## Urban food waste solutions from farm-to-fork: A conference for advancing sustainable urban systems (SUS) research networks

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**Summary**
Faced with a growing population and a shrinking pool of natural resources, urban areas face an unprecedented challenge to provide a resilient food supply. This challenge is made even more complex by the vast resource consumption and resulting waste generated across the food supply chain. Transforming a wasteful, inefficient urban food system into a sustainable, regenerative urban resource will require researchers and stakeholders to co-develop knowledge together. They will need a deep understanding of both the fundamental drivers causing food to be lost along the food supply chain and novel solutions for reducing these losses and recovering energy and value from inevitable wastes. Sustainable urban food solutions require novel research approaches, organized under the principle of convergence. This approach integrates knowledge and methods across disciplines, and carried out via collaborations between scientific researchers and stakeholders in the food supply chain.

Our Sustainable Urban Systems (SUS) workshop aimed to catalyze new collaborations, provide a platform for exchanging knowledge across fields, and establish a sustainable urban systems research agenda. Our workshop was organized around the specific and compelling problem of sustaining the urban food system by minimizing and managing food waste for broad social, economic, and environmental benefit. Key outcomes were:

1) Creation of a shared understanding of food waste challenges at the urban scale, informed by individuals and organizations representing varied disciplines, perspectives, regions, and sectors;
2) Identification of fundamental, boundary-spanning research questions that can be addressed through new research collaborations across disciplines;
3) Establishment of interdisciplinary research networks that are poised to begin and to grow new transformational collaborations.

**Background**
In the next 30 years, the global population concentrated in urban areas is expected to double [1]. This trajectory has the potential to create immense social, economic, and environmental impacts, but it also presents an opportunity for transformative solutions to enable sustainable urban systems. Food is at the heart of both these sustainability challenges and opportunities. A safe, stable, and nutritious food supply is essential to ensuring the health and well-being of urban populations. Yet the current urban food supply chain is not up to this challenge; it is expensive, inefficient, resource-intense, and ecologically damaging at local and global scales.

Food production consumes up to 20% of the national energy budget [2] and 50% of freshwater withdrawals annually [3], and returns nutrient-laden effluents into vulnerable ecosystems. The food supply chain contributes up to 15% of global greenhouse gas releases [4,5], but is increasingly vulnerable to climate change [6]. Unfortunately, 30-50% of food produced using these vast resources is never consumed, due to crop losses and commercial and consumer wastes, amounting to over 1.3 billion tons of food waste per year [7].

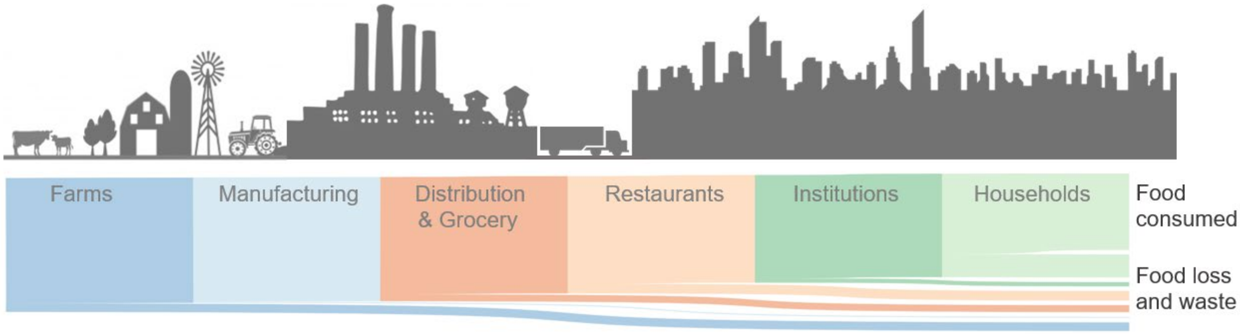


Figure 1: Food loss and waste along the urban food supply chain, from “farm-to-fork” [8]

These losses prevent food from reaching urban populations and create new impacts that ripple across cities and surrounding rural regions. Urban food waste is managed predominantly by landfilling, which leads to added cost, energy use, and greenhouse gas emissions, particularly methane, released as food waste degrades in landfills [8]. Food waste management magnifies impacts from urban water and wastewater infrastructure and transportation for waste collection and hauling. Even though 70% of food is consumed by urban populations [9], attendant ecological, health, and economic impacts are felt by teleconnected rural systems from which food is produced and to which waste is often sent for disposal.

Much of the food waste stream is not, in fact, “waste,” but edible food that could be used to alleviate urban food insecurity. Efforts to “rescue” excess foods using technology (e.g. apps) and community partnerships do exist in some urban areas. However, there is often a mismatch between donated foods and nutritional needs of receiving populations, particularly considering the related goal of improving urban health outcomes. Avenues also exist to recover the energy and resources embedded in wasted foods via composting or anaerobic digestion, which have the potential to provide clean energy and resources that urban areas require. Yet there are steep economic and technical hurdles to widespread adoption of these alternate pathways and the many novel food waste valorization technologies that are rapidly emerging.

**Vision**

Transforming the food supply chain is a critical step towards achieving sustainable urban systems (SUS). Such a transformation would: 1) maximize efficiency and prevent losses in the food supply chain, so that nutritious food actually reaches the population that needs it; 2) recover the energy, water, and nutrients contained within unavoidable food waste and return the produced bio-energy and value-added products for use in other urban systems; and 3) improve the overall social, economic, and environmental performance of the entire urban food system.

Sustainable food systems are not only a fundamental part of SUS, they are also a compelling lens through which to advance the convergent science and discovery of the SUS research agenda. Understanding fundamental drivers of urban food loss and waste requires systematic investigation and modeling of complex, dynamic, and still poorly-understood urban systems interfaces that lead to unsustainable outcomes. Food loss and waste is influenced by complex stakeholder interactions within the urban scale and across urban-rural boundaries. Solutions to urban food waste challenges will be paralleled by transformation of legacy urban systems including energy, transport, buildings, water, governance, education, and community and business engagement.

