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Findings from an Interdisciplinary Study of Food Waste Management

by Skyler Horton, Hannah Nadeau, Andrew Flynn, Taylor Patterson,
Shayla Rose Kleisinger, and Brie Berry

Abstract

This paper explores challenges and opportunities for reducing food waste in Maine through five distinct, yet interrelated, case studies. Our research focuses on how Maine might create and support a more circular food system that can reduce waste and promote the use of surplus food in agricultural and industrial processes. This stakeholder-engaged research identifies potential policy interventions across scales, but also highlights the need for more interdisciplinary research opportunities for students. Our research adopts an interdisciplinary approach, and our team members represent diverse academic backgrounds, including nursing, the human dimensions of climate change, environmental engineering, ecology and environmental sciences, biomedical engineering, and anthropology. This interdisciplinary team acts as a model for future groups interested in finding long-term answers to problems that require complex understanding and analysis.

INTRODUCTION

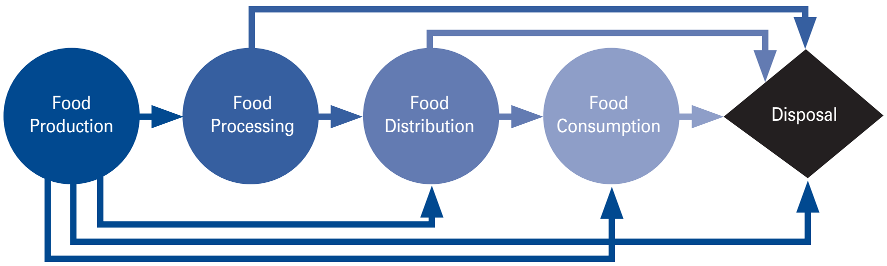
Food waste management is a significant issue in Maine and across the United States. In 2017, 65 percent to 75 percent of food waste—approximately 170,000 tons—was not recycled in Maine (Isenhour 2018). Indeed, most wasted food in the state is landfilled or incinerated (Maine DEP 2017)—processes that are expensive and environmentally taxing and that treat surplus food as a waste product, ignoring the significant inputs (water, labor, fossil fuels) that were used to produce the food as well as the residual value that remains in uneaten food. This paper, authored by an interdisciplinary team of graduate and undergraduate students, will explore the challenges and opportunities within Maine to divert food from landfills and incinerators. Here we define *food waste* as any food that is not used for human consumption during processing, sale and redistribution, and consumption (FAO 2014). We argue that food waste can be put to better use and should not be taking up space in our landfills, and we suggest several areas for further inquiry. We also outline how our interdisciplinary, stakeholder-engaged, and solutions-oriented approach offers opportunities for students, faculty, and community partners to tackle this complex challenge. In the following sections, we define the issues associated with food waste before exploring five different case studies that focus on different ways to divert food waste from landfills and incinerators in Maine.

THE COSTS OF FOOD WASTE

Food waste is economically, socially, and environmentally costly. The high water content of food means that it is heavy, making it expensive to transport. The high specific heat of food waste means that it is also expensive to incinerate because it requires a lot of heat to turn the water into steam (Miller 2015). These factors create a large economic burden on the municipal budgets of small communities in Maine. Not only is wasted food expensive to manage, it also creates an economic problem due to foregone profits, as, for example, when fresh produce spoils in grocery stores and is subsequently thrown out (Isenhour et al. 2016). Businesses and communities spend significant amounts of money on waste management (Isenhour et al. 2016), and diverting food waste from landfills and incinerators can reduce these substantial economic burdens.

Food waste causes both local and global environmental issues. In landfills, food waste degrades and generates methane using anaerobic bacteria (US EPA 2018). Methane is a powerful greenhouse gas that is much more effective at trapping heat in the atmosphere than CO_2, and 20 percent of total US methane emissions comes from landfills (US EPA 2018). Leachate, the liquid produced when rainwater percolates through waste in landfills, can carry harmful chemicals into the environment. This toxic leachate can contaminate nearby drinking water

