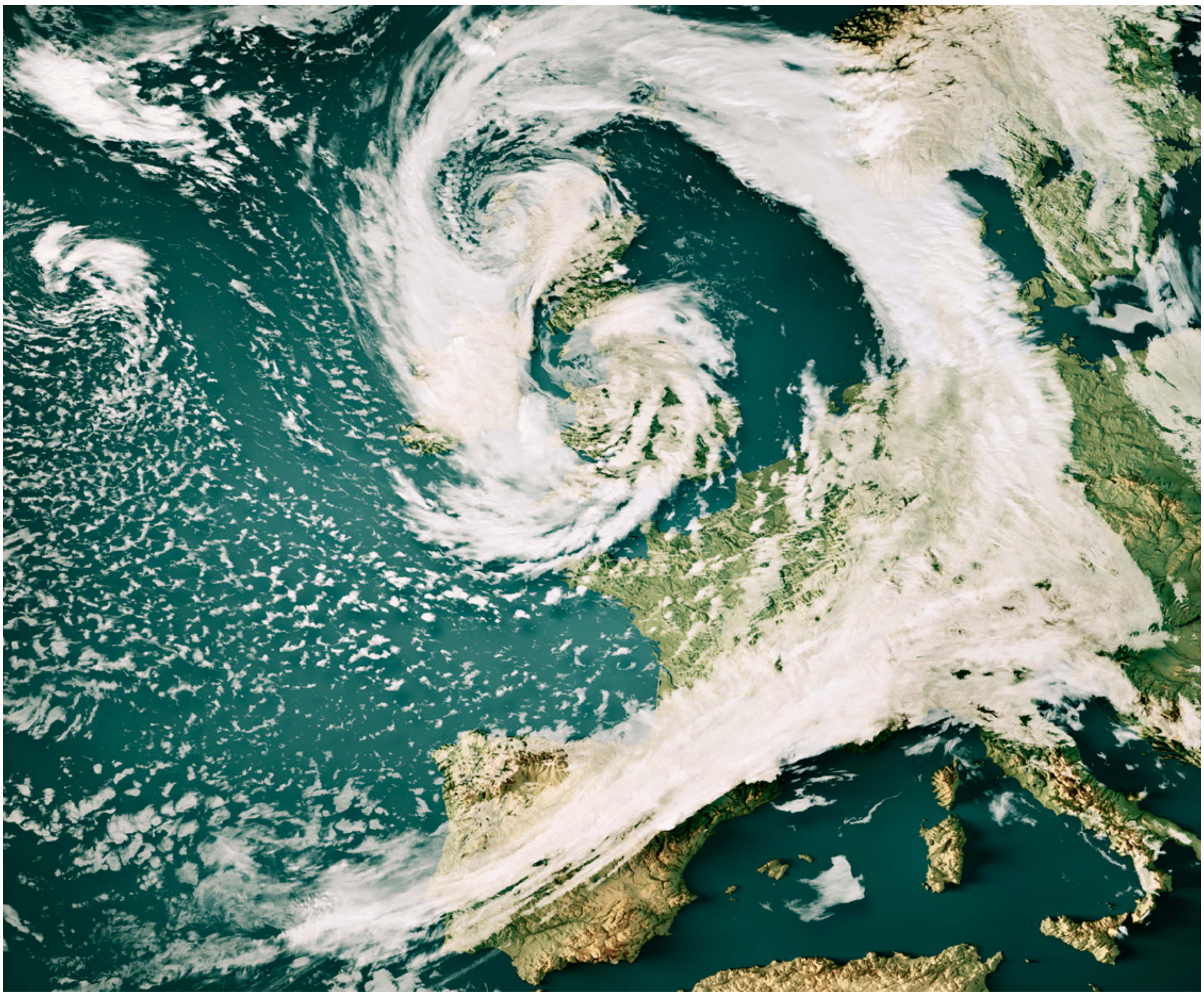
Food Science and Technology Solutions to Improve Food and Nutrition Security:

Mitigating and Adapating to Extreme Weather Conditions

feeding the minds that feed the world



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About IFT

Since 1939, the Institute of Food Technologists (IFT) has served as the voice of the global food science community. IFT advocates for science, technology, and research to address the world's greatest food challenges, guiding our community of more than 200,000. IFT convenes professionals from around the world—from producers and product developers to innovators and researchers across food, nutrition, and public health—with a shared mission to help create a global food supply that is sustainable, safe, nutritious, and accessible to all. IFT provides its growing community spanning academia, industry, and government with the resources, connections, and opportunities necessary to stay ahead of a rapidly evolving food system as IFT helps feed the minds that feed the world. For more information, please visit ift.org.