**Workshop Goal**

Achieving this ambitious vision will require a novel approach to research that meaningfully integrates insights from multiple disciplines and from engaged stakeholders. This SUS Workshop was organized with the goal of creating three foundational elements for convergent SUS research described by the recent ACERE report [1]:

1) A networked community of researchers working across disciplinary boundaries to create novel methods, models, data sources, scientific discoveries, and innovative solutions;.
2) A shared understanding of sustainability challenges co-developed by academic research and expertise of stakeholders embedded in urban food systems.
3) Deep integration of knowledge and research approaches across disciplines to create fundamental advances that can be brought to bear on the food waste challenge and yet be transferable to other complex urban systems.

The SUS workshop was organized accordingly to meet these goals. The 47 participants came from across the United States. Participants from academic disciplines included people in science, engineering, economics, business, policy, social science, education, public health, computer science, architecture, and design. Participants from non-profit, consulting, business, government, non-governmental organizations, entrepreneurial, and education sectors also participated. People from all parts of the food supply chain were included, from farming and food production and retail to food rescue, waste collection, hauling, and recycling.

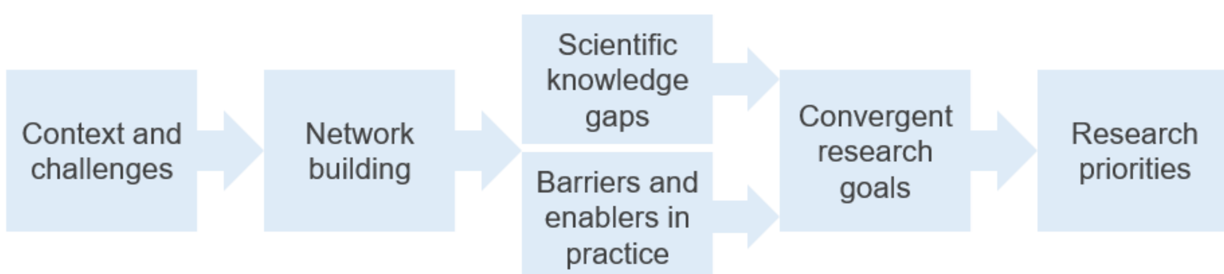


Figure 2: Overall workshop organization, which emphasized knowledge co-creation among convergent networks of academic researchers and food system stakeholders

**Key Findings**
The workshop findings summarized below (Figure 3) focused on research priorities in three dimensions:

1) priority research needs on innovative, interdisciplinary solutions that have the potential to transform the urban food system;
2) research to fill data gaps and address systemic barriers and enablers that must be addressed for these solutions to be realized; and
3) research to tackle fundamental, cross-cutting challenges that are at the heart of sustainable transformations in urban systems.

The details provided for each dimension were synthesized from content analysis of workshop materials, including presentations, breakout group discussions, interactive polling, diagrams constructed by groups, and specific ideas and research needs identified during the workshop.

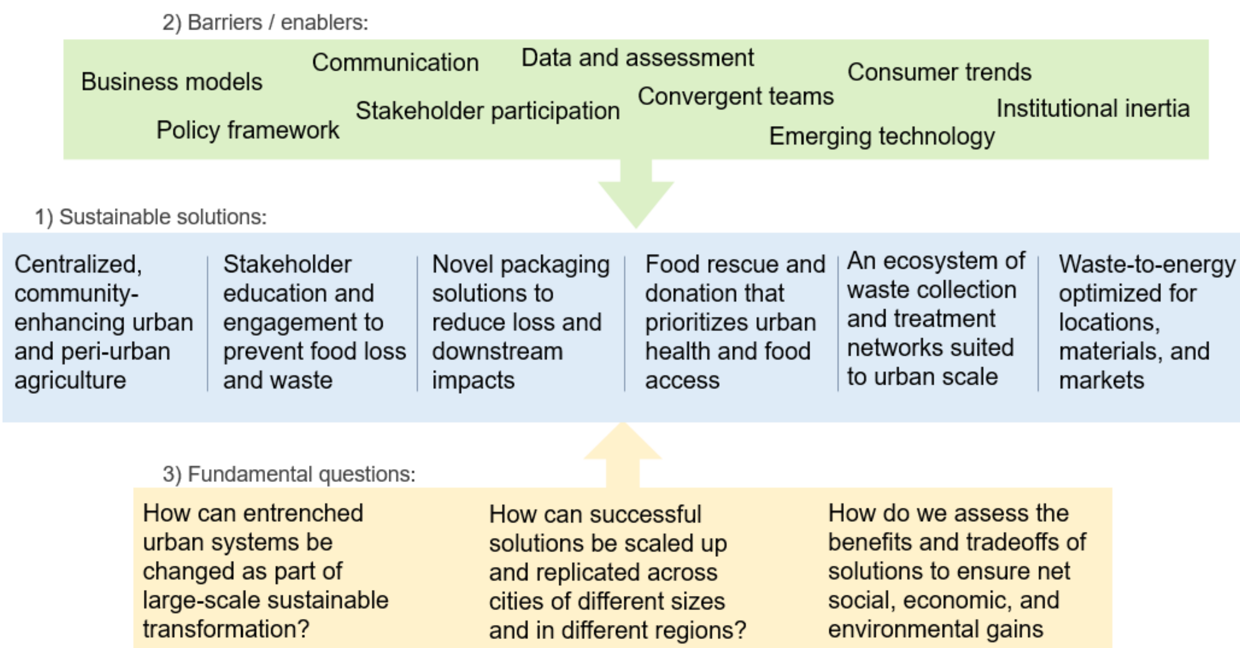


Figure 3: Overview of Key Workshop Findings

**Theme 1: Convergent research towards sustainable solutions**
A mid-workshop poll offered to all participants via the sli.do platform asked “What is the most critical challenge that needs to be addressed to advance sustainable urban food waste systems?” with five potential responses. Polling results, shown below in Figure 4, were divided between measures aimed at *preventing* and *reducing* food losses, so that more produced food can actually reach intended urban residents, and measures aimed at *sustainably managing* unavoidable wastes to return value back to urban and connected rural regions.