FIGURE 1: **Linear Food System**



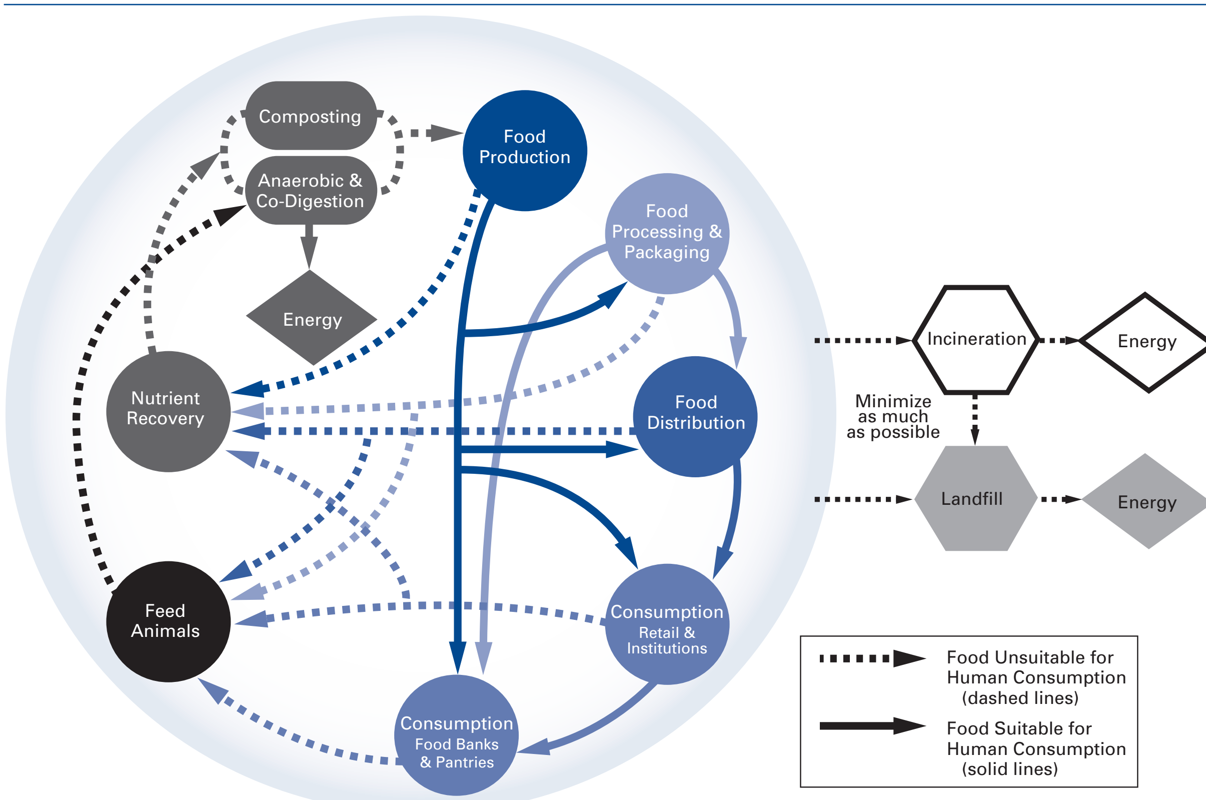
wells and cause large concentrations of toxic metals to be trapped in the surrounding soil. Incinerators create similar issues for the atmosphere. If incinerator gas is not scrubbed correctly, high concentrations of toxic substances can affect organisms living downwind of the facility.

LINEAR VS CIRCULAR FOOD SYSTEMS

The negative impacts of food waste are a product of a linear system (Figure 1), where surplus food is produced, processed, consumed, and then discarded in landfills or incinerators. Linear systems are unsustainable and resource intensive because when surplus food is landfilled, all of the energy, nutrients, and labor that went into its production is wasted. Linear systems also require a lot of inputs, especially in the form of fossil fuels for transportation and fertilizer, which produce greenhouse gas emissions linked to climate change. There are efforts in Maine and beyond to create more-circular food systems, where surplus food is reused and recycled back into the system rather than disposed of in landfills or incinerators as a way to reduce the negative impacts from current food waste management.

Circular food systems (Figure 2) recover the value in surplus food instead of burning or burying it. Processes like composting and anaerobic digestion, explored in more detail later in this article, can generate economic and environmental value. Take, for example,

FIGURE 2: **Circular Food System**



the path of an apple in a circular food system. When apples are harvested and processed, waste is generated in the form of second-quality apples or processing scraps from chopping and packaging. In a circular system, second-quality apples could be redistributed to people in need, while inedible scraps could be composted or anaerobically digested rather than discarded. The latter two processes not only reduce the amount of waste that is landfilled or incinerated, but also generate fertilizers that can be used in agricultural production and, in the case of anaerobic digestion, can produce energy that can feed back into the electrical grid.

FOOD WASTE IN MAINE

Maine's population and geography affect how waste is managed in the state. Maine is one of the most rural states in the country, and while most Mainers live in rural communities with less than 2,500 people (US Census Bureau 2012), the population is unevenly distributed across the state. Maine's rural character and low population density create challenges for managing all sorts of waste, including surplus food. The costs associated with transportation and collection of waste are particularly burdensome for rural communities because Maine municipalities are responsible for managing their local waste programs (Blackmer et al. 2015), and waste management is often one of the biggest costs for municipalities (Isenhour et al. 2016). Transporting food waste from remote rural communities to processing facilities can present logistical and economic challenges, and cost is an important consideration for determining waste management practices, particularly as many communities face declining populations and associated shrinking tax bases. While there are challenges to diverting surplus food from landfills and incinerators, there are also opportunities to reduce municipal costs and promote more-circular food systems by composting and anaerobically digesting surplus food.

