating generalizable insights across urban systems of diverse scales and types.

Conference process overview

To develop the research agenda, we followed the "double-diamond design" process (detailed below) that leveraged not only the ideas and accumulated knowledge of the 40 interdisciplinary urban food system practitioners and researchers attending the conference and associated field trips, but also input from nearly 300 practitioners and researchers who participated in a pre-conference survey. The process identified top urban food waste challenges, then selected key approaches to address them, and finally, identified the research most needed to inform and advance those approaches. The process generated robust discussions built on broad input from the field and yielded interdisciplinary and community-engaged conversations to produce the groundwork for a convergent research agenda.

We have maintained an open channel of communication with the organizers of the NSF conference, 'Urban food waste solutions from farm-to-fork: A conference for advancing sustainable urban systems (SUS) research networks,' held at the Golisano Institute for Sustainability at Rochester Institute of Technology (Rochester, NY) on August 5-6. Through several group calls, and through attendance of organizers at one another's conferences, we have sought to further broaden the input and refine the formulation of the research agenda emerging from each conference, setting the stage for more diverse and effective collaborations.

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[6] Conrad Z, Niles MT, Neher DA, Roy ED, Tichenor NE, et al. (2018) Relationship between food waste, diet quality, and environmental sustainability. PLOS ONE 13(4): e0195405. https://doi.org/10.1371/journal.pone.0195405

[7] Dave C. Love, Jillian P. Fry, Michael C. Milli, Roni A. Neff, Wasted seafood in the United States: Quantifying loss from production to consumption and moving toward solutions, Global Environ-mental Change, Volume 35, 2015, Pages 116-124, ISSN 0959-3780, https://doi.org/10.1016/j.gloenvcha.2015.08.013.

[8] Eugene A. Mohareb, Martin C. Heller, and Peter M. Guthrie. Cities' Role in Mitigating United States Food System Greenhouse Gas Emissions, Environmental Science & Technology 2018 52 (10), 5545-5554. DOI: 10.1021/acs.est.7b02600

The remainder of this report outlines the flow of the conference and its affiliated activities, synthesizes key themes of the emergent research agenda, and connects these themes to the National Science Foundation's conceptualization of a convergence research agenda for next generation sustainable urban systems efforts.

B. Conference Design and Execution

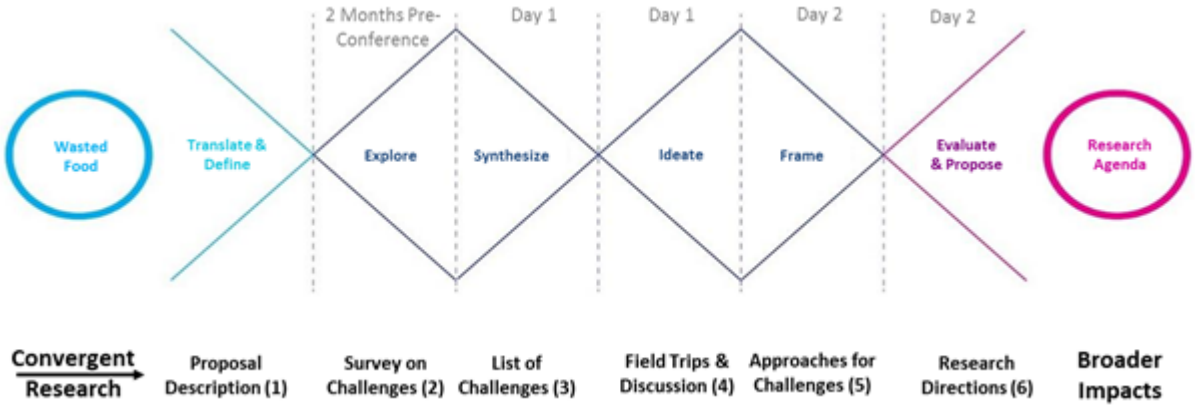

Figure 2: The Double Diamond Model of the UK Design Council Outlines our Conference Methodology

The conference structure brought together a set of innovative approaches to address the challenges wasted food poses for urban systems. It was organized and conducted according to the principles of ***Participatory Design***, which involves stakeholders directly in the research process. Direct involvement ensures that they are represented and invested in the process, which infuses the definition, approach, execution, and outcome of a research effort with community perspectives and priorities.[9,10]

The conference was organized and conducted around our version of the ***Double Diamond Model*** from the Design Council[11] (Figure 2). While most processes of creating agendas begin by brainstorming ideas (divergent thinking) and then narrowing the list (convergent thinking), they often stop there. The Double Diamond model highlights the need for this process to happen twice: first to solidify agreement on the challenges and only then to develop the approaches. Omitting the first step is a common error and can lead to generating the right answers to the wrong questions. In the case of a project such as this one, which brings together participants with diverse expertise to address a set of challenges that connect differently to each of their work, the Double Diamond takes on even greater importance. As depicted above, our adapted Double Diamond had six steps:

[9] Schuler, D., & Namioka, A. (Eds.). (1993). Participatory design: Principles and practices. CRC Press.
[10] Boyer, B., Cook, J. W., & Steinberg, M. (2011). In Studio: Recipes for Systemic Change: Helsinki Design Lab. Sitra.
[11] UK Design Council (2018) Retrieved From: https://www.designcouncil.org.uk/news-opinion/design-process-what-double-diamond

1) Translate & Define - *Proposal*: Clarify our focus.

2) Explore – *Pre-conference survey*: Inform conference activities by surveying a broad group of practitioners and researchers for input on key challenges (major problems or bottlenecks associated with reducing, rescuing and recycling wasted food in urban centers) and related research needs.

3) Synthesize – *Select challenges*: Summarize and select challenges (major problems or bottlenecks) for further work.

4) Ideate – *Field trips and discussion*: Generate ideas about approaches (solutions) to challenges through field trips and subsequent reflection and discussion.

5) Frame – *Approaches to challenges*: Select approaches for further focus.

6) Evaluate and propose – *Research Directions:* Identify important research directions that must be pursued to improve success in advancing the selected approaches.

Pre-Conference Survey

While the conference attendance was necessarily relatively small, we wanted to obtain broad input from the field to inform the discussions. A survey was developed to seek input from practitioners and researchers regarding top challenges and key related research needs. The survey instrument was designed by the team, reviewed by colleagues, and then cognitive testing was performed to assure that questions were interpreted as intended. The 10-minute survey was administered online via the Qualtrics platform, and included the following questions:

1) Background:
    a. Respondent's organization/s related to wasted food
    b. Respondent's role
    c. Organization's geographic focus
2) Identify 5 top challenges in addressing urban waste of food. (open-ended)
3) List 5 research questions important for addressing the identified challenges (open-ended)
4) Other comments

The survey was disseminated to our networks via listservs, social media, and personal/professional contacts. Furthermore, conference attendees were invited to share it. It was fielded from July 18-August 1, 2019. Analysis was performed in Atlas.ti using a codebook developed iteratively, using both deductive (pre-determined) and inductive (based on data) codes. We used a multiple coding approach involving four coders. To build consistency across the team, two training rounds and multiple meetings were used to discuss interpretations. Following is a basic overview of findings; a future report will synthesize the findings in detail.