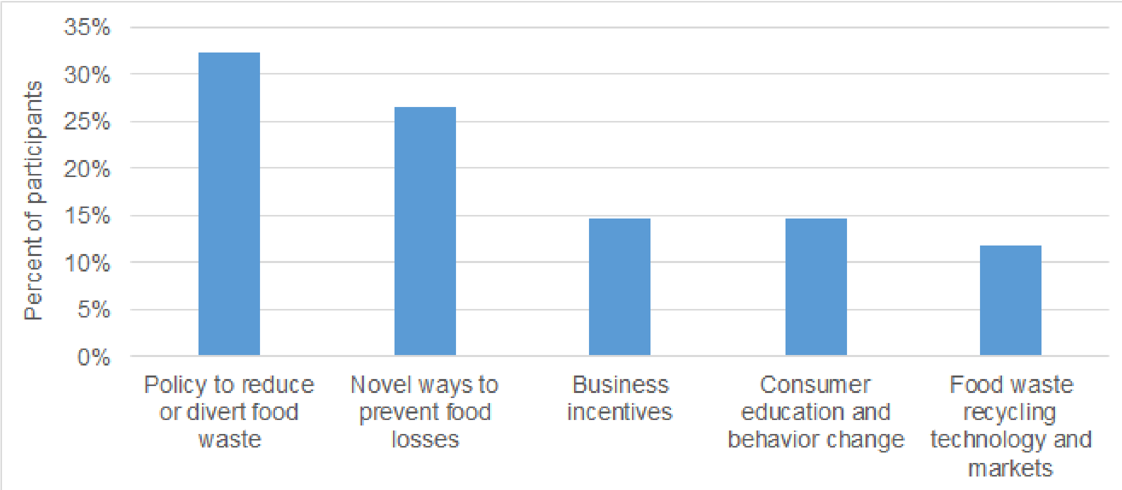


Figure 4: Participant poll on critical challenges for sustainable urban food waste management

Participants used this framing during interdisciplinary breakout sessions aimed at brainstorming and refining future convergent *research priorities* that could lead to innovative solutions along both dimensions of food waste prevention and management. Six promising solution spaces, which span the entire food supply chain, are detailed further below. These solutions came directly from

**1-1: Centralized, community-enhancing urban and peri-urban agriculture**
Urban agriculture includes growing, processing, and distributing foods in or near urban centers, including peri-urban spaces. Workshop participants identified 'urban ag' as having the potential for reducing food loss from harvest and transport and providing a secure, nutritious food supply with co-benefits for urban health and resilience. Discussions were enhanced by a presentation from Aerofarms Chief Science Officer Ed Harwood and a tour of RIT's vertical "Farm in a Box."

Figure 5: Tour of RIT Farm in a Box, led by vertical farming expert Dave Brault

Despite the promise of urban agriculture, participants raised issues about key technical, economic, and social knowledge gaps surrounding such a transition:

| Challenge | Research Need |
|---|---|
| Widespread adoption of urban ag will shift spaces and people engaged in food production and distribution | ● Models to study diffusion of innovation to risk-averse food producers and potential economic implications<br>● Analysis of economic and labor impacts between urban and rural workforces<br>● Assessment of supply-demand to guide production volume and timing |
| Feasibility and efficiency of urban agriculture varies significantly by crop | ● Empirical analysis of environmental conditions, nutrient, light, and water needs, and crop yield across urban agriculture systems<br>● Models of the impact of urban agriculture crops on the food production system and traditional agricultural production<br>● Environmental assessment of resource and waste impacts |
| Urban production still requires storage and packaging to minimize degradation and nutritive losses | ● Creation and analysis of novel packaging, distribution, and cold-chain solutions (discussed further in 1-2; it is critical these two innovations co-evolve to optimize performance of both)<br>● Testing food labeling and quality / safety detection methods to better inform and engage consumers in sustainable outcomes |

**1-2: Stakeholder education and engagement to prevent and minimize food loss**

The largest fraction of food losses arise during the final stages of commercial food sales and consumer food consumption. The graphic in Figure 5 underscores the importance of engaging stakeholders from these stages to realize meaningful reductions, and decrease the amount of waste actually requiring management.


Figure 6: Graphic shared during the presentation by Elaine Blatt of Oregon Department of Environmental Quality, based on survey of Oregon residents

However, participants identified the challenge that successful engagement of those with the ability to reduce these losses depends on education, messaging, buy-in, and actionable solutions, leading to key knowledge gaps:

| Challenge | Research Need |
|---|---|
| Who is actually responsible for food waste prevention and has the ability to implement solutions? | ● Analysis of institutions, bureaucratic structures, and organizations to assess how prevention is operationalized<br>● Case studies of successful business or municipal initiatives<br>● Policy and economic analysis to determine the role and mechanisms for food loss prevention (vs. management only) |
| Consumers face a complex, potentially confusing array of messages about food loss and related environmental issues | ● Testing messaging and platforms used to convey food and waste issues to consumers, particularly strategies that avoid “blame” and relate food loss to broader environmental initiatives<br>● Longitudinal studies to measure the impacts of residential communications on food loss reduction goals<br>● Community-oriented design and engagement to incorporate food access and health issues |
| There are potential “lessons learned” from analogous waste systems and international approaches | ● Case studies on food loss relative to regional differences, cultural norms, socio-economic conditions, and food access and choice<br>● Comparative analysis of food loss prevention systems with analogous waste systems (hazardous materials, e-waste, etc)<br>● International case studies of countries or regions at different stages of implementing food loss prevention efforts |

**1-3: Novel packaging solutions to prevent food loss and downstream impacts**

Food packaging was a key theme identified, due to its dual role in the food waste challenge. Packaging has the potential to reduce food waste by extending shelf life and preventing spoilage. However, packaging can also enter the food waste stream as a contaminant that limits downstream management alternatives and is rarely itself easily upcycled or converted to energy. Currently, food packaging creates negative environmental externalities without sufficiently reducing food losses.