With an expansive bottle bill and product stewardship programs as well as the nation's first ban on polystyrene foam (Ellis 2019), Maine has a history of leadership in waste reduction. In 1989, the state adopted a waste management hierarchy that prioritizes source reduction and material reuse over landfilling. The state also set a goal for recycling 50 percent of Maine's municipal solid waste by 1998 (MRS Title 38, §2132 1989). Although the state has yet to meet this recycling target, in the past decade there have been efforts to adopt a more circular food system in Maine, including the establishment of private commercial compost facilities, farm-based composting efforts, municipal programs at waste transfer stations and wastewater treatment plants, and a large-scale anaerobic digester. While these programs have significant potential to divert surplus food from landfills and incinerators, most rely on food inputs from industrial generators and have little involvement with households. Further, many of the recently established food-scrap-diversion companies are located in southern Maine, presenting challenges for serving the more rural northern and western areas of the state.

In 2015, Maine's municipal solid waste totaled 1,194,209 tons, of which only 3.3 percent (39,659 tons) was composted (Maine DEP 2017). While landfills and incinerators will no doubt continue to play a role in Maine's waste management landscape, there are opportunities to divert food waste from these disposal sites. Solutions must balance the need for centralized infrastructure and localized community- and household-scale models. They must take into account the economic, social, and environmental impacts of food as it moves from farms and processors to consumers. Our interdisciplinary approach is an attempt to develop solutions to the many issues associated with food waste.

AN INTERDISCIPLINARY APPROACH

We are starting to see a shift in how research is conducted in universities. This shift involves the movement towards interdisciplinary research teams in undergraduate, graduate, and professional programs (Nancarrow et al. 2013). The National Academies of Sciences define interdisciplinary research as

> a mode of research by teams or individuals that integrates information, data, techniques, tools, perspectives, concepts, and/or theories from two or more disciplines or bodies of specialized knowledge to advance fundamental understanding or to solve problems whose solutions are beyond the scope of a single discipline or area of research practice. (Andreasen et al. 2005: 2)

Interdisciplinary work can create collaborative opportunities or completely new research fields (Andreasen et al. 2005; Bader and Jaeger 2014). An interdisciplinary approach is vital to understanding the economic, social, and environmental dimensions of food waste and developing feasible solutions to the problem.

Food systems are complex and cross multiple disciplinary boundaries. By bringing together scholars from civil and environmental engineering, nursing, economics, anthropology, climate studies, and biological engineering to study food waste, we aim to provide a more comprehensive view of the issue. This approach has the potential to generate realistic solutions that can be both sensitive to the challenges Maine faces and able to build upon the state's unique resources. This article is based on five individual, yet interrelated, research projects located at different nodes along the circular food system. We explore the potential for innovative **food packaging** to reduce food waste. We address **consumption** with research that focuses on food waste in a hospital setting. To address **recovery**, we explore how risk perceptions shape the actions of composting and anaerobic digestion operators, the potential for community-composting initiatives to solve rural food waste issues, and the potential for anaerobic digestion to create multiple benefits within the state. These case studies highlight challenges and opportunities for the state of Maine as it seeks to reduce wasted food and its associated economic, ecological, and social impacts.

PAPER-BASED ALTERNATIVES TO PLASTIC FOOD PACKAGING

Background

Throughout the second half of the twentieth century, pulp and paper was the dominant industry in Maine. At peak demand, 11 paper mills were spread across the state. As of 2016, however, only six of these pulp and paper mills remain operating (https://www.bls.gov/iag/tgs/iag322.htm). Many paper companies have turned their focus to new types of products (Fishell 2014), and some are collaborating with universities in the state to explore ways the paper industry can evolve. In recent years, researchers have been developing alternatives to plastic food packaging using paper-based materials. Plastic food packaging protects food from outside contaminants and can slow food spoilage (Marsh and Bugusu 2007); however, most plastics are not biodegradable and can only protect food from contaminants temporarily. Recognizing the significant downsides of plastic food packaging, researchers have begun to explore biodegradable alternatives that can reduce packaging waste and improve the packaging material's ability to increase the shelf life of food products.

Research

The University of Maine stands as a pillar for research on pulp- and paper-based products, particularly through the Process Development Center, where a wide variety of products are manufactured and studied in a small-scale paper mill. This research focuses on cellulose nanofibrils (CNF), a product created from pure wood pulp, which is composed of cellulose and known for its antimicrobial characteristics. The Process Development Center harvests these fibers from cellulose in a mechanical grinding process. The result is a water-based, paste-like material that can be dried into thin sheets. Researchers are using these thin sheets with layers of food-grade oils with the goal of creating a biodegradable, food-safe substitute for plastic packaging. CNF sheets have demonstrated the ability to decrease water adherence, which can stop contaminants from penetrating and interacting with food products. This decreased water adherence is particularly important in the context of food waste, as it means that CNF sheets have the potential to reduce food spoilage. Further, because this packaging alternative is created without heavy chemicals (such as bisphenols used in the lining of food and drink cans), the resulting product is fully biodegradable, which has the potential to reduce overall waste generation (IPEN 2018).