Executive Summary

For over 80 years IFT has engaged experts in food science and technology and related disciplines from academia, government, and industry to help solve many of the world's greatest food-related challenges. In 2021, IFT formed the Food & Nutrition Security Steering Committee (FNSSC) to help identify key challenges in food and nutrition security and elevate food science and technology solutions. In 2024, the FNSSC hosted their fourth virtual roundtable discussion on "Food Science & Technology Solutions for Mitigating and Adapting to Climate Change" from November 12 to 13. The goal was to identify opportunities and solutions for food science and technology to address the dual challenge of adapting to and mitigating climate change to improve food and nutrition security into the future.

Key Challenges Facing the Food System's Middle Segment

While much attention has been given to the impact of climate change on agriculture and consumer behavior, the **middle segment of the food value chain**—comprising food processing, packaging, distribution, and storage—plays a crucial but often overlooked role in shaping a sustainable future. Key challenges include:

- **Resource Inefficiencies and Fragmented Systems Thinking:** Food processing and packaging contribute to energy use, water consumption, and waste generation, yet adoption of sustainable innovations remains slow due to cost and scalability. Siloed decision-making limits interdisciplinary approaches to sustainability.
- **Systemic Vulnerabilities in Supply Chains and Food Safety**: Climate disruptions threaten food safety and production, requiring more resilient infrastructure and risk management.
- **Food Waste and Loss**: A major driver of greenhouse gas emissions, food waste remains a systemic issue due to logistical, regulatory, and consumer behavior challenges.

- **Barriers to Adopting Sustainable Solutions:** Emerging technologies such as cellular agriculture and upcycled ingredients offer promising sustainability gains, but their high costs, regulatory uncertainty, and consumer skepticism pose barriers to widespread adoption.

- **Gaps in Workforce Development and Education:** Current food science training programs often lack interdisciplinary perspectives, leaving professionals ill-equipped to tackle the multifaceted challenges of climate change.

- **Evolving Political and Economic Landscape:** Shifting funding priorities, regulatory complexities, and geopolitical tensions create uncertainty for climate-focused food initiatives.

Science and Technology-Driven Solutions

Despite challenges, food science and technology solutions can drive sustainability and climate resilience by:

- **Advancing Circular Economy Practices:** Transitioning to a circular bioeconomy reduces waste and enhances resource efficiency.

- **Enhancing Supply Chain Resilience Through AI and Data Integration:** AI-driven modeling and shared databases can predict supply chain disruptions, optimize sourcing, and improve food safety monitoring.

- **Scaling Food Waste Reduction Initiatives:** Policy reforms, incentives, and upcycling can drive food waste reduction and economic benefits.

- **Facilitating the Adoption of Sustainable Processing Technologies:** Financial and regulatory support of proven sustainable technologies can lower cost and drive adoption.

- **Modernizing Workforce and Education:** Education and training programs can equip and empower students and the workforce to drive sustainability within their organizations.

- **Addressing Political and Economic Barriers to Innovation:** Public-private partnerships, streamlined regulations, and stable investment funding can accelerate climate-focused innovation

Call to Action

These insights reinforce the urgency of integrating sustainability into every facet of the food system. To accelerate progress, stakeholders across industry, academia, and policy must take coordinated action:

- **Strengthen the circular bioeconomy** by investing in scalable solutions for upcycled ingredients and regional bioeconomy hubs.

- **Embed AI and digital tools** in food supply chains to enhance resilience and reduce environmental impact.

- **Reduce food waste at scale** by aligning regulatory frameworks, expanding redistribution networks, and improving consumer engagement strategies.

- **Expand sustainable food processing technologies** through targeted investments and regulatory streamlining.

- **Modernize education and workforce training** to prepare professionals for sustainability-driven roles in the food industry.