Figure 7: Packaging contamination in food waste management systems, photos shared by Steven Sherman in his presentation at the SUS Workshop

There is significant research need at the intersection of technology and consumer understanding and acceptance of sustainable packaging solutions.

| Challenge | Research Need |
|---|---|
| Unsustainable packaging is cheap; greener packaging technology that reduces spoilage is too expensive. | ● Identifying sources of major food losses due to spoilage or poor packaging to prioritize targeted innovation<br>● Fundamental analysis of the molecular mechanisms of spoilage<br>● Packaging design that responds to shelf life, time, transit, environmental conditions for specific materials<br>● Development of low-cost bio-based packaging materials |
| Consumers perceive packaging to be "bad" (environmentally) and may make regrettable substitutions | ● Economic and behavioral analyses of consumer needs, perception, and acceptance of packaging alternatives<br>● Sustainability analysis of consumer-level packaging choices (materials, forms, single- vs. re-use) |
| Packaging enters the waste stream as a contaminant or must be removed via costly depackaging | ● Technical and economic analysis of packaging designed to degrade on the time scale of food after functional use<br>● Material flow analysis and life cycle assessment of packaging end-of-life pathways and disposition<br>● Exploration of novel, cost-effective depackaging technology |

**1-4: Food rescue and donation that prioritizes urban health and food access**

Food rescue and donation are typically touted as preferred options on the "food waste hierarchy" (Figure 8), but agencies and organizations represented at the workshop questioned whether the goals of waste management and feeding people could be conflated, particularly given the potential stigma of excess food being perceived as "waste" that is less desirable for consumption and the wide array of efforts to solve hunger, nutrition, and food security challenges outside the typical domain of waste management.

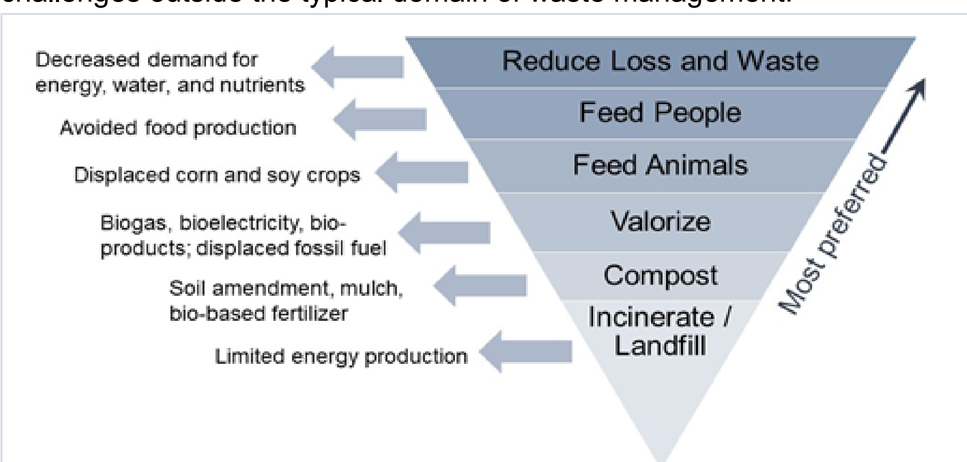


Figure 8: Conventional food recovery and management hierarchy, (Adapted from the U.S. Environmental Protection Agency)

While there is clearly a role for food rescue and donation initiatives, workshop discussions emphasized the need to re-evaluate how these efforts fit within overall sustainable urban food systems. Discussions asked how to optimize co-benefits of waste minimization, public health, and social equity.

| Challenge | Research Need |
|---|---|
| Stakeholders in food rescue sector face complex risks to engagement | ● Policy analysis to identify sources of and potential reduction mechanisms for actual and perceived risks or liability<br>● Qualitative and case study methods to assess real and perceived barriers by stakeholders<br>● Benefit-cost analysis of economic and policy incentives for participation |
| Minimizing food discards (actual "waste") that ends up in the donation stream | ● Analyzing ways to reframe and message food recovery that focus on food access and do not conflate with "waste"<br>● Creating and testing cost-effective and possibly semi-automatic ways of sorting, processing, and distributing donated food<br>● Modeling potential for policy or economic incentives that lead to misuse of food donation pathways |
| The multiple co-benefits of food rescue are challenging to quantify | ● Empirical measurements of food donated across different regions and points in the supply chain<br>● Methods and data to carry out public health, social equity, and economic benefits of food donation, across varied spatial and demographic landscapes<br>● Systems analysis of environmental benefits and material diversion potential of food rescued vs. entering waste stream |

**1-5: An 'ecosystem' of waste collection and treatment networks suited to the urban scale**
Even with the solutions discussed above, waste is inevitably generated from the food supply chain. Waste must be managed to return resources to productive use and minimize impacts of waste disposal. Waste management systems vary widely in scale and suitability to urban environments. On one hand, urban-scale, decentralized options (micro-haulers, small-scale on-site technology) may offer local investment, employment, and entrepreneurial opportunities and greater flexibility for small-medium enterprise to access food waste solutions (an example shown in Figure 9). On the other hand, collecting and hauling waste from an urban area to a large, centralized facility in nearby rural regions may be cheaper, but adds transport impacts and displaced costs and benefits, such as organic materials recovered from composting.

Optimizing both options, recognizing that not all actors will require the same scale solution, in a waste management "ecosystem" will also vary across urban regions. Industrial stakeholders at the workshop emphasized barriers to changing legacy waste infrastructure and mindsets. Little research exists on decentralized systems and their interaction and co-optimization with traditional waste management.


Figure 9: Example of interacting decentralized and centralized waste management interactions: an urban university cafeteria using a food waste pulper to remove water (and associated weight) from food waste to minimize cost and impacts of hauling to rural anaerobic digestor.

| Challenge | Research Need |
|---|---|
| Decentralized solutions are not yet proven as viable parts of waste management system | ● Case studies documenting or demonstrating the technical feasibility and economic performance of decentralized solutions<br>● Material flow analysis to quantify the extent of waste flows potentially managed by these pathways |
| Significant “inertia” behind traditional centralized options | ● Systems-level optimization of interaction and cooperation between centralized and decentralized solutions<br>● Assessment of economic incentives, financing, and policy mechanisms to catalyze adoption<br>● Decision models for food waste generators, considering financial, environmental, and social factors |
| Decentralized system deployment and scale-up may mirror lessons learned from analogous systems | ● Adaptation of ecological models to simulate the interactions between actors in waste management systems<br>● Case study analysis of analogous systems, including traditional milk runs, ice cream truck or paper route delivery, traditional recycling collection<br>● Comparative analysis across varied urban scales |

**1-6: Waste-to-energy optimized for locations, materials, and markets**
The amount, characteristics, and timing of food waste generation vary widely with size, scale, geography, demographics, economic activities, and cultural influences across urban areas. The technologies best suited to managing this waste stream will also vary, according to local or regional policy, infrastructure, siting restrictions, and cultural attitudes (e.g., NIMBY). Products recovered from food waste valorization will also change according to markets, incentives, and policy in different regions, and the relative economic or environmental benefits of generating different energy products (electricity, syngas, natural gas) and/or bio-based products (biochar, compost, specialty chemicals, recovered nutrients).