Respondents:

Response far exceeded our hope of gaining input from at least 20 practitioners and 20 researchers. In fact, 289 individuals completed the survey, suggesting wide interest in the topic. Table 1 describes the organizations represented. Over half (54%) had a local focus, including cities. In terms of organizational focus within the food recovery hierarchy, the largest group (44%) had a mixed focus, followed by recycling (25%). The most common organizational type was non-governmental organization (37%), followed by government (29%).

Table 1: Organizations represented in pre-conference survey, July 2019.

Organization geographic focus		**Organization focus by food recovery hierarchy stage**		**Type of organization**	
Local	54%	Mixed	44%	NGO	37%
National	16%	Recycling	25%	Government	29%
State	13%	Rescue	16%	Business	15%
Other	11%	Unknown	9%	Research	13%
Institutional (e.g., university)	6%	Prevention	5%	School	7%

Challenges and research needs

In total, the respondents identified 1,107 challenges. For the double diamond "step 3" discussions in the conference (described below), we grouped and narrowed these into 53 prevention-related challenges, 49 rescue-related challenges, and 55 recycling-related challenges. Some challenges were repeated across the three categories due to joint applicability. Survey respondents identified 848 research questions in total, each affiliated with an identified challenge. While these questions were not directly presented to conference participants as part of the conference, they did affect our ideas as we shaped the event, and we returned to review the list as part of developing this report.

To understand issues prioritized in the survey, an initial analysis summarized the top 10 codes by organizational focus in terms of food recovery hierarchy stage (prevention, rescue, recycling, mixed/all). Interestingly, two codes rose to the top across all four: policy and cost+economics. Four codes were in the top 10 for three of the four categories: responsibility-business (the responsibility for acting attributed to business, suggesting recognition of the role of upstream businesses in shaping behavior); responsibility-individual (the responsibility for acting attributed to individuals); education; and infrastructure. Table 2 presents a preliminary summary of frequently mentioned issues, to be updated when the full survey analysis is completed.

Table 2: Frequently mentioned issues in pre-conference survey (preliminary summary)

PREVENTION
Need to raise awareness and knowledge among the public and frontline food workers
Need for different message framing, such as "surplus, not waste"
RESCUE
Food safety issues, and need for more awareness of Good Samaritan policies protecting food donors from legal liability
Need to increase donations of prepared food in particular
Logistics challenges
RECYCLING
Need for more curbside composting
Scale: some respondents focused on the need for distributed compost sites, while others focused on the need for more large, centralized sites
Challenges in siting compost and other recycling facilities
CROSS-CUTTING
Need to raise the issue of wasted food as a priority; need to find champions or identify incentives for action
View that the relative affordability/convenience of discarding food is a key problem to be addressed
Need for data
Emphasis on policies such as "pay as you throw" (cost for discards rises with volume); vs concern that such policies put a burden on both food rescue organizations (if more poor quality food is donated) and households with lower incomes (who may pay the cost)
Cost issues and questions about who should/could pay for managing wasted food
Opportunity for engaging staff/volunteers; concerns about their knowledge/skills/interest
Built environment challenges/opportunities, e.g., finding sites, congested streets; proximity
Need for evaluations and identified best practices, for policies and interventions
Two policy barriers were mentioned with particular frequency: zoning; K12 school regulations
Lack of cooperation/coordination/policy harmonization
Equity concerns
Thanks: a number of respondents thanked us for performing the survey.

Conference Day 1: Synthesize and Ideate

The conference began with a set of 10-minute presentations to orient the diverse audience to the content and approach of the event, and to get everyone on the same page. The presentations shared ideas such as the SUS concepts and key definitions. They also encouraged all to participate fully, emphasizing the important role of every participant in the room.

- Wasted Food Introduction
- Sustainable Urban Systems
- Wasted Food in an Urban Sustainability Context
- Convergence and Interdisciplinarity
- Making Change in Cities
- NSF Overview
- Baltimore and Introduction to Field Trips
- Survey Overview

Photo: Introductory talks

Synthesize – *Select challenges*

Photo: Selecting challenges

The first interactive task was to narrow the set of challenges identified in the survey into a smaller group of key challenges for focus. Participants were divided roughly by expertise into three groups based on reduce/rescue/recycle. The challenges for their topic areas were printed on sheets of paper and participants were asked to sort and group them.

Ideate – *Field trips and discussion*

Following the preliminary synthesis of challenges, we again expanded the group's ideation through off- and on-site field trips and discussion. Two "off-site field trip" talks were presented at lunch on the first day. Meg Kimmel from the Maryland Food Bank spoke of the food bank's innovative efforts in food rescue and in addressing the underlying conditions that create need for anti-hunger programming. She also spoke of the Food Bank's new culinary job

Photo: Convention Center presentation

training program, which catered our lunches on both days. Next, Leana Houser, Recycling Manager at Johns Hopkins University (JHU), spoke of the university's efforts to reduce and recycle waste. She described several innovative efforts including a campus system alerting students to available leftover food. This service was used to assure no food would be wasted at our conference.

Photos: Filbert St. Garden/Baltimore Compost Collective

We continued with on-site field trips to the Baltimore Convention Center and the Filbert Street Garden/Baltimore Compost Collective. The Baltimore Convention Center was chosen because it is a large-scale operation with extensive food waste prevention, rescue, and composting efforts. Mac Campbell showed how he orchestrated a web of partnerships and stakeholders from farmers to non-profits and compost haulers to make the city's premier event venue zero-waste. They also discussed: technologies and approaches that were begun and then abandoned in favor of more robust solutions; the important role of frontline workers and of champions; and their efforts to challenge standard industry practices such as significant over-ordering.

Attendees then toured the Filbert Street Garden composting operations. This site was chosen both as a representative of the nuanced challenges of small-scale compost processors and haulers, and because of its compelling story. The garden is located near the city's aging trash incinerator, and local asthma rates are high. Residents have been active in organizing to shut down the incinerator, and this is likely to happen. Marvin Hayes, master composter and youth mentor, shared how the Baltimore Compost Collective has married workforce and youth development with an alternative approach to disposing of food scraps (food comprises the largest portion of municipal solid waste), and the opportunity to create a valued soil amendment. At the same time the program has faced challenges including threatened city takeover of the space, and the ongoing effort to create financial sustainability.