- **Advocate for science-based policies and long-term investment stability** to support climate-resilient food innovations.

With a commitment to innovation, collaboration, and evidence-based action, the food science and technology community can drive real, scalable solutions to mitigate and adapt to climate change. The time for action is now.

IFT Food & Nutrition Security Steering Committee (FNSSC)

Hongda Chen, PhD, USDA National Institute of Food and Agriculture, USA

Alyson Greenhalgh-Ball, Conscious Impact, UK

Lamin Kassama, PhD, Alabama A&M University, USA

Ana Maria Quirós, University of Costa Rica, Costa Rica

Geoff Smith, PhD, Essential Nutrients Foundation and Southeast Asia Region International Life Sciences Institute, Singapore

Gulden Yilmaz, PhD, Wageningen University, The Netherlands

Virtual roundtable discussion, “Food Science & Technology Solutions for Mitigating and Adapting to Climate Change”

Invited Speakers

Wayne Martindale, PhD, Founder, MPC Research, UK

Lee-Ann Jaykus, PhD, former William Neal Reynolds Professor in the Department of Food, Bioprocessing, and Nutrition Sciences at North Carolina State University, USA

Arlin Wasserman, MPH, MS, Founder and Managing Director, Changing Tastes, USA

Reza Ovissipour, PhD, Assistant Professor, Food Science & Technology, Texas A&M University, USA

Ana Maria Quiros, MS, Food Engineer, University of Costa Rica, Costa Rica

Ziynet Boz, PhD, Assistant Professor Sustainable Food Systems Engineering, University of Florida, USA

Panelists

Emily Bass, Associate Director of Federal Policy for Food and Agriculture, Breakthrough Institute, USA

Kenzie Bear, MS, Proteins Procurement Manager, Conagra, USA

Hongda Chen, PhD, National Program Leader for Bioprocess Engineering and Nanotechnology, National Institute of Food and Agriculture (NIFA), USA

Paloma Lopez, Chief Sustainability and Communications Officer, Groupe Bel, USA

Carmen Moraru, PhD, Professor, Department of Food Science, Cornell University, USA

Lara Ramdin, PhD, Chief Scientist and Latin America Ambassador, Food X Climate, USA

Moderator

Anna Rosales, RD, VP of Science and Policy, IFT

IFT Listeners/Organizers

Renee Leber
John Ruff, CFS
Lisa Sanders, PhD, RD

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Introduction

Changes in climate, extreme weather events, and natural disasters pose unprecedented challenges to global food systems that require urgent action. Droughts, floods, fires, heatwaves, and other extreme weather events disrupt agricultural production, intensify food safety risks, threaten food and nutrition security, and increase strain on already limited resources. Addressing climate change within the food system is essential to ensure a healthy and sustainable future for a growing global population.

Critical to these efforts is the "middle segment" of the food value chain, which encompasses food processing, preservation, packaging, and distribution. While most attention has focused on changes or impacts in agricultural production or consumer behaviors, the middle segment holds transformative potential for creating a more sustainable, climate-smart food system. With advancing technologies that reduce energy use, minimize food loss and waste, and optimize the use of limited resources, the middle segment can have a scalable impact on climate change mitigation and adaptation globally.

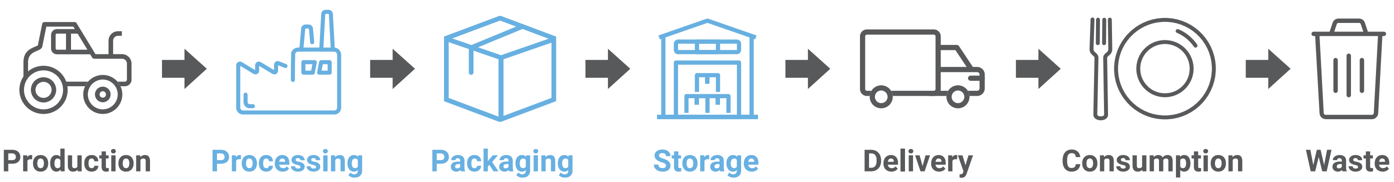

Figure 1. The middle segment of the food value chain is critical to creating a climate-smart food system.