These hyper-local sources of variability create a “matching” problem for decision makers in terms of determining the best technology pathway for a specific waste in a specific urban region. Solving this matching problem will require experimental demonstration and validation of new technologies, economic and environmental analyses of alternate pathways, and models describing how stakeholders identify and implement social and/or technical practices for food waste diversion.

Figure 10: A potential waste-technology-product pathway, from the workshop presentation of Julia Levin of the Bioenergy Association of California demonstrating the use of biogas from municipal waste as a transportation fuel.

| Challenge | Research Need |
|---|---|
| Food waste variability impacts management decisions | ● Geospatial informatics about food waste generation and associated variability in location, composition, and quantity<br>● Physical and chemical characterization of food waste from major sources, based on attributes that influence technology performance |
| Waste valorization technology performance and sustainability will vary for different urban regions | ● Empirical analysis of valorization technologies, beyond lab scale and across the technology readiness spectrum, using consistent performance metrics<br>● Testing the ability of technologies to manage contaminants (e.g., microplastics) and persistent pollutants (e.g., PFAS)<br>● Assessing the integration of complementary technologies (e.g., depackaging, dewatering, gas cleaning) with valorization pathways |

| | |
|---|---|
| Optimal “matches” between waste, technology, and resultant products are not generalizable across urban systems | ● Systems models that assess economic and environmental benefits and impacts of waste-technology-product matches<br>● Spatial optimization of waste-technology-product matches for varied regions<br>● Decision models and predictive tools to analyze optimal food waste pathway without the need for extensive empirical analysis |

**Theme 2: Convergent research on sustainable food system barriers and enablers**
Research described above is necessary to advance innovative solutions for reducing food loss and managing food waste. Deploying these solutions in practice, however, requires consideration of interactions with existing urban systems and the potential barriers to be overcome and enabling systems to be leveraged. Many of these issues are captured in the above sections, but additional priority research needs were identified through workshop discussions and convergent breakout group activities:

**2-1 Business models and economic incentives**
Food losses are typically perceived as wastes with no economic value, rather than organic resources, a perception that historically has limited efforts to measure and characterize it and efforts to deploy market based solutions to reduce or manage it. Business and industry stakeholders at the workshop emphasized the challenges of entering the market and competing against traditional waste management, due to the high costs of food waste separation and hauling and low profit margins on recovered energy and products. Research needs identified included analysis of how to effectively price the externality of food waste to create incentives for minimizing losses, economic mechanisms to encourage businesses to donate healthy food, creating higher value products from waste valorization, financing mechanisms for launching waste collection and treatment infrastructure, and changing the message around food loss to emphasize organic resource recovery.

**2-2 Food and food waste policy**
With a growing number of states and cities enacting food loss and waste regulations, workshop discussion frequently turned to the role of policy in enabling urban food system transformation. A key question was how science can inform effective policy making regarding cost, efficacy, and trade-offs across the spectrum of different intervention mechanisms (mandatory vs. voluntary) and approaches (prevention vs. management). In addition, the interaction of policies related to food and food waste remains under study, even though there is significant interdependencies among food policy (related to health, safety, Farm Bill, etc.), energy and climate policy (carbon and renewable energy credits), water policy (non-point source discharges, wastewater treatment), and local regulations governing the operation of businesses and waste infrastructure within a given urban region. Nascent food waste policy would also benefit from research on parallels between food waste and analogous waste systems with a longer regulatory history.

### 2-3 Changing technology and consumer trends

The nature of food losses and wastes continues to evolve in parallel with changing consumer preferences and behaviors, such as the increased consumption of prepared/convenience foods, emergence of meal delivery services, demand for foods free of preservatives that might extend shelf life, and integration of “smart” technologies that change the ways that food is purchased and prepared. Very few studies exist that measure or model how such trends may impact ultimate losses and wastes, suggesting a critical need for future research in this area. However, scaling-up and generalizing from such studies to analyze cumulative benefit to the urban food system was anticipated to be a barrier, given the wide disparity in adoption of new technologies across socio-economic, cultural, and regional differences in urban populations, underscoring the importance of multiple urban case studies and comparisons. Discussion on this issue also emphasized the importance of interdisciplinary integration. For example, including historians on SUS projects provides expertise in using historical examples as resources for thinking through complex, emergent issues and for anticipating future scenarios.

### 2-4 Decision oriented data

The lack of high-quality, actionable data was one of the main themes across all discussions and breakout groups. Actors in the food supply chain have incomplete information about how much food loss and waste they generate or the specific costs of its management. Policy makers lack information about the capacity to donate or recycle food within a state or region, which may limit their ability to set appropriate targets. Food donation systems (donors and recipients) only have partial information about the others’ needs, such as nutritional content of excess food and dietary needs and cultural preferences of receiving populations. For all the potential solutions explored, the field lacks a shared set of metrics used to calculate benefits and tradeoffs or the data with which to make these comparisons. There is significant potential in new data collection approaches, such as crowdsourced citizen science that can provide new data streams while also educating the public on food system issues.

### 2-5 Knowledge co-creation through convergent team science

In an introductory breakout session, workshop participants were divided into random groups, where they shared their expertise associated with the food system via “lightning talks” and then used this information to generate a network model showing how a convergent research network can be seeded through deliberate interactions mapped across the food system. An example of a group’s diagram is shown below (Figure 11) to highlight the diversity of perspectives included.