Dinner on Day 1 continued the second round of ideation with a vibrant group discussion. One emergent theme explored the need for *both* large and small-scale approaches in order to address the diverse challenges of wasted food, as demonstrated by Filbert St. Garden and the Baltimore Convention Center. Second, the group felt that engaging frontline workers throughout the food and food waste systems was critical to understand challenges and implement solutions. They also noted important opportunities to use the issue of wasted food to engage youth and build community. Several participants noted being struck by comments about the fragility of

several described efforts and systems to address waste, including reliance on key individuals, need for resources, and dependence on effective intersections between urban systems. Finally, the discussion touched on how little we know, from the lack of detailed data about food moving in and out of cities; to information about which solutions have been implemented, where; to data on intervention effectiveness generally and in particular contexts.

Photo: Dinner

Beyond discussion, the practical task at dinner was to narrow the still-long lists of challenges from the morning sessions, considering the afternoon and evening ideation. Organizers synthesized challenge lists from the different groups and removed duplicates. Then participants voted with sticky dots for the top challenges to be addressed by our group the next day (Table 3.)

Table 3: Refined list of challenges

Inadequate prevention of food waste for consumers and consumer-facing organizations [e.g., retail, restaurant]
Need for cost-effective availability of comprehensive data
Need to advance complementarities and diffuse competition for food and scraps across layers of the "hierarchy" in rescue
Need to identify how best to balance centralized vs. distributed recycling approaches
The culture of over-consumption leads to waste; loss of traditional anti-waste attitudes, knowledge and practices
We don't promote and document co-benefits of reducing wasted food, for example, equity, health, justice, environmental, and economic benefits
Wielding financial incentives to induce change without exacerbating inequality

Conference Day 2: Frame, Evaluate and Propose

Frame – *Approaches to challenges*

Day 2 started with a recap of Day 1, and then continued into a "carousel" session where participants developed approaches (solutions) to the challenges listed above. We placed seven carousel stations around the room, each featuring one of the above challenge categories. Groups were assigned to carousels to brainstorm approaches. When the bell rang, they moved one carousel to the right and repeated. In the third and fourth rounds, participants selected their own carousels, and in the fifth round

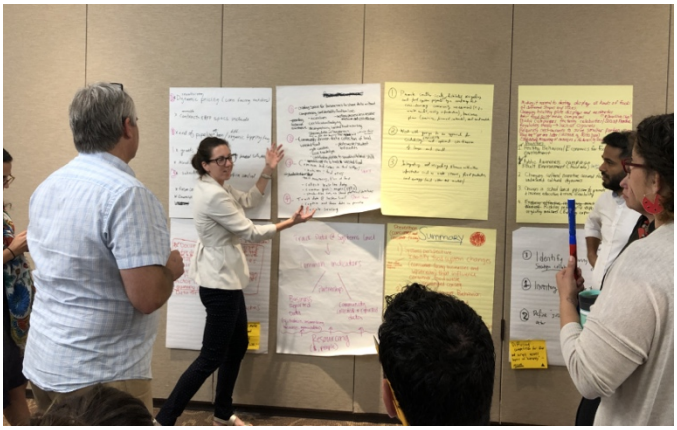

Photo: Framing challenges

they returned to their original stations to organize and synthesize the approaches generated across the multiple rounds.

The organizing committee then synthesized the list of cross-cutting approaches generated during the carousel session into the 18 approaches listed in Appendix A.

Evaluate and propose – Approaches

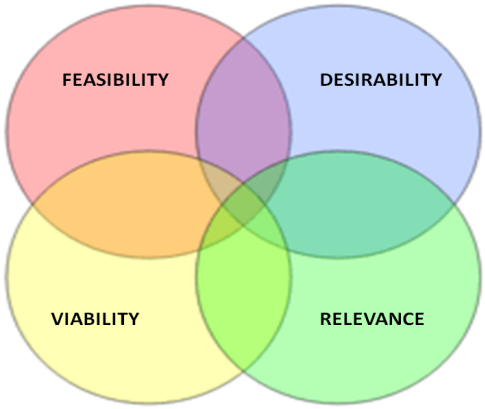

Figure 3: Innovation Framework for Evaluating Approaches

We adapted ***a classic innovation framework***[12] to evaluate and cull this list of approaches in order to select a few for focus in developing our research questions. Traditionally, the innovation framework focuses on an approach's desirability (extent to which it fills a need of stakeholders to enable them to advance urban sustainability and address waste of food), viability (extent to which the approach is likely to succeed in its goals and be sustainable), and feasibility (extent to which it is currently possible). We added a fourth circle for relevance (extent to which the approach is relevant to our conference purpose, e.g., fits at the intersection between wasted food and sustainable urban systems; and is likely to lend itself to convergent research approaches).

Conference participants rated the selected approaches on these four criteria using the Sli.do app, and scores were averaged (Appendix A). Table 4 presents the top-ranked approaches.

Table 4: Top Rated Approaches (Solutions) after Voting

Develop (+incentivize) strategic collaborations between area actors in food rescue, recycling, prevention, and related areas of urban system. Move beyond talking to shared planning/action/leveraging resources.
(Systems perspective beyond individual): Identify food system changes that influence consumer food waste, including relation to other food-related topics and unintended consequences.
When collecting and communicating data, consider food systems as a whole with food waste as a component. Capture and analyze data at various points in the system to better understand issues like how to measure prevention.
(Individual behavior) Changing consumer behavior through effective (evidence-based), simple, and targeted messages and interventions (education and beyond).

[12] Menold, J., Simpson, T. W., & Jablokow, K. W. (2016, August). The Prototype for X (PFX) Framework: Assessing the Impact of PFX on Desirability, Feasibility, and Viability of End Designs. In ASME 2016 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference (pp. V007T06A040-V007T06A040). American Society of Mechanical Engineers.

Develop narratives about the co-benefits that reach different audiences; disseminate through marketing tactics.
Health Behavioral Economics for food retail environment - e.g. dynamic pricing. 1)Public awareness campaigns and 2) Built food environment.
Inventory local actors as a step to advancing collaboration (scale of operation, amount/types of food, models of operation, what they would consider "success" in sourcing, logistics, other).
Prioritize community-driven local data collection: 1) Train local residents to collect data; 2) School-based initiatives like student-led plate waste audits; and 3) Connect to career pathways.
Changing cultural narrative around food; better understand cultural dynamics.
Assess and document models of all sizes, classifying and quantifying co-benefits in order to identify the appropriate scale of models that can generate the most relevant co-benefits
Training and engagement of frontline actors in the food system.

Evaluate and propose – *Research Directions*

In the final stage of our process, we sought participants' insights about research needed in order to advance these selected approaches to the identified challenges. Participants split into six groups diversified by expertise and discipline. They then brainstormed the data, technology, theory, and other knowledge that, if created, could further the approaches outlined above.