This research is still in early phases, and more work is needed to understand the interactions of the packaging with food products and to stabilize the material to ensure it will protect food products for long periods. Further, because CNF is more expensive than conventional plastic packaging, there may be cost barriers to its widespread adoption among food packagers. If CNF food packaging can ensure that food remains fresh and safe for longer than plastic packaging can, however, this material has the potential to be more cost-effective than traditional plastic.

Opportunities

While CNF packaging is still in the development phase, this project indicates that it has the potential to reduce not only food waste, but also food system waste more generally. CNF packaging has the potential to offer two important advances in the context of food waste: (1) increasing the shelf life of food and subsequently decreasing food wasted due to spoilage and (2) reducing overall food system waste by offering a biodegradable alternative to plastic packaging. CNF food packaging can build on Maine's leadership in the paper products industry and its history of leadership on solid waste issues. CNF food packaging offers a unique opportunity to take advantage of an established Maine industry while reducing food waste.

FOOD WASTE MANAGEMENT IN HOSPITALS

Background

According to the American Hospital Association (AHA 2019), there are more than 6,000 hospitals in the United States; these hospitals produce more than 7,000 tons of waste *every day* (Plisko, Flora, and Cusick 2015). Maine has more than 36 hospitals, which produce more than 42 tons of waste every day. While there is research on hospital waste generally, there is little work on food waste and disposal processes in hospitals. If studies on the generation of municipal (Criner and Blackmer 2011) and institutional (Wilkie, Graunke, and Cornejo 2015) food waste are any guide, however, we expect that food makes up a significant portion of the waste generated at hospitals. This research investigated how hospitals and healthcare facilities in Maine manage food waste. Specifically, we explored the hospitals' experiences with composting and anaerobic digestion compared to landfilling and incineration.

Research

Our hospital research team conducted preliminary research with hospital professionals who are engaged in decision-making around the management of food waste at their facilities. The questionnaire focused on (1) the amount of food waste generated at the facility, (2) the processes for waste disposal, and (3) the barriers to composting and anaerobic digestion. The research team used the questionnaire to guide semistructured interviews at seven Maine hospitals. We selected hospitals for this study based on size, location, and hospital type to capture the range of food waste practices in healthcare facilities across the state. The types of hospitals interviewed fell into three categories: acute care, psychiatric, and critical access. Acute care hospitals have more than 25 staffed beds and care for all types of medical and surgical patients, whereas psychiatric hospitals deal with extended mental illnesses. Critical access hospitals are facilities that meet specific criteria: (1) greater than 35 miles from any other hospital; (2) limited to 25 staffed beds; and (3) maintain an annual average stay of 96 hours or less for acute care patients. The team interviewed nutritional and environmental service directors and managers at four acute care hospitals, two psychiatric hospitals, and one critical access hospital.

While we anticipated that most hospitals would use landfills and incinerators to dispose of food waste, five out of the seven hospitals discarded food waste via the garbage disposal, which moves food through the wastewater system. Hospitals that use the garbage disposal as their primary way to manage food waste put scraps from food preparation and uneaten leftovers from patient trays into the garbage disposal, where it is shredded and filtered out of the water along with grease. The food creates a sludge-like product, which is later removed from the grease trap, dewatered, and burned. This result is interesting as it eliminates the need for any type of weekly trash-removal service related to food waste. It does, however, create the added cost of grease-trap cleanings every one to two months depending on the amount of food being disposed. Only two hospitals did not use the garbage disposal as a main method for disposing of food waste: one hospital contracted with an anaerobic digestion company to collect its food waste, and the second placed all food waste in bags to be collected and incinerated along with other unregulated wastes produced at the facility, which is treated as municipal solid waste (MSW) and either incinerated and landfilled or just landfilled.

> Maine has more than 36 hospitals, which produce more than 42 tons of waste every day.

The questionnaire—developed with input from industry experts—included one question concerning the specific barriers hospitals face when disposing of food in a way that supports a circular food system. That is, What prevented more hospitals from composting or using anaerobic digestion? Our findings indicate that cost and procedural requirements are the biggest barriers.

Four participants reported that composting or anaerobic digestion services were developed within their hospitals, but were discontinued because the storage bins became too messy and were too heavy for staff to lift. Participants also noted that Maine's winter weather made it difficult to transport and store the food waste bins. Finally, many of these programs were reliant on individuals to take charge and keep the program running. Without these key personnel maintaining active involvement, the programs failed. Despite these barriers, five hospital representatives interviewed were willing to consider establishing or attempting to restart programs that keep food within the circular food system (Table 1).