This activity highlighted the potential for deep integration across disparate fields and knowledge co-creation with key stakeholders leading to new fundamental insights. But it also demonstrated the challenges of achieving this goal. The example network shown here included academics from science, engineering, health, and social science as well as stakeholders representing state agencies, private companies, and start-up enterprises. Where traditional academic research still finds collaboration across multiple disciplines challenging, the added layer of collaborating meaningfully with stakeholders outside academia adds additional complexity. Thus, creating effective SUS research networks will require parallel investigation into the tools and methods that lead to effective convergent team science.

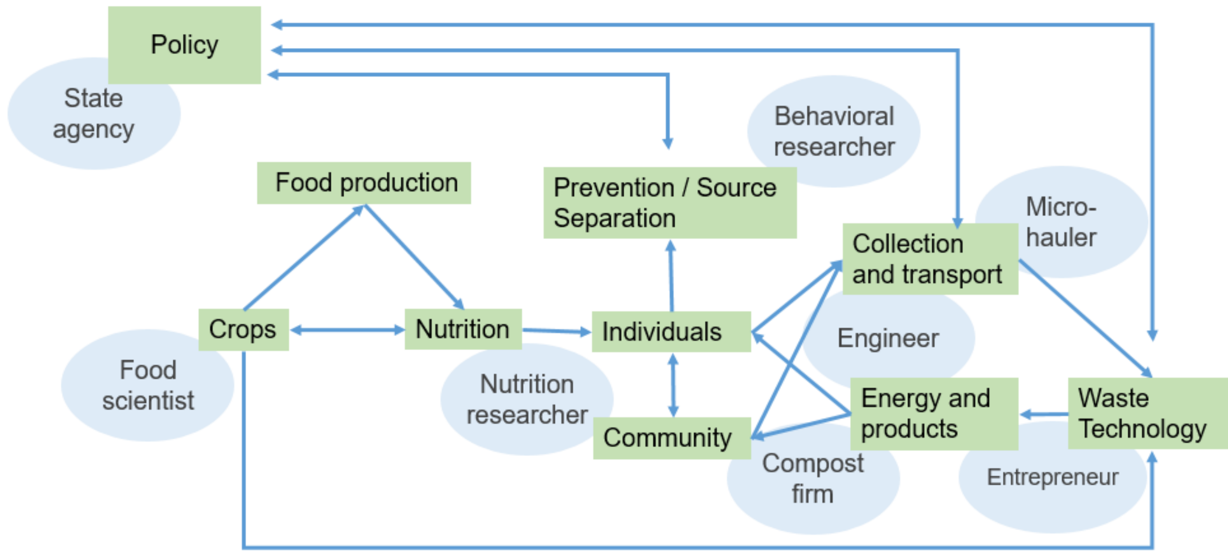


Figure 11: Example convergent network diagram, where facets of the urban food system are shown in green boxes and individual researchers and stakeholders in the group in blue ovals.

**Theme 3: Fundamental questions underlying urban food system transformation**

Across all presentations and breakout group, underlying themes repeatedly emerged during the workshop and were strongly echoed in post-workshop content and text analysis. These three cross-cutting challenges are fundamental to all of the research priorities discussed above and are necessary for transforming urban food systems towards sustainability.

**3-1 How can entrenched urban systems be changed through large-scale sustainable transformation?**

"Change" was the most common content term appearing in workshop diagrams, notes, and discussions. Participants grappled with the challenge of radically transforming unsustainable facets of the urban food system, maintaining features that are currently effective, and avoiding new social, economic, and environmental challenges. Research needs include investigation into the fundamental mechanisms, drivers, and dynamics of large-scale urban transitions and into the future-oriented scenarios of alternate transition scenarios. Specific priorities identified include studying individual behavioral change, analysis of institutions and organizational change, analyzing cases of transition within governance structures, and modeling evolution of complex adaptive systems.

**3-2 How can successful solutions be scaled up and replicated across cities of different sizes and in different regions?**

Workshop participants continually grappled with the challenge of defining what is "urban" from the standpoint of food systems and food waste, given the significant transboundary flows and urban-rural linkages. Workshop discussions underscored the caution against trying to apply global solutions to what are fundamentally hyper-local challenges.  Future research should prioritize “site specific” analyses as well as comparisons across different geographies, scales, and urban attributes. For example, more food waste may be generated in the largest cities, but solutions can be intractable due to the scale and complexity of these urban regions. On the other hand, changes across many small cities might lead to greater reduction if the smaller scale presents less barriers to implementing solutions. Future SUS and food system research must be contextualized based on the community in which this research is based.

**3-3 How can benefits and tradeoffs or food system solutions be assessed to ensure net social, economic, and environmental gains**

Recent public attention on the food waste issue has led to rapid implementation of available solutions without full evaluation of their ability to actually reduce food loss and waste or their relative benefits and impacts. The dynamic landscape of emerging technologies and changing food loss trends make it more difficult to rigorously assess potential solutions, even more so because there are no standard methods to carry out such analyses. Evaluating food system solutions has two dimensions. First is the fundamental research to measure a solution’s effectiveness, i.e., the ability to perform as intended and meet expected outcomes of reducing and managing food loss and waste. Second is the research to create and apply methods and modeling approaches to assess systems-level sustainability co-benefits and tradeoffs of implementing a potential solution. Cross-cutting both of dimensions is the attendant need to standardize aspects of these methods and the metrics they assess for comparability and generalizability across studies, which is particularly critical given the wide variability in urban systems (see point 3-2 above) that may confound interpretation of case comparisons. As our ability to quantify benefits of food system solutions improves, so will our ability to communicate these findings to stakeholders to support decisions leading to sustainable urban systems.