Additionally, changing some current paradigms within the food system is vital to achieving a more sustainable and resilient food system for the future. Moving away from a linear approach and toward a circular bioeconomy designed to minimize waste and valorize byproducts will be necessary to maximize the use of limited resources. Similarly, considering the availability and accessibility of climate-sensitive foods within dietary recommendations as well as the climate impact of specific dietary recommendations is needed.

This white paper summarizes insights from leading experts on solutions and actionable strategies for the future to leverage food science and technology in climate adaptation and mitigation. It highlights the scale and urgency of the issue as well as the role of food scientists in collaboration across governments, industries, and academia to create a sustainable food system that ensures food and nutrition security into the future.

> **"Engaging for action is really important. Because at the end of the day, if we want to impact climate change, we have to act."**
>
> *Wayne Martindale, PhD, MPC Research*

Defining Terms

Climate change and sustainability are two interrelated topics that are often difficult to disengage from one another. Within the context of this white paper, these are the definitions used for climate change and sustainability.

Climate change, according to the UN, refers to "the long-term changes in the Earth's climate that are warming the atmosphere, ocean and land" (1). These changes cause extreme weather events and impact the ecosystem balance that supports life, biodiversity, and health.

Sustainability is "meeting the needs of our current generation without compromising the ability of future generations to meet their own needs" (2).

Both terms are used throughout this paper as sustainable food production must consider impacts on the environment and climate as outlined in the FAO's sustainable food value chain framework (Figure 2) (3).