Table 1: **Hospitals' Past, Present, and Future Participation in Composting and Anaerobic Digestion (AD)**

	Have used composting or AD in the past	Currently using composting or AD	Willing to try composting or AD again	Willing to try composting or AD for first time	Unwilling to try composting or AD
Hospital 1	Yes	No	Yes	No	No
Hospital 2	Yes	Yes	No	No	No
Hospital 3	No	No	No	No	Yes
Hospital 4	No	No	No	Yes	No
Hospital 5	No	No	No	Yes	No
Hospital 6	Yes	No	Yes	No	No
Hospital 7	No	No	No	Yes	No

Opportunities

Our preliminary findings reveal that large amounts of hospital food waste may be entering the wastewater system. The implications of this type of disposal and the effects it can have on the wastewater system are not fully understood due to limited research on the topic. A more environmentally sustainable solution for hospitals may be recovering food waste through composting or anaerobic digestion. Hospitals receive and dispose of a steady amount of food, which can create a constant supply of food waste, something processors need to maintain their systems. Our study found that despite barriers to composting and anaerobic digestion, hospitals are willing to try alternative ways to dispose of their food waste. Maine's critical access hospitals may be the ideal healthcare organizations for introducing disposal alternatives because their small size and consistent staff may promote participation in, and acceptance of, changes toward more-sustainable practices (Allen-Gilliam et al. 2016).

We believe that more research is needed to better understand the barriers Maine hospitals face when trying to reduce food waste or implement sustainable food management practices. Further research could illuminate options that hospitals might use to reduce both costs and waste. For example, the Healthcare Environmental Resource Center (http://www.hercenter.org/wastereduction/solidwaste.php) suggests that hospitals might reduce food waste by focusing on preprocessing waste, preparing less food to avoid surplus, and donating excess to food pantries or to farmers for feeding to livestock. Other hospitals have changed their entire processes for sourcing and serving food, as well as managing surplus, in an effort to improve health outcomes and reduce negative environmental impacts associated with wasted food (Eldridge 2012).

This study collected data from only seven hospitals. For a comprehensive view of food waste processes from all healthcare organizations in Maine (e.g., critical care access, acute care, extended care, and clinics), continued data collection is needed. We recommend employing strategic system-level initiatives that include education on strategies to reduce and divert food waste. The research reported here is a first step toward developing policies and procedures that are customized for healthcare facilities. A comprehensive understanding of hospital disposal practices for food waste throughout the state is essential. It is important to understand the needs of different parts of the state and to discover processes that hospitals are using successfully. Once we have achieved a complete picture, the goal of future research is to guide hospitals in decision-making with solutions that are specific to a hospital's size, location, and institutional barriers.

COMMUNITY-COMPOSTING PROGRAMS

Background

Composting is a natural process that harnesses and accelerates the decomposition of organic matter to create a nutrient-rich soil amendment. It can be used to reduce waste generation, mitigate emissions of harmful greenhouse gasses, conserve landfill space, and create a more circular food system. When composted instead of landfilled or incinerated, nutrients from food waste are returned to the soil rather than lost. Composting also helps to reduce methane emissions produced when food scraps and other organics decompose in landfills.

Research

Composting programs are an effective way to manage organics; however, there are some challenges associated with creating such programs. Our project used a single-case-study methodology to identify and overcome barriers to creating a community-composting initiative in rural Maine. Although backyard composting operations are easy to set up and require no permit, programs big enough for use by an entire community require permits, an ample amount of land, and larger equipment. Our found that the greatest barrier to starting a composting program is the initial cost. The larger equipment and construction needs, like a stable pad for the compost pile, can be prohibitively expensive. Although these fixed costs can eventually pay for themselves through the sale of the compost produced, the initial price of starting a program is high. Another issue of concern is the selection of an appropriate site for a composting program. Odors from the composting site make it important that the proposed site is far enough away from neighbors so the smell is not a nuisance.

Our applied research project worked directly with stakeholders to identify the processes of establishing a community-composting program. This project helped develop a site located on Bo Lait Farm in Washington, Maine. The owners were interested in composting as a second source of income for their family. The organic dairy farm has approximately 90 head of cattle, providing manure, a source of nitrogen, for composting. Our team worked to get grant money from the Maine Department of Environmental Protection, which made it possible for the farmers to build a gravel composting pad on their property, one of the first steps to developing a community-scale composting program.