**Workshop Approach**

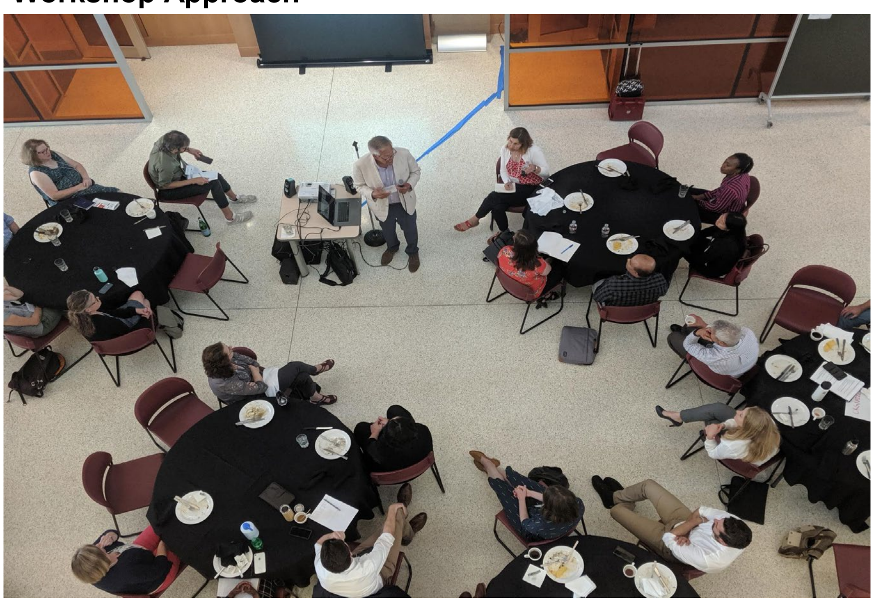

Figure 12: Working lunch presentation and discussion with Ed Harwood, Chief Science Officer of AeroFarms, a leading urban agriculture firm

The findings described above were achieved by a workshop organized around interactive sessions and activities aimed at creating shared understanding and brainstorming novel research questions:

- Context-setting presentations and discussions by researchers and stakeholders,
- Rapid introductions of participants to highlight research focus, collaborative needs, collaborative offerings
- “Convergence”-oriented break-out groups exploring how disciplines can be integrated to address research challenges
- Exploration of scenarios and data-gaps that require insight from multiple disciplines
- Construction of collaborative network diagrams and systems models
- Digital facilitation of inputs, questions, feedback using Sli.do
- Networking and informal dialog

Four break-out sessions provided the main platforms for convergence exchange and research ideation. These sessions re-shuffled participants in different disciplinary and interdisciplinary small groups around four objectives:

**Breakout 1:** Identifying how collaborative networks of researchers and partners can be formed to address the fundamental drivers of urban food loss and waste and the gaps remaining that can be filled through future partnerships and network expansion. Each interdisciplinary group identified ways that their knowledge and complementary research skills could be connected to identify novel food system solutions and offer new collaborative approaches in a convergent research network.

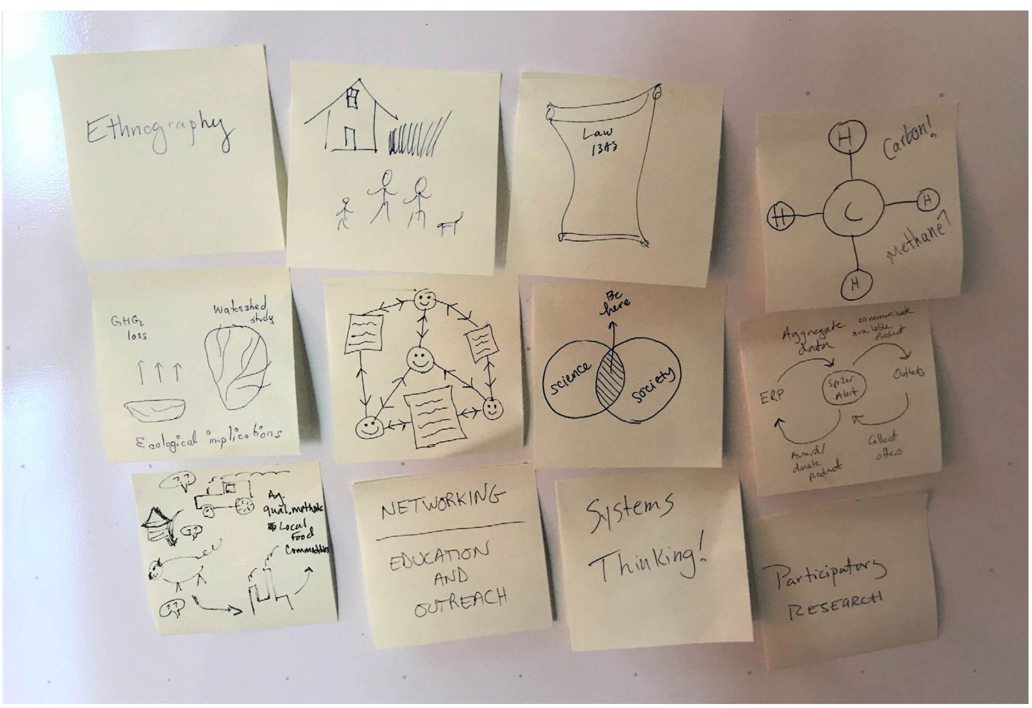


Figure 13: Notes used to graphically represent how disciplinary perspectives can converge towards research networks focused on sustainable urban food systems, from Breakout 1.

**Breakout 2:** Understanding and clarifying the fundamental research questions that excite and engage researchers working in closely related fields. Each group worked to identify the most significant fundamental challenge of their field, the methods needed to address it and their current state of application, and the barriers and data gaps to be tackled to advance knowledge in the field. An example of this brainstorming is shown below for the group focused on the challenge of minimizing losses across the food supply chain.

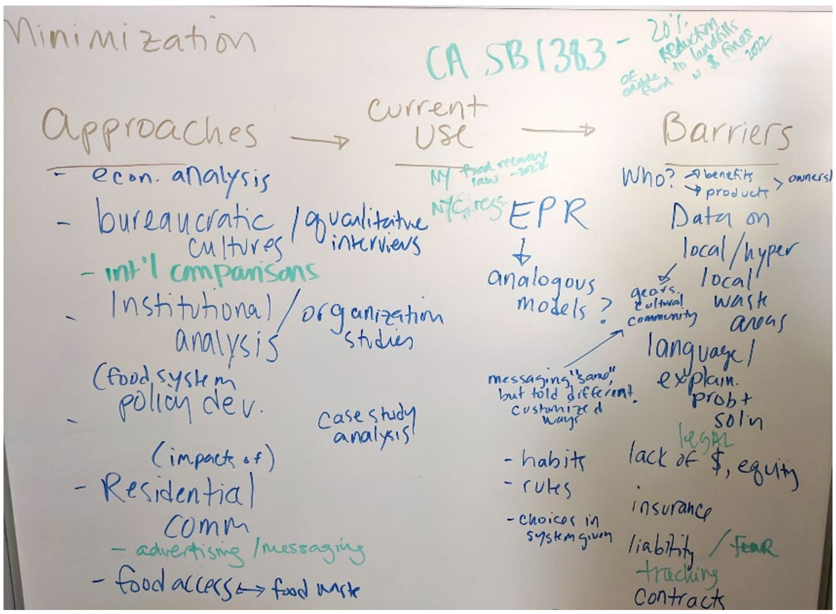


Figure 14: Brainstorming on methods, data gaps, applications, and barriers to solutions for minimizing urban food losses