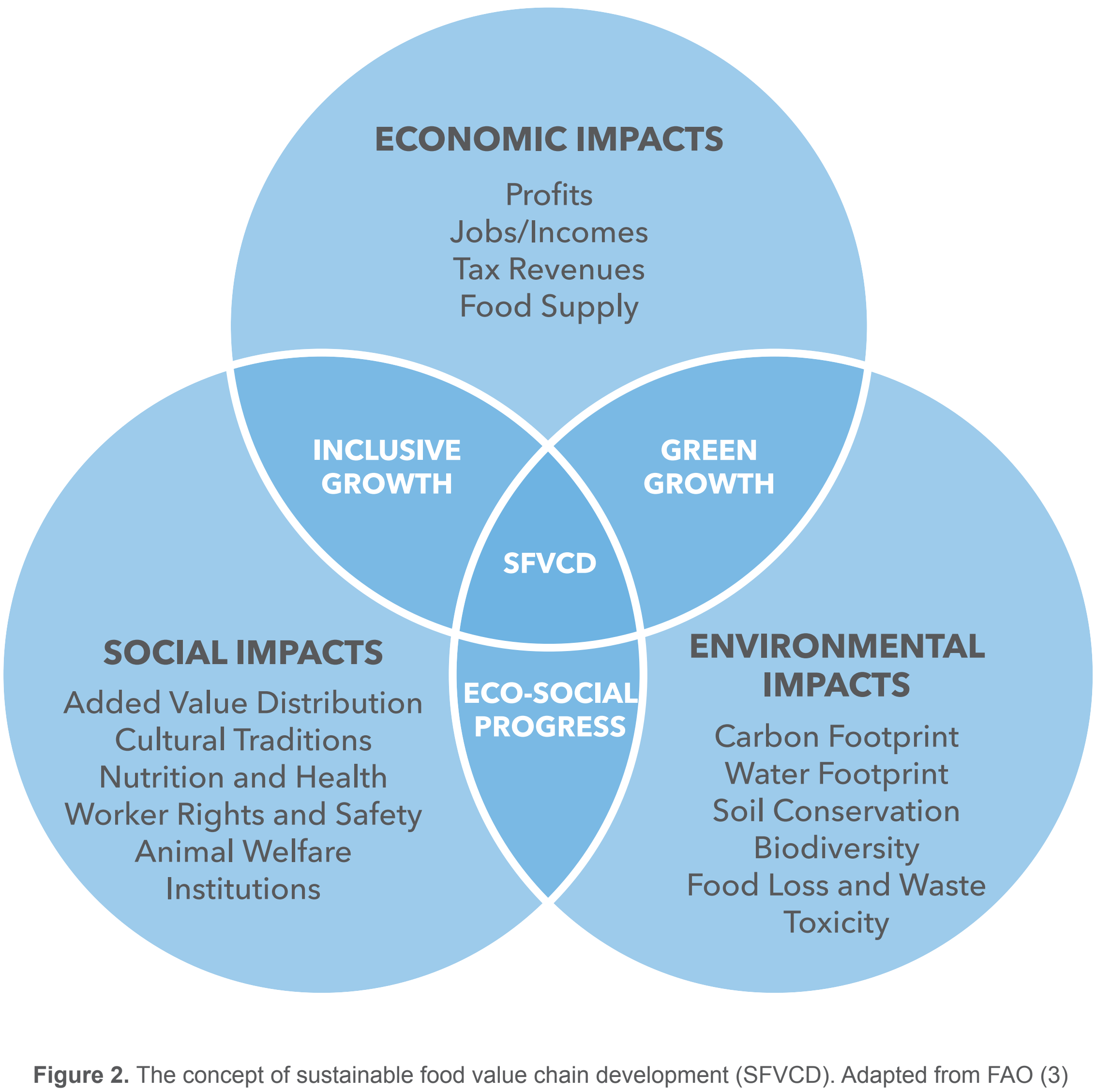

Figure 2. The concept of sustainable food value chain development (SFVCD). Adapted from FAO (3)

Challenges for the Middle Segment to Mitigate and Adapt to Changes in Climate

1. Resource Inefficiencies and the Need for Systems Thinking

Food systems are resource-intensive, with agriculture accounting for the majority of resource use and greenhouse gas (GHG) emissions. While food processing and packaging contribute less directly to these impacts, they still present opportunities for improvement, particularly in reducing energy use and waste. Packaging, for example, plays a crucial role in preserving food and reducing waste but often relies on resource-intensive production processes and can generate pollution. Additionally, some processing methods, such as thermal and refrigeration technologies, are energy-intensive and contribute to the overall environmental footprint of the food supply chain. This highlights the need for innovations that reduce resource use without compromising food safety, quality, and availability.

The global food system is large and complex, with numerous sectors that often operate in silos, addressing problems specific to their domain without considering the interconnected nature of the system. This lack of integration can exacerbate resource inefficiencies and limit opportunities for systemic improvements. For example, citrus product manufacturers in Florida and winemakers in California must contend with byproducts from their production processes. These often end up wasted due to the lack of processing systems that can handle the heterogeneity of the biomass created even though they have potential to create value-added products. Another example of a lack of systems thinking can be seen in some dietary guidelines and nutritional advice. The Mediterranean diet is frequently recommended and lauded as one of the healthiest diets, yet its key components—such as olives, olive oil, and tree nuts—come predominantly from five small growing regions that are highly vulnerable to climate change. Promoting such diets without considering the sustainability of their production under shifting climatic conditions can inadvertently exacerbate resource pressures and regional vulnerabilities. These challenges highlight the need for a paradigm shift toward integrated systems thinking that encompasses resource use, waste management, and sustainability across the entire food supply chain.

2. Systemic Vulnerabilities in Food Production, Supply Chains, and Safety

The global food system is increasingly vulnerable to disruptions from extreme weather events, such as hurricanes, droughts, wildfires, and floods, which are growing in frequency and intensity due to climate change. These events threaten agricultural yields, disrupt supply chains, and jeopardize food security for millions. For example, the Mediterranean growing regions—critical for crops like olives and tree nuts—are warming 20% faster than the global average. These regions face prolonged droughts, wildfires, and soil salinization, all of which reduce productivity, strain supply chains, and contribute to bad business practices, such as adulteration of high-value products like olive oil. For food manufacturers, severe weather events like hurricanes or tornadoes have the potential to take out manufacturing facilities or destroy or contaminate crops intended for use in foods. Many of these climate-related vulnerabilities are not being integrated into risk management structures in major food companies, yet food manufacturing serves as a major control point in the entire food system where innovation, sustainability, and resiliency can be embedded.