Data: The participants highlighted extensive needs for data throughout the food and waste systems to better enable research and support the identified approach. They noted needs for quantitative data including spatial and temporal data; and qualitative data such as case studies to better understand the "how" and the human element, including issues of equity. Examples included data on frequent shoppers and online orders, retailer level waste by category, data on frontline workers, specifics on movement of food within and beyond the city, and collection of other datasets beyond proxy data. In addition, the highlighted opportunities in co-creation of data, and in training residents to collect original data.

Technology: Participants highlighted needs for technology to streamline data collection and analyze data quickly in order to diagnose problems. They suggested organizing information through new approaches such as blockchain and social media analysis. Participants proposed app-driven incentives for right sizing food portions and helping with restaurant leftovers and value-added foods. Satellite imagery combined with truckload weight could be an avenue for collecting data on wasted food, as well as RFID tags at different points of the food system. Technologies that collect individual-level data, such as on purchases and discards, could combine with community food-sharing platforms to reduce waste while providing insights on drivers. Sensors could be used in research, such as for detection of food decay.

Theory: Participants felt more theory was needed around the relationship of the food system to other urban systems, in particular the Food-Energy-Water-Health nexus. Understanding political economy solutions to wasted food along with social and behavioral models to clarify the drivers

of wasted food were also brought up. Participants also discussed the need for improved theory development to support intervention design, including going beyond widely used rationality-based models such as the Theory of Reasoned Action. Another idea was for a theory of valuing food and farm labor in order to encourage less waste.

Other Knowledge: Other issues were raised in the group discussion, including the implementation of dynamic pricing models in order to reduce wasted food and the implications of interventions on equity. Ethnographic knowledge of planning, purchasing and preparation process and the relationship with food waste and what is perceived as edible or inedible. Thinking about future trends of population and climate is essential to thinking about the future of wasted food. Concurrently, helping understand co-benefits across geographies, demographics, and age groups could help with sustainable interventions, such as training and community-building.

Research Objectives: Following the small group discussions, organizers formulated selected research questions into more formalized examples, based on ideas presented in their groups and the broader discussions of the conference. They elaborated the research objective, intellectual merit, and broader impacts, as shown in the Table 5 examples.

Table 5: Examples of Two Research Objectives that emerged from the Research Directions

	Example 1: Workers	**Example 2: Typologies**
Research Objective	To understand how learning from, training, and incentivizing frontline workers can impact wasted food, the local economy, and outcomes for the local economy. In pursuit of this objective, we need to understand who those workers are and how their industry is transitioning. We will also want to understand how the personal valuation of frontline workers impact the discard of food by consumers.	To develop a framework for a typology of organizations and contexts in the wasted food space to measure metrics of success and the impact on co-benefits from this system.
Intellectual Merit	Frontline workers have not been utilized as a knowledge base, and the new science is the co-production of new knowledge by people who are impacted the most. This qualitative research will help close the gap between workers and consumers. This lends itself to convergence research.	Allows modeling of intervention impacts with greater appropriateness/relevance. No such typologies exist.
Broader Impacts	Potential positive economic benefit for households, communities, and cities. The injury rates are very high for this industry. There is an improvement in management practices and peripheral outcomes.	Provide tools to assist with evaluation. Provide shared evidence across cities/orgs.

The collection of research directions and sample research questions was the end of the conference. The organizing committee then met to organize these ideas to produce a synthesized research agenda as described below.

C. Research Agenda for Addressing Wasted Food as a Sustainable Urban Systems Opportunity

Building from the survey, the conference output, and the reflections of the organizing committee, we present the following Research Agenda. Each item is anchored by a knowledge gap and linked via letters A-F to the relevant elements of convergence SUS science, as outlined in the January 2018 NSF report *Sustainable Urban Systems: Articulating a Long-term Convergence Research Agenda*. (Ramaswami et al. 2018, Table 1). For easy reference, Table 7 (p. 27) summarizes these linkages between our Research Agenda and the key elements of SUS science.

Knowledge Gap I: Tools, Typologies and Results: Evaluation and Systems Modeling

Few publicly available evaluations exist for interventions to prevent, rescue, or recycle wasted food. As the number of program and policy interventions increases, the lack of evaluation data to learn from this work presents a barrier to progress. Evaluation, using standardized, policy-relevant methods, is critical for characterizing impacts and suggesting ways to improve intervention effectiveness. Additionally, evaluations are needed to assess sustainability and other co-benefits and co-harms in urban systems (i.e., equity, economics, health, environment, and society).

In addition to the need for traditional evaluations of individual programs and policies, the SUS lens highlights the complementary need for evaluations that assess these interventions in context. Similar to other domains of urban sustainability, systems models contribute insights that can support development of interventions to prevent, rescue, or recycle wasted food. For example, models of urban transport are necessary to understand the movement of food and food waste through cities. However, transportation models have generally not been integrated with other urban models, presenting a ripe area for research.[13] Beyond integrating models of urban infrastructure, future systems models need to be able to represent interactions across scales. For example, especially in the context of wasted food, multiple small community efforts and partnerships can be scaled up for large-scale urban and national-level solutions, especially when combined with more centralized approaches. To our knowledge, there are currently no models of waste of food that can scale to the city-level in order to understand the aggregate impact of community-level interventions, although multiple existing and under development projects may be modified in this direction.

Evaluation can also identify shared themes and synergies across interventions and cities, and reveal ways to improve intervention effectiveness in varying contexts. Research needs:

1. Create a suite of tools and related indicators that can be used to enable systems modeling of intervention impacts and evaluation of individual organizational efforts. This would include methods and data to integrate the variety of components of urban sustainability. [Key Elements of Convergence SUS Science: A, C]

[13] National Academies of Sciences, Engineering, and Medicine. 2019. *Enhancing Urban Sustainability with Data, Modeling, and Simulation: Proceedings of a Workshop*. (pg 19) Washington, DC: The National Academies Press. https://doi.org/10.17226/25480.

2. Develop typologies of interventions and cities to enable tailored selection of indicators and evaluation research methods, and interpretation of findings based on factors such as city size, intervention type, goals, organization scale, co-benefits, and other factors. Connecting these typologies with the new data may lead to valuable modeling opportunities for strengthening understanding of potential intervention impacts. To our knowledge, there is no existing typology of urban systems and organizations more broadly, so this tool will enable further analyses in multiple other SUS domains. [D,E].