Many farmers work full time on their farm, leaving them with limited time to haul materials and conduct community outreach. Therefore, developing partnerships is a critical step in supporting community composting. As part of our research, we identified a newly established composting company in Camden, Maine (now called Scrap Dogs Community Compost). We helped these stakeholders cocreate a mutually beneficial business plan. The owners of Scrap Dogs are responsible for hauling organics to the farm and performing community outreach, while the farmers are responsible for managing the compost pile. By working together, the partners are able to recover higher quantities of organics and provide services throughout midcoast Maine.

> Community-composting programs work with local stakeholders to find practical solutions for managing food waste.

Over the course of the project, we conducted outreach in the local community to identify generators of food scraps who might be interested in composting. We had many restaurants and other business commit to participating before the farm started accepting food scraps. Now that the site has started accepting materials, Scrap Dogs services are available for households, municipalities, local businesses, schools, hospitals, and food processors. Households pay a fee for pickup and earn credits toward compost from the program. This gives community members the option of composting without having to manage a pile themselves. We coordinated with Mid-Coast Solid Waste, the transfer station in Camden, to establish a drop-off site for organic materials, so households that don't want to pay for pickup but do want to divert their organics will soon be able to drop them off at Mid-Coast Solid Waste. This program helps the transfer station decrease the amount of materials that is landfilled, saving the town money on tipping fees. It also helps households save on pay-as-you-throw (PAYT) bags because organics can be disposed in the composting drop-off site at no cost.

Opportunities

This research project indicates that community-composting programs may be a way to reduce food waste in rural Maine. Community-composting programs work with local stakeholders to find practical solutions for managing food waste. Locally based composting projects circulate money in the community, promote community inclusion and empowerment, increase environmental awareness, build healthy soils, support local food production and food security, educate the community on composting, sustain local jobs, and strengthen the skills of the local workforce (Platt, McSweeney, and Davis 2014). These programs keep food waste in their communities because it is valued as an educational, environmental, and economic resource.

Our research identified dairy farms as potential hosts for community-composting operations. The farmers already own land, have manure that can serve as a stable base for compost, and don't have to worry about their neighbors complaining about bad odors because they are already used to the manure. Maine has 246 dairy farms throughout the state. Implementing composting programs on a dairy farm gives farmers a second source of income and a way to manage their manure, which can be mixed with food scraps to produce a soil amendment. The number of dairy farms in Maine is slowly decreasing due to the low profit margins for milk; a second source of income could help these farms stay in business.

Community-based composting programs have the potential to strengthen Maine's economy and resource stewardship. These programs employ local haulers, farmers, and outreach coordinators, which circulates money throughout the local economy. They help cut back on greenhouse gas emissions caused by organics decomposing in landfills as well as emissions from hauling materials across the state. Community-composting programs also help to create a more circular food system by cycling nutrients within the local area, instead of losing the nutrients through landfilling, incineration, or hauling them to facilities that are farther away.

Our hope is that this project can serve as an example for other communities looking to divert their organics or farmers looking for a second source of income. A key finding from this work is the importance of partnerships. Time is a major consideration when starting a program: conducting outreach into the community, applying for grants, starting a business, and hauling food waste are all time consuming. Partnerships that include community members, university researchers, and state agencies can draw on diverse expertise and support. Strong partnerships may be a determining factor in whether a community-composting effort succeeds. Partnerships can also increase the amount of participants involved in the initiative, making the program more inclusive and profitable.

FOOD RECOVERY THROUGH ANAEROBIC DIGESTION IN MAINE

Background

Anaerobic digestion (AD) is a long-established process that can reduce the volume of food scraps going to incinerators and landfills, recover renewable energy from surplus food, and generate a useful soil amendment. AD processes and technology have been around for centuries. The anaerobic digestion process operates without oxygen, using microbes to break down complex organic matter, like food scraps and manure, into a stable solid organic product called sludge. AD sludge can be dewatered and used as bedding for farm animals, while the liquid from dewatering the sludge can be used as a fertilizer. In addition, the AD process creates two major gas products: methane and carbon dioxide. Methane can be burned for heat and electrical power, or it can be compressed and filtered to use as fuel for vehicles. In addition to diverting food waste from landfills, AD can generate revenue through the sale of electricity across the grid.

Research

The AD process is not without challenges, however. AD relies on specific microbes, called methanogens, that are sensitive to changes in conditions. This research explored how different conditions in the AD process affect the stability of the system and its outputs. We created a mini-digester in a lab to test the impact of different feedstock compositions. Our results show that the digester environment has a narrow range of livable pH conditions for the microbes. Importantly, we found that the composition of the feedstock is important. We studied systems that use both food scraps and manure and found that the feedstock must have the correct ratio of food scraps to manure to keep the environment livable for the microbes. The first step in the digestion process involves fermentation, which produces acid. If there is too much food, too much acid forms, and the pH drops below the permissible range and the microbes die. In addition, the feedstock can only have a certain amount of metals, sodium, for example. If the metal concentration gets too high, it can prevent the microbes from producing methane.