> Mediterranean growing regions are basically on the front lines of climate change, making growing conditions difficult and dramatically reducing productivity. Yet some of the most popular dietary advice given by the professional nutrition community is urging people to eat a diet that may be exacerbating the impact of climate change and increasing competition for culturally appropriate foods that are in dwindling supply.
>
> *Arlin Wasserman, PhD, Changing Tastes*

Food safety risks are deeply intertwined with systemic vulnerabilities. Changes in temperature and precipitation patterns can impact the prevalence, growth dynamics, and persistence of pathogens as well as their pathogenic potential, thus increasing the risk of foodborne illness. For example, warming oceans can increase the growth of pathogenic Vibrio and fluctuating precipitation can increase mycotoxin contamination in crops. Catastrophic events, such as hurricanes, can compromise water systems, increasing contamination risks for agricultural products. Despite these risks, food safety remains a poorly researched area within the broader base of climate research, and there is limited integration of resilience planning across supply chains to mitigate these vulnerabilities. These challenges continue to leave food systems exposed to disruptions and highlight the urgent need for coordinated action to address interconnected risks.

> Water is food and food is water. You cannot have safe food if you do not have safe water.
>
> *LeeAnn Jaykus, former William Neal Reynolds Professor in the Department of Food, Bioprocessing, and Nutrition Sciences at North Carolina State University, USA*

3. Food Waste and Loss Across the Supply Chain

Food waste and loss represent one of the most significant challenges to global sustainability, contributing an estimated 8–11% of GHG emissions. In high-income countries, the majority of food waste occurs at the consumer level, driven by behavioral patterns and logistical inefficiencies. In contrast, in low- and middle-income countries, food loss primarily occurs upstream due to field losses and inadequate storage, transportation, and processing infrastructure.

Food processing plays an essential role in minimizing food waste by extending shelf life, maintaining food quality, and ensuring safety from production to consumption. Techniques such as thermal processing, drying, fermentation, and emerging technologies like high-pressure processing and microwave-assisted sterilization can reduce spoilage and improve nutrient retention, especially in perishable and seasonal foods. These preservation methods help stabilize the food supply, reduce post-harvest losses, and enable more resilient food systems, particularly in times of disruption. While current technologies have made significant contributions, there remains room for continuous improvement, particularly in scaling sustainable methods and increasing access in low-resource settings. For a more comprehensive review of how food processing supports waste reduction and sustainability goals, see IFT's white papers on "Reducing Food Loss & Valorizing Food Processing Side Streams" and "Sustainable Production of Nutritious Foods Through Processing Technology."

Food waste is also not frequently considered when making dietary recommendations or giving nutrition advice. For example, many "low-carbon" diets emphasize fresh produce, which may be beneficial nutritionally, but tend to result in higher food waste due to perishability and inedible portions. These dynamics highlight the importance of assessing the entire system to develop balanced and effective strategies that consider food waste.

Inefficiencies in resource utilization compound the problem. Byproducts from food production, such as bones, skins, and crop residues, are often discarded despite their potential for valorization. However, it is important to acknowledge that waste streams are not always consistent or predictable. Their heterogeneity often poses challenges for product development, as existing systems are optimized for uniformity, consistency, and efficiency. Collaborative efforts across the supply chain to valorize byproducts and minimize waste are critical, but progress has been slow due to a lack of coordinated strategies and infrastructure. Addressing these challenges requires both technological innovation and shifts in consumer and industry behaviors to create a more efficient and sustainable food system.

4. Barriers to Adoption of Sustainable Solutions

The adoption of sustainable technologies and practices is often hindered by significant economic, cultural, and regulatory barriers. Emerging technologies such as cellular agriculture and precision fermentation hold promise for reducing GHG emissions and resource use, yet their current high costs and scalability challenges prevent widespread implementation. However, substantial progress has been made toward lowering cost—cultivated meat has decreased from $300,000 per burger in 2013 to less than $40 today—but continuing progress is necessary to achieve mass-market adoption. Funding gaps also compound these challenges, particularly for startups transitioning from R&D to commercialization, creating a "valley of death" where promising innovations fail to scale.

Consumer awareness and behavior further complicate the adoption of sustainable solutions. Cultural preferences and misconceptions about processed foods can create resistance to innovations like alternative proteins and foods with longer shelf-life, even if these options are more sustainable and reduce waste. A lack of coordinated messaging across industries and policymakers further limits the ability to build public and industry support for sustainable practices.