3. Develop new mathematical approaches to integrate datasets and build models that can integrate mathematical paradigms (e.g., simulation, equilibrium, and learning) to account for food waste's intersection with engineering, psychology, economics, business, and public health. Developing tools that capture the highly nonlinear structure of the food supply chain is critical, including tractable algorithms that can be used to solve such nonlinear models. New network approaches can also analyze the interconnectedness of food waste actors and actions. [E,A]

4. Perform traditional evaluations of the large number of program and policy interventions underway to address food waste, including collection of quantitative and qualitative data to understand impacts, co-benefits, co-harms, and ways to improve. Evaluation methods should be standardized to the extent feasible, to enable comparison across interventions and cities, and also to support the creation of models that incorporate evaluation impact information. Interventions of importance for evaluation include both traditional programs and novel/entrepreneurial ones. Policies of importance for evaluation include not only those directed to food waste, but also related policies such as those shaping food procurement, wages, public benefits, food safety, and food literacy; and regulations shaping environmental and occupational practices. [C,B,F]

Knowledge Gap II: Intervention Spillovers Across the Supply Chain and the Food Waste Hierarchy, and Across Urban Systems

In order for food to meet its intended human consumption use (not be wasted) it must survive all links of the food supply chain without progressing below the first two levels of the food waste hierarchy (source reduction and feed hungry people – see Figure 1). Hence, systems-based approaches represent a critical knowledge gap within the wasted food space as success (increased waste prevention) at one point in the system may influence existing prevention efforts at another point in the system. For example, consider a farmer with a perishable produce item that does not meet normal cosmetic standards and would previously have been plowed under (e.g., ugly food). The farmer aims to prevent waste and ships it to a retailer. In isolation, this would be assessed as a successful prevention intervention. However, the new shipment of ugly produce adds more product into a perishable supply chain pipeline. This additional quantity of food must compete against all other food with overlapping shelf life and may increase the odds of food being recycled or wasted (spillover to other parts of the hierarchy) in processing, distribution, or retail (spillover to other parts of the supply chain). Spillovers may also flow in the other direction. For example, organic waste bans have been introduced in several localities, but less is understood about how this intervention at the end of the food supply chain and at the bottom of the food recovery hierarchy transmits incentives and impacts to earlier links in food

supply chain behavior and alters the mix of prevention, recovery, and recycling efforts. Further, spillovers occur across urban systems. For example, an intervention considered beneficial from a food waste perspective can negatively impact other SUS systems such as energy due to the need for food cooling, or can have substantial economic or equity costs. These cross-system tradeoffs should also be assessed. The research needs:

1. Create models of food flows down the food supply chain and recovery hierarchy suitable for systems-level assessment of one or more interventions. [Key Elements of Convergence SUS Science: B]

2. Calibrate models for several typical urban systems and focal interventions and identify patterns of interactions to formulate a typology of competitive and complementary intervention sets for achieving improved urban system sustainability. [D, E]

Knowledge Gap III: Leveraging Front-Line Workers in Cities

Workers are at the heart of efforts to address wasted food; indeed, they are at the heart of all urban systems. An estimated 21% of the U.S. workforce focuses on food (over 24 million workers in 2012), including workers in retail, food service, food distribution and wholesale, food production and processing, and waste management[14]. These workers have a frontline opportunity to influence the success of urban efforts to reduce and manage food waste. They are also affected by such efforts in diverse ways. Moreover, they represent a human link between efforts to address food waste and diverse urban/transboundary systems. As the research on wasted food continues to expand, virtually no studies have focused on workers per se, although the literature on business interventions does include worker-informed studies. There is thus a critical gap in understanding how best to leverage workers as a resource, or how to realize co-benefits and prevent co-harms for individuals, businesses and systems.

While the issue of workforce was not highlighted in our conference proposal, it was mentioned repeatedly in our pre-conference survey, and we thus noted it in the introductory session. The theme grew in prominence over the course of the conference, particularly strengthening during the evening reflection following the field trips. Participants prioritized the issue for several reasons in addition to the dearth of research.

Why Workers?

Formative studies (including our own research[15]) suggest that frontline workers often have different understanding of needs, barriers, opportunities, and protocols than their managers. Policies developed without recognition of such insights may be destined to fail. For example, in the case of food safety, national policy emphasizes worker training. However, workers report that they know what to do, but face barriers such as lack of sick leave, the cost (time and financial) of laundering uniforms, workplace time pressures (so strong that even handwashing is

[14] King RP, Anderson M, DiGiacomo G, Mulla D, Wallinga D. 2016. State Level Food System Indicators. https://www.hfhl.umn.edu/research/food-system-indicators/food-system-indicators-report Accessed September 28, 2019.

[15] Ceryes CA, Antonacci CA, Bickers A, Harvey S, Neff RA. "Maybe it's still good?": Workers' experiences of supermarket food waste reduction and rescue efforts. Manuscript in preparation.

a challenge), poor architectural layouts, and a desire not to burden coworkers.[16] Firms such as Leanpath do build their food service waste prevention activities around worker insights (among other data), but their services are proprietary and costly, and not generally connected to the research arena.

Our conference and survey participants noted that workers often embrace the opportunity to engage on the issue of food waste, particularly when empowered with tools, training, and support. This issue holds broad appeal, given cultural values in support of reducing waste, donating food, and creating environmental benefits. Many food system workers are or have been food insecure, making food waste particularly disturbing. Thus, addressing wasted food might provide inroads to enhance feelings of pride in one's work, advance positive workplace climates, and even improve worker retention.

Food rescue and recycling represents a jobs opportunity for cities, which can be developed and targeted, including through training and targeted opportunities, as well as efforts to improve job quality. At the same time, many food sector jobs are poorly paid, with low workplace power; eight of the country's ten lowest paid occupations are in the food industry.[17] Compared to those with greater workplace power, those with low power may feel unsafe or stigmatized in speaking up about waste. Their suggestions may also be less attended to, they may feel less ownership of problems, and they may feel more pressure to simply get the job done without taking initiative for broader change. Additionally, rates of injury and illness in several food and waste management sectors are more than double the national average, while fatality rates in waste management, truck transportation, and waste collection are four to eleven times the national average.[18] Safety and health risks tend to be highest for less-experienced employees, meaning rapidly growing industries such as food waste rescue and recycling should be watched.

From a broader SUS perspective, a workforce angle on wasted food is beneficial because many of the research needs apply to frontline workforces in other urban systems, which are often similarly underpaid and largely untapped in terms of potential contributions to SUS efforts. NSF identified "The future of work at the human-technology frontier" as one of its 10 Big Ideas.[19] Additionally, through their roles, workers represent a human bridge linking diverse systems. For example, truck drivers literally transport food and waste into, through, and beyond urban systems using transportation networks and energy systems. Their routes, choices and interactions at every stage are shaped by diverse economic, social, and policy systems. Inside a grocery store, an individual stocker must decide for each food item whether to keep, toss, or, if opportunities exist, donate or compost. These decisions are shaped not only by store policies and individual judgment, but also by policy system factors such as date labels; economic system factors including the cost of waste and potential cost to the store's image from selling lower quality

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[16] Clayton ML, Clegg Smith KA, Neff RA, Pollack KM, Ensminger M. Listening to food workers: Factors that impact
proper health and hygiene practice in food service. International Journal of Occupational and Environmental Health. 2015 21:4.