Anaerobic digestion can play an important role in creating a more circular food system in Maine, but, as our research shows, access to the correct quantity and quality feedstocks is critical for maintaining successful AD systems. AD efforts also face other challenges, such as the collection and transport of food waste to the digestion site. There is a need to balance the environmental benefits of AD with the economic and environmental costs of transporting food scraps.

Opportunities

While these challenges might seem insurmountable, Maine has an existing operating AD facility, Exeter Agri-Energy, located in Exeter, Maine. Exeter Agri-Energy is a successful model of the AD process in the state of Maine. The facility has worked to balance variable feedstocks, overcoming some challenges to run a sustainable system. Exeter Agri-Energy's work shows that, based on the food waste that is being introduced, facility operators can add a certain amount of manure and buffer solution (such as sodium hydroxide, NaOH) to achieve the optimum feedstock pH and food-to-manure ratio and to avoid system crashes due to high metal concentrations and low pH.

Maine's relatively large size provides opportunities for siting AD facilities on farms, but farmers need more research-based information about AD processes so they can judge whether investing in an AD facility is worthwhile. If more Maine farmers across the state establish AD facilities, it could mitigate the issue of travel distance for waste collection and transport, which may make AD operations more profitable. In addition, research by university-industry partnerships on the AD process can result in better standards for feedstock mixtures, which, in turn, can improve the reliability of AD facilities. Although much work remains, our research represents one step toward a better understanding of AD processes and may help farmers and processors to develop their own practices.

COMPOSTING AND ANAEROBIC DIGESTION: RISK PERCEPTIONS OF PROCESSORS

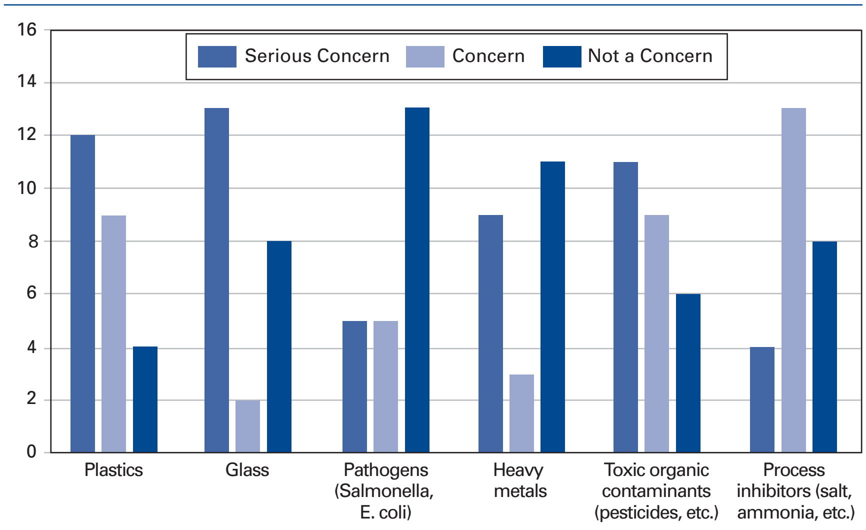
Background

For background information on composting and anaerobic digestion, please refer to the previous two sections.

Research

Although the growth of composting and AD industries across New England is good for waste management systems, we see the potential for this growth to create new risks for these industries as they integrate food waste into their systems. To create markets for the soil amendments they produce, composting and AD facilities have to ensure that their products are safe. This part of our research explored risk perceptions of stakeholders at compost and AD facilities in an attempt to identify potential barriers to safe circular food systems. We were also trying to understand the challenges associated with ensuring the safety of waste streams using diverted food. Risk perceptions are the subjective judgements people make about risks, their characteristics and their severity. Understanding stakeholders' risk perceptions can help operators

FIGURE 3: **Operators' Concerns Associated with Food Waste Contaminants**



develop risk-mitigation strategies, so they run a more successful business and contribute to a more sustainable food system. To understand risk perceptions among operators, we surveyed 117 facilities licensed to accept food waste across New England. We also conducted follow-up interviews with several facilities to gain a deeper understanding of the risks and problems that operators are facing.

Our results indicated that the operators' primary concerns were with the presence of contaminants in feedstocks—in both food waste and amendments (see Figure 3). Collected and sourced from a variety of locations and businesses, the contents of surplus food collection bins can vary greatly. Operators were most concerned with trash, sharp objects, and chemical contaminants. Many operators were less concerned with pathogen contamination than we initially expected. Operators cited economic barriers to paying for pathogen tests and noted that they felt either the risks were low enough so they didn't need run these tests or the tests were too expensive.