Regulatory barriers also hinder the adoption of sustainable practices. For example, the lack of incentives or liability concerns prevents broader adoption of food waste reduction initiatives, such as donating leftover restaurant food to homeless shelters. Additionally, compliance with evolving regulations, such as the European Green Deal initiatives, demands real-time, accurate reporting of carbon, water, and biodiversity metrics, which poses significant challenges for food companies. These regulatory requirements often strain resources and limit the ability of smaller companies to participate in sustainability efforts.

5. Workforce Development and Education Gaps

The complexity of modern food systems demands a workforce equipped with interdisciplinary skills and systems thinking, yet current education and training programs often fall short. Food scientists and technologists are typically trained within narrow disciplinary boundaries, limiting their ability to address multifaceted challenges such as climate adaptation and circular bioeconomy integration. This siloed approach hinders collaboration and innovation, particularly in addressing the interconnected issues of resource use, waste management, and food safety.

Early-career professionals often lack exposure to real-world systems, such as community food networks, farm operations, and supply chain dynamics. This disconnect weakens their understanding of how theoretical knowledge translates into practical solutions. Workforce engagement within the manufacturing sector also remains underutilized as a driver of sustainability. Embedding sustainability metrics into workforce practices has the potential to improve resource efficiency and reduce environmental impacts, yet such initiatives are rarely prioritized. Bridging these gaps requires rethinking education and training paradigms to integrate systems thinking, interdisciplinary collaboration, and hands-on learning experiences.

6. Evolving Political and Economic Landscape

The political and economic landscapes present both challenges and uncertainties for advancing climate-related food initiatives. Shifting funding priorities, such as a focus on renewable energy over food systems, risk diverting resources away from critical agricultural and food technology research. Additionally, conflicting narratives about climate change and food systems undermine public trust and engagement with science-based solutions.

Geopolitical factors further complicate progress. Trade disruptions and policy shifts affect the stability of food systems and the ability to implement long-term sustainability strategies. For example, startups and small businesses face growing difficulties in securing funding as investors pivot to other sectors, while governments grapple with balancing immediate needs against long-term climate goals. Advocacy efforts are essential to protect science-based policies and ensure sustained investment in food-related climate solutions, but these efforts must contend with a fragmented political and economic environment. Without coordinated action, the evolving landscape threatens to stall progress and worsen existing vulnerabilities.

The challenges outlined to this point reveal the multifaceted and interconnected nature of issues facing food systems in the context of a changing climate. Addressing these challenges requires innovative, collaborative, and systemic approaches that balance environmental sustainability, economic feasibility, and social impacts. In the following sections, we explore solutions discussed in the roundtable to build a more resilient and sustainable global food system.

Solutions for the Middle Segment to Mitigate and Adapt to Changes in Climate

1. Address Resource Inefficiencies and Foster Systems Thinking

Promote Circular Economy Practices

Transitioning toward a circular bioeconomy is pivotal for minimizing resource inefficiencies and valorizing agricultural and processing byproducts (Figure 3). One of the key principles of a circular bioeconomy is the cascading use of biomass to create multiple value-added products, utilizing as much as possible and landfilling as little as possible. A recent report from the Foundation for Food and Agriculture Research (FFAR) in partnership with Schmidt Futures identified opportunity areas to enhance the use of biomass as an alternative to fossil-based resources (4). These included the development of transformational technologies, data knowledge and sharing, modeling for availability and process optimization, implementing policies and infrastructure, and establishing regional bioeconomy hubs.

The scalability and efficiency of circular bioeconomy practices depend, in part, on the ability to handle heterogeneous biomass feedstocks. Modular processing systems, designed to adapt to variable input characteristics, could significantly enhance resource efficiency. Establishing regional bioeconomy hubs tailored to local biomass can help address the variability of byproduct availability while fostering regional economic growth and sustainability. As previously mentioned, a bioeconomy hub in Florida focused on citrus waste could serve as a platform for collaboration between local researchers, industry, and policymakers, ensuring a cohesive approach to resource utilization.