[17] Current Population Survey. 39. Median weekly earnings of full-time wage and salary workers by detailed occupation and sex. Available at: https://www.bls.gov/cps/cpsaat39.htm. Accessed September 28, 2019.

[18] Bureau of Labor Statistics. Survey of Occupational Injuries and Illnesses (SOII) 2016 and Census of Fatal Occupational Injuries (CFOI) 2016.

[19] https://www.nsf.gov/news/special_reports/big_ideas/

items; and cultural system factors such as pressure to present customers with the appearance of abundance and perfection.

Research needs:

1. Learn from frontline workers, including harnessing real-world knowledge of human-built, natural, and social systems in cities and beyond; and studying the drivers and interactions within and among these systems; and the related challenges and opportunities. Study the role of frontline workers in advancing sustainable urban systems more broadly. Use co-constructed knowledge to design systems models and shape interventions. [Key Elements of Convergence SUS Science: A,C,F]

2. Test multi-level interventions in cities to leverage this most-directly engaged population, such as technological tools, workplace policies, trainings, or incentives for food waste prevention/rescue/recycling activities. Develop and apply theories of change to advance these efforts. [C]

2. Study broader co-benefits and co-harms of food waste and related interventions for individual workers, firms, cities, and society. These may include co-benefits and co-harms in economic, physical, and social well-being, job development and retention, and firm profits. [B,C-2]

3. Examine multiplier and spillover effects of interventions (e.g., changes in workers' home behaviors and knowledge sharing with friends, family, neighbors, and civic organizations). [A,C,F]

4. Examine the role of working conditions in addressing food waste and preventing the need for food recalls (a form of massive waste), including: wage levels; workplace power levels; morale levels; type of workplace culture; structures and styles of management and operational procedures; and training programs. [A]

5. As this relatively new area of convergent research is developed, lessons, approaches and theories may be borrowed from a) research with workers in related fields such as medical errors, food safety, food systems, and occupational safety and health; and b) research on food waste in non-occupational settings. Studies should examine applicability and adaptation of insights. [D,C]

Knowledge Gap IV: Preventing Consumer-Level Waste of Food in Cities

Until a human consumes food, it is at risk of being wasted. Thus, consumers are positioned as the last and perhaps the most important link in any food supply chain where the goal is to reduce wasted food. In the United States, urban consumers may be responsible for over 40% of system-wide wasted food. Programs to influence consumer prevention behaviors are proliferating, especially at local levels. Yet, little knowledge has been produced about effective consumer-

level prevention. One recent systematic review of literature[20] summarized that a significant evidence gap existed such that "...it is difficult to make evidence-based decisions to prevent or reduce consumption-stage food waste in a cost-effective manner."

Prevention is inherently challenging to measure at any stage in the supply chain because it requires estimating counterfactual waste levels in the absence of the preventative effort. This is particularly difficult at the consumer level where data collection is the thinnest, least accurate and most inconsistent. Furthermore, consumers do not operate in a vacuum. They respond to the choices and choice architecture shaped by earlier actors in the food supply chain, including retailers, manufacturers, processors, and farmers. Consumer actions to prevent food waste might also induce other risks. For example, consumers motivated to reduce wasted food might be tempted to consume foods with elevated odds of causing foodborne illness or to consume simply too much food to reduce wasted food. Research needs:

1. Develop evidence-based interventions at all supply chain stages to prevent consumer food waste; create implementation tools; evaluate long-term impacts, including unintended consequences. Innovations in modeling that permit the robust creation of counterfactual scenarios provide one important approach to such intervention development. [Key Elements of Convergence SUS Science: C-2]

2. Produce quantitative and qualitative data to identify drivers and levers of change for consumer-level food waste in cities, segmented by consumer type; study the influence of the rapidly changing food landscape (e.g. online food shopping, smart appliances); and understanding tradeoffs. [C-1]

3. Advance the science of co-production between researchers, practitioners, and community members to develop and share data and best practices; coordinate with other efforts addressing other food or waste-related topics (e.g., promoting food literacy to improve nutrition and reduce waste) [F]

Knowledge Gap V: Equity

We expected the theme of equity to run through all of the discussions and to be centered within each of the highlighted knowledge gaps. However, the strength of focus in discussions, and the importance for SUS research more broadly leads us to highlight it as its own knowledge gap. A September 2019 analysis from the *American Community Survey* indicates that U.S. income inequality, measured by the Gini coefficient, is the highest it has been in fifty years.[21] Most conference discussions on equity focused on socioeconomic and racial/ethnic dimensions of equity, as well as the workplace equity themes highlighted in Knowledge Gap IV. In the context of urban wasted food, we also emphasize the importance of inequities around gender, disability status, age, and education. Table 6 provides a typology of ways that wasted food and inequity

[20] Reynolds, C., Goucher, L., Quested, T., Bromley, S., Gillick, S., Wells, V.K., Evans, D., Koh, L., Kanyama, A.C., Katzeff, C. and Svenfelt, Å., 2019. Consumption-stage food waste reduction interventions–What works and how to design better interventions. *Food Policy*. 83:7-27.

[21] Guzman G. American Community Survey Briefs. Household Income: 2018. Available at: https://www.census.gov/library/publications/2019/acs/acsbr18-01.html. Accessed September 28, 2019.

intersect, along with examples.

Table 6: Intersections between inequity and waste of food

	A: Level and type of inequity	B: Interventions to address inequity
C. Food waste	A→C: Families with low incomes and those with low supermarket access may be less likely to purchase fresh produce due to concern about perishability and waste. C→A: Low levels of food waste and surplus can mean reduced buffer for resilience in case of disaster, which may increase future food-related inequities.	B→C: Inequities in food literacy education and knowledge may lead some to be particularly likely to discard food unnecessarily based on inaccurate food safety concerns.
D. Food waste intervention	A→D: Power differentials across organizations affect the extent to which they are able to compete for food or food scraps as a resource. D→A: Siting a food waste recycling facility in a community may increase environmental injustice concerns. And: Donating rescued food of questionable quality can exacerbate stigma and negative feelings among those who rely on that food source.	B→D: Effective anti-hunger programs at a social level could lead to reduced need for food rescue, and thus shift the desired balance of food surplus/waste management activities D→B: Effective food waste prevention and management activities in a neighborhood contribute to a sense of community well-being (and potentially also to gentrification)

Through conference discussions, survey insights, and our own analyses, we highlight four key groups of research gaps.