**Breakout 3**: Understand how the convergence of disciplines can lead to creating portfolios of novel solutions for sustainable food systems in urban set//tings. This breakout re-configured groups into interdisciplinary cohorts organized to brainstorm research towards solutions to the challenges identified through the last two breakouts and context-setting presentations. This breakout resulted in refined problem foci that launched Breakout 4.

**Breakout 4:** Creating systems models of drivers and solutions to identified urban food system challenges. Groups built on the six key challenges identified in the past three breakouts: 1) urban agriculture; 2) sustainable packaging; 3) policy; 4) food rescue and donation; 5) decentralized food waste management; and 6) food waste-to-value. Groups constructed diagrams with their specific, fundamental problem at the center. They then identified factors influencing these problems and disaggregated them to the underlying root causes. Next, they described what a transformed, sustainable system would look like, and identified the key mechanisms expected to drive this change. Finally, they identified feedback loops and interactions expected to limit or catalyze the desired changes.

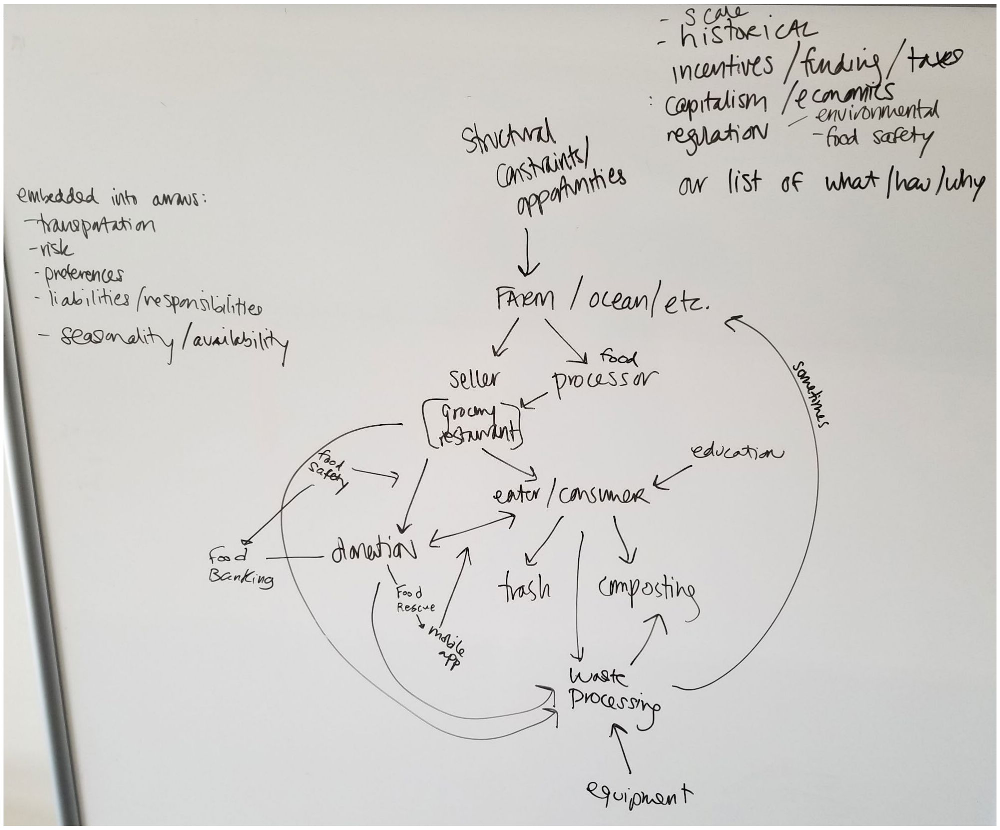

Figure 15: System diagram representing transformation of food rescue and donation solutions to minimize food loss and improve urban public health

**Conclusions, recommendations and next steps**

A safe, sustainable, secure food supply is a necessary facet of a sustainable urban system. Research described herein - and the new convergent collaborations assembled to carry out this research - offers the potential for transforming the urban food system by minimizing food losses, improving public health and sustainability outcomes, and reducing and managing unavoidable food waste. However, carrying out such research will only be possible through new mechanisms of research funding and collaboration:

1. Knowledge co-creation between academic researchers and food system stakeholders requires deep and sustained partnerships and platforms for exchanges that go beyond traditional academic structures or funding mechanisms.
2. Collaboration between vastly different yet relevant fields requires methods for effective convergent team science that are not familiar to many researchers or routinely integrated into collaborative funding streams.
3. Creating generalizable knowledge about fundamentally local systems requires embedded case studies across multiple urban systems with varied sizes, scales, geographies, socio-economic demographics, and cultural histories; a long-term research endeavor that goes beyond typical funding time frames or expected outcomes.

This workshop demonstrated how new collaborations across academic disciplines and knowledge co-created with food system stakeholders can lead to a compelling, creative, and novel research vision. Bringing this vision to bear on the challenge of sustainable urban food systems will require fundamental research advances on all facets of food loss and waste: from experimental analysis and “proof of concept” for novel technologies to models of how these solutions overcome cultural, political, and technical barriers for widespread deployment; from economic and environmental benefit-cost analyses for a single urban case study to a generalizable decision model drawing from U.S.-wide urban cross-comparisons; and from lessons learned in historical analyses of sustainable interventions to future-oriented scenarios of complex, interacting urban agents and infrastructure that will give rise to a sustainable urban food system.

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