Because trash is so visible, it is no surprise it was one of the most common responses of survey respondents, who identified fruit stickers, plastic utensils, and straws as contamination risks. Trash presents risks to the marketability of the compost product, but it also presents safety concerns for the consumer. For example, survey respondents noted that glass cannot be removed once it is introduced into composting and digestion systems and will end up in the compost. Stakeholders were also concerned with less-visible risks. Chemicals, for example, are invisible risks that can be transported through the composting process and contaminate the soils to which they are applied. Once chemicals enter the soil, they degrade at different rates, and crops grown in contaminated soils could pose a risk to consumers (O'Connor et al. 2005).

According to our survey, risks from contaminants are contextual. Operators perceive risks differently based on their systems, feedstocks, and other factors. While compost and AD operators referenced many similar perceived risks, these risks affect these processes differently. For example, AD operators indicated concerns about process inhibitors like sodium, grease, and stringy plastics, which can ruin batches, bind pumps, and clog systems. The presence of these contaminants in feedstocks, especially in unpredictable quantities, can mean costly and time-intensive interventions. Compost operators, whose product must be perceived as safe by home gardeners and agricultural users, were more concerned with visible contaminants like plastic and glass.

Opportunities

Understanding operators' perceived risks provides insight into potential gaps between perceptions and measured risks. These gaps are important areas of future research. We will use this research into perceived risks to develop a *risk matrix*, a document that compiles all the risks that operators face along with possible mitigation strategies. The document will help reduce contamination rates of feedstocks and end products by helping stakeholders identify contamination risks for specific feedstocks and consider unanticipated risks along the composting and AD processes. Stakeholders will then be better prepared to address potential contaminants in their food waste feedstocks, which will in turn help produce higher-quality end products. Composting and AD programs across New England can potentially take significant amounts of food out of the waste stream and put them back into the food system. To support and encourage growth in these programs, researchers must work with stakeholders to understand and plan for unanticipated risks.

DISCUSSION

These diverse and yet interrelated case studies demonstrate how complex food waste issues can be. To address the barriers to and opportunities for diverting and managing surplus food, we intentionally situated our projects at multiple points along the circular food system. Our interdisciplinary approach allowed us to see the connections between different segments of the food system as well as potential disjunctures that make it challenging to divert food from the waste stream. For example, we realized it is important to understand the barriers to food waste diversion that hospital managers face if we want to engage them in successful and long-lasting diversion efforts. Similarly, if AD and composting programs are to be successful, we must attend to both the composition of the food waste and how processors perceive risks. Our interdisciplinary work is explicitly focused on finding solutions to food waste by considering the issue from multiple perspectives and grounding our research in the experiences and knowledge of stakeholders.

POLICY IMPLICATIONS

While our work ranges from nanofibrils to hospitals and food waste processors, we are all committed to applying our research to the challenges that Maine is facing. We have identified the potential for policy interventions at nodes throughout the circular food system. Policies might be implemented at the institutional or organizational level, within municipalities, or at the state or regional level. At the institution level, we see potential for hospitals, in particular, to build upon existing models (Eldridge 2012) that improve patient nutrition and reduce the cost of food service and associated food waste. At the municipal level, there are opportunities to promote community-scale composting alongside PAYT initiatives. Pairing PAYT with community composting could generate income, create jobs, and reduce municipal costs while also keeping food out of landfills and incinerators. At the state level, as many Maine mills are struggling in the face of a changing global economy, policies could assist with the transition to, and production of, CNF packaging. Finally, our work suggests that we can coordinate regionally by developing knowledge-sharing networks on potential risks and benefits of composting and anaerobic digestion. As state-level regulations on food waste disposal are taking effect across New England (Vaz 2015), it is increasingly important to coordinate policies to ensure that necessary infrastructure exists to support these initiatives and to make sure that stakeholders are aware of best practices and emergent risks. Because waste does not stay within state boundaries, policy structures at the regional level might aid our efforts to reduce food waste.

CONCLUSION

Food waste is a complicated issue, but it is not unique in that respect. Our experience with interdisciplinary research has shown us that complicated problems need to draw on different perspectives to develop actionable solutions. This experience also leads us to recommend the creation of other interdisciplinary teams to study other complicated problems. Not only have we worked across disciplinary lines, we have also collaborated with faculty, graduate students, and stakeholders. These experiences have enriched our understanding of food waste and have transformed our academic trajectories. We think that more undergraduate students should have research experiences like the one we experienced in this interdisciplinary research on food waste in Maine.

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Andrew Flynn is currently a senior majoring in civil and environmental engineering with a concentration in environmental engineering at the University of Maine. Growing up in a household that composted, the idea of reusing and recovering food waste has long been of interest to him. This research experience has given him the tools to explore a specific solution related to the recovery of food scraps and a better understanding on Maine's current food waste management system.

Taylor Patterson is a University of Maine ecology and environmental science major with a minor in economics. Sustainability issues have sparked her interest since childhood. She began researching food waste her sophomore

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