1. Perform background and descriptive research to characterize the central issues linking equity, wasted food, and related interventions, and to understand how inequities challenge positive SUS outcomes and their co-benefits. For example: studies may collect and describe geographic and surveillance data; and quantify relevant inequities. [Key Elements of Convergence SUS Science: A,B]

2. Perform analytic studies to understand interrelationships between equity and other issues in wasted food, including linkages to broader food system themes such as food access. These studies may use quantitative and qualitative tools, and modeling. [B]

3. Perform systems modeling to understand key complexities, clarify relationships, test potential policies for impact, assess unintended equity consequences of interventions to address wasted food, and highlight potential areas for further research. [C]

4. Use wasted food as a laboratory or lens through which to gain increased insight into opportunities for promoting more equitable SUS outcomes, including through developing and testing interventions to address either waste of food or underlying social power imbalances, as well as theory development. This research may build on existing bodies of literature with connection to the waste and SUS context. [F]

Knowledge Gap VI: Data on Wasted Food and Connected Systems

A unifying theme emerging from the conference, and dominant need for launching the research thrusts identified above, is the need for data. Despite expanded data in the wasted food space, significant data gaps persist while variability in data quality, coverage, integration, harmonization, and availability undermine analytical progress. Participants expressed that successful knowledge co-production will require creating, curating, integrating, harmonizing, and increasing access to both qualitative and quantitative data on wasted food and other indicators relevant to food and urban systems. This will require dedicating resources (e.g., personnel and equipment), identifying incentives (e.g., technical assistance, monetary incentive, information feedback, norm development), and changing social and organizational cultures (e.g., ensuring protection of proprietary data, destigmatizing waste creation and reporting) to ensure progress.

Data collection approaches: Participants noted a need to spur innovation in active and passive data collection to ensure cost-effectiveness, enable new types of data to be collected, protect the personal privacy and proprietary interests of those providing data, and empower data availability for knowledge co-production. Not only is greater granularity of data on wasted food and food scraps needed at each stage in the supply chain, but also the ability to link this data across geographically and organizationally separated segments of the food supply chain to provide system wide assessment and analyses. Additional community wide data collection was also emphasized as a need that could be creatively met through the training and empowerment of a diverse array of citizen scientists to provide essential data. This stimulated discussion about the continuing need for practical tools and training materials to ensure the standardization of primary data collection, whether conducted by citizen scientists, front-line food system workers, or major organizations.

The group also noted the need for novel data collection approaches that could spur new knowledge. For example, while photo-based diaries reduce respondent burden for consumer-level data collection, the translation of such photos into reliable data (mass and nutrient composition) generally relies on human raters and can only be automated in certain rigid circumstances (e.g., if the recipe and serving size for all menu items is also gathered). Advancements in image processing could make such approaches more cost effective. Others suggested approaches leveraging remote sensing to track the movement of food shipments, leveraging multi-element/multi-isotope analyses to understand the location of origin of wasted food for better resolution of LCA impacts, or building on successes in municipal sewage epidemiology to understand the amounts and types of food actually consumed within an urban system. [Key Elements of Convergence SUS Science: A]

Data needs of particular priority: As noted above, respondents noted that measuring food waste prevention presented a particular challenge. Compared to measurement of the quantities of food

recovered or recycled, prevention requires assessment of a counterfactual level of waste necessitating additional data collection and modeling activities. Hence, research refining assessment of food waste prevention was repeatedly emphasized.

A clear theme that emerged during synthesis was the need to collect data about household or establishment level efforts to reduce, recover and recycle wasted food, including the benefits and costs associated with and resulting from these efforts, such as life cycle impacts; jobs created; community food security; changes in sales, revenues, and operational costs; and any changes to food safety risks.

Data curation: Participants noted a need for a data curation entity to ensure data are available and useful for academic research and co-production of knowledge. A large and multifaceted curated database may stimulate novel analyses and permit replication of results to ensure robustness. To accomplish systems-level analyses, any such data curation platform would need to house extensive consumer and household level data, and be available in a manner that encourages use by academic and other teams interested in knowledge co-production. Features such as geocoding that permit spatial visualization and integration of relevant secondary data at the appropriate scale of analysis (metro, state, region) would accelerate progress. It was also noted that the voluntary participation required to obtain most business and consumer data would require appropriate analysis and modeling to ensure conclusions drawn would be valid for more representative samples.

Opportunities identified in data curation included harnessing several ongoing efforts to aggregate and warehouse food waste data collected from businesses along the food supply chain, including the U.S. EPA's Food Loss and Waste Champions program, The Food Waste Atlas (World Resources Institute and Waste & Resources Action Programme), The Consumer Goods Forum Food Waste Case Study collection, the Food Waste Reduction Alliance, and the Pacific Coast Collaborative, most of which were represented at the conference.

A particular opportunity is that Reducing Food Waste through Economics and Data (ReFED), which was also represented at our conference, is developing an initiative to curate, house and share data on food waste and food waste reduction solutions. Their data will derive from the above-mentioned data collection efforts, directly from business, and from other organizations. Two of the conference co-organizers serve on a voluntary board of experts to help inform this data collection effort. Any initiative should engage ReFED to ensure additive rather than duplicative efforts, with additional foci to ensure data are harmonized and structured to ensure integrity of conclusions drawn and to permit more systems-wide analyses.

D. Map of Knowledge Gaps to Convergence Science in Sustainable Urban Systems

The knowledge gaps identified through our conference connect directly to the key elements of convergence SUS science presented in the January 2018 NSF report, *Sustainable Urban Systems: Articulating a Long-term Convergence Research Agenda.* (Ramaswami et al. 2018, Table 1). Table 7 summarizes these linkages.

Table 7: Map of Wasted Food Knowledge Gaps to Convergence Science in SUS

Key Elements of Convergence SUS Science	Wasted Food Knowledge Gaps Identified
A. Developing new data and methods to understand current drivers and interactions among natural, human-built, and social systems in urban areas as they impact multiple sustainability outcomes across scales.	I.1, I.3, III.1, III.4, III.5, V.1, VI
B. Developing the science to assess the sustainability outcomes nexus in urban systems, i.e., the co-benefits and trade-offs among multiple human and planetary well-being outcomes across spatial (local to global) and temporal scales.	I.4, II.1, III.3, V.1, V.2
C. Understanding the levers for change in diverse urban systems ("theories of change"), combining: 1. A focus on integrative design, technology innovation, and sociotechnical transitions. 2. A focus on multi-level actors and governance	I.1, I.4, III.1, III.2, III.4, III.6, V.3 IV.1 IV.2
D. Advancing comparative studies, typology studies, and scalability studies to develop a generalizable science of theories of change across diverse city types.	I.2, II.2, III.6
E. Developing the science to model the future of SUS across the three perspectives.	I.2, I.3, II.2
F. Developing the science of knowledge co-production among researchers, communities, industry groups, practitioner groups and governments at multiple levels, leveraging real world experimentation ongoing in urban areas.	I.4, III.1, III.4, IV.3, V.4

Moving Forward

Waste of food is important in its own right, as a critical resource for urban systems, which is being landfilled at a striking rate. Addressing waste in cities has strong co-benefits for health, economics, equity, environment, and other outcomes—and contributes to our national goal to halve food waste by 2030. The value of wasted food for SUS research is even broader. Due to food's centrality, necessity, resource costs, and interconnectedness with other systems, food and waste of food represent a powerful testbed issue for diverse SUS research efforts.

Collaborations will be essential for any successful path forward. We are energized by the participants at our conference and by our interactions with the organizers of the related NSF SUS conference at the Rochester Institute of Technology. We look forward to developing collaborations with these and other groups to co-generate the knowledge required to advance urban sustainability science and address this opportunity facing urban populations across the globe.

Acknowledgements

In addition to all the attendees of the conference and respondents to our survey, we would like to thank NSF for funding this conference through grant number 1929791, and our program officer Brandi Schottel for attending the conference and providing her valuable insights. We also thank Becca Bartholomew for her excellent service as conference facilitator.

APPENDICES

Appendix A: Approaches to Challenges

The table below lists all the approaches and their average score that were generated in our conference during the Framing Approaches session on Day 2:

Table A1: Full list of all Approaches with Average Score

Score	Approach
8.35	Develop (+incentivize) strategic collaborations between area actors in food rescue, recycling, prevention, and related areas of urban system. Move beyond talking to shared planning/action/leveraging resources.
8.325	(Systems perspective beyond individual): Identify food system changes that influence consumer food waste, including relation to other food-related topics and unintended consequences.
8.275	When collecting and communicating data, consider food systems as a whole with food waste as a component; Capture and analyze data at various points in the system to better understand issues like how to measure prevention
8.15	(Individual behavior) Changing consumer behavior through effective (evidence-based), simple, and targeted messages and interventions (education and beyond).
8.075	Develop narratives about the co-benefits that reach different audiences; disseminate through marketing tactics
7.875	Health Behavioral Economics for food retail environment - e.g. dynamic pricing. 1)Public awareness campaigns; 2)Built food environment
7.775	Assess and document models of all sizes, classifying and quantifying co-benefits in order to identify the appropriate scale of models that can generate the most relevant co-benefits.
7.75	Training and engagement of frontline actors in the food system
7.65	Develop common indicators on food systems; 1) Collect baseline data; 2) Standardize data; 3)Build shared platforms/databases
7.575	Inventory local actors as step to advancing collaboration (scale of operation, amount/types of food, models of operation, what they would consider “success” in sourcing, logistics, other)
7.475	Implement differential tipping fees or bans of organic waste
7.425	Improving regulation and exploring effective regulatory measures. (Balancing corporate and public interest)

7.375	Create space for business to share data w/o compromising confidentiality or bottom line 1) Offer incentives; 2)Destigmatize sharing; 3)Competitive certification programs; 4)Technical assistance on business optimization for sharing data
7.15	First promote smaller-scale distributed recycling and food system projects by community assessment (waste audit, existing infrastructure), business plan (training, financial risk reduction instruments), and end markets.
7.125	Prioritize community-driven local data collection; 1) Train local residents to collect data; 2) School-based initiatives like student-led plate waste audits; 3) Connect to career pathways
7.075	Changing cultural narrative around food, better understand cultural dynamics
7.05	Changes in school lunch program to promote more food system engagement and increase education and a more flexibility
6.575	Integrating recycling streams with other infrastructure such as waste streams, food production, energy (and other end markets), and sharing trucks

Appendix B: Agenda Overview

Day 1

8:30am-9:00am	Breakfast and Registration
9:00am-10:40am	Session1 (Introduction and Survey Results)
10:40am-11:00am	Coffee Break
11:00am-12:10pm	Session 2 (Synthesis)
12:10pm-1:15pm	Working Lunch
1:30pm-5:00pm	Session 3 (Field Trips)
6:00pm-9:00pm	Working Dinner

Day 2

8:30am-9:00am	Breakfast
9:00am-9:30am	Recap from Previous Day
9:30am-10:30am	Session 4 (Carousel Method for Building Approaches)
10:30am-11:00am	Coffee Break
11:00am-12:00pm	Voting on approaches
12:00pm-1:00pm	Lunch
1:00pm-2:30pm	Session5 (Framing Approaches to Research Directions)
2:30pm-3:00pm	Coffee Break with stretching
3:00pm-4:30pm	Session 6 (Research Agenda)
4:30pm-5:00pm	Wrap up

Appendix C: Attendee List

Name	Organization
Angel Arroyo-Rodriguez, AICP, RS	Ohio State University, College of Engineering and Ohio EPA
Beth Feingold, PhD, MPH, MESc	State University of NY - Albany
Brandi Schottel, PhD	National Science Foundation
Brenda Platt, BS	Institute for Local Self-Reliance
Missy Hall	Rochester Institute of Technology
Daniel Warshawsky, PhD	Wright State University
Elise Golan, PhD	USDA
Jennifer Otten, PhD, MS	University of Washington School of Public Health
Kai Robertson, MBA	World Resources Institute
Katy Franklin, BA	ReFED
Leda Cooks, PhD	University of Massachusetts - Amherst
Lesly Baesens	Denver Public Health and Environment Department
Meg Kimmel, CFRE	Maryland Food Bank
Nicole Civita, LLM, JD	University of Colorado, Boulder
Nora Goldstein, BA	Biocycle
Norbert Wilson, PhD, MSc	Tufts University Friedman School of Nutrition Science and Policy
Shannon Kenny, MEM	Environmental Protection Agency
Yvette Cabrera, MS	Natural Resources Defense Council - Food Matters Cities Program
Zachary Tofias, MBA	Food, Water and Waste at C40 Cities Climate Leadership Group
Marie Mourad, PhD	Green Mary
Jessica Oehman	Rochester Institute of Technology
Melissa Terry	University of Arkansas
Eli Yewdall, MS	ICLEI USA
Kelsea Schumacher, PhD	Portland State University, Institute for Sustainable Solutions
Elaine Blatt, MA	State of Oregon, Dept. of Environmental Quality
Rhodes Yepsen	Biodegradable Products Institute
Sarah Buzogany, MS	Baltimore City Dept of Planning
Marie Spiker, PhD	Academy of Nutrition and Dietetics Foundation
Jonathan Deutsch, PhD, AOS	Drexel University
Genee Smith, PhD	Johns Hopkins Bloomberg School of Public Health

Anne Rosenthal, MPH	Farm to School Baltimore City
Lucyna Kurtyka, MS	Foundation for Food and Agriculture Research
Denise Osterhues	Kroger Supermarkets
Liz Marchetta, MPH MBA	Baltimore City Schools
Ava Richardson, MPH	Baltimore City Department of Planning
Brian Roe, PhD	Ohio State University
Kat Klosek, MPP	GovEx – Johns Hopkins
Laura Moreno, PhD	University of California - Berkeley
Roni Neff, PhD	Johns Hopkins Bloomberg School of Public Health
Sauleh Siddiqui, PhD	Johns Hopkins Whiting School of Engineering