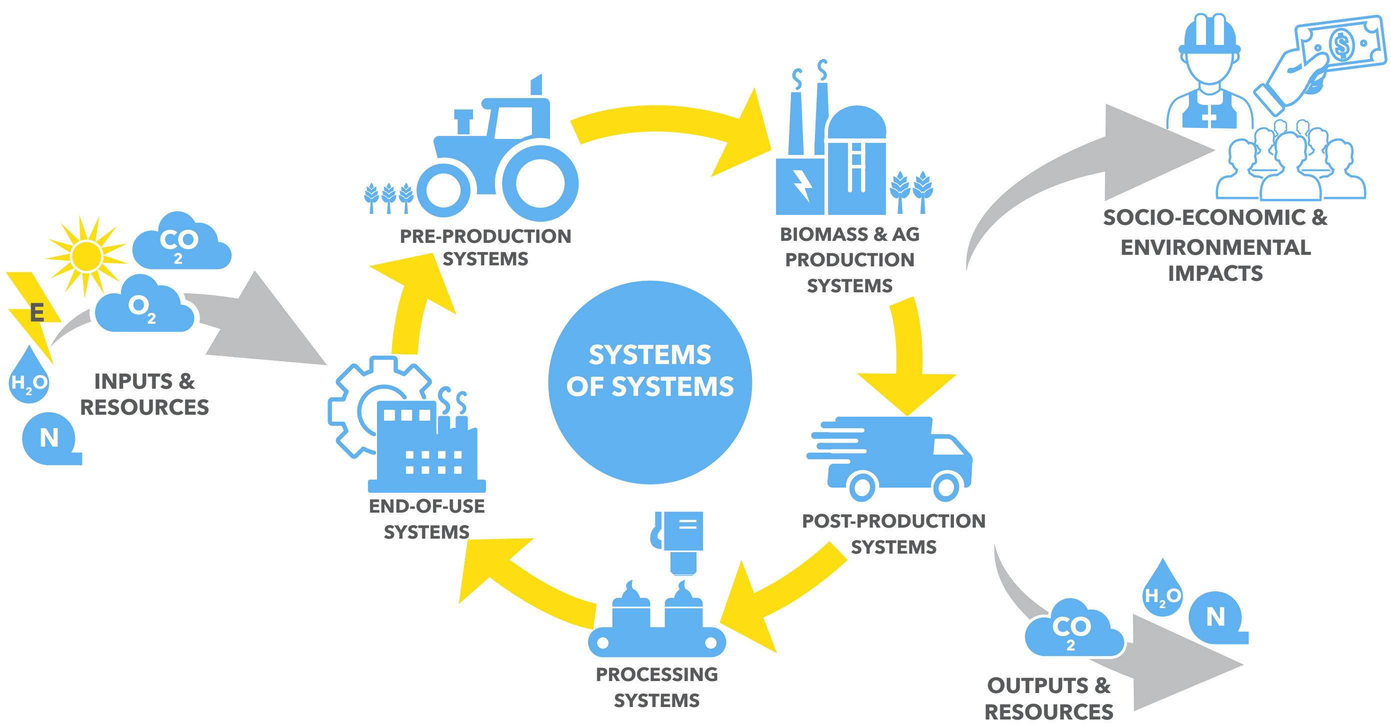

Figure 3. Key components of a circular bioeconomy. Adapted from ASABE CBS Initiative.

Bioeconomy:
The production of renewable biological resources from the agricultural, forestry, and aquaculture sectors, and the conversion of these renewable resources and waste streams into value-added products, such as food, feed, bioenergy, and other bio-based products.

-European Commission (5)

Biomass:
Any organic matter that is available on a renewable or recurring basis, including agricultural crops and trees, wood and wood residues, plants, algae, grasses, animal manure, municipal residues, and other residue materials.

-FFAR & Schmidt Futures (4)

Improve Integration of Climate and Sustainability Data into Food Systems and Recommendations

Utilizing real-time climate data and predictive modeling tools is another crucial step to improve resource efficiency. Many tools for evaluating environmental impacts of climate are available today, such as the World Food LCA database, ecoinvent, Agri-footprint, PRe, and the National Aeronautics and Space Administration (NASA), yet these databases are not regularly used. Providing more local context may enhance their use by modeling the environmental impact of changes in climate or diet in a local community or city. For example, modeling a transition to a low-carbon diet in a local community in the UK demonstrated a potential 20 to 30% increase in food waste due to the increase in plant-based food waste instead of animal waste (6, 7). Predictive models can also identify potential supply chain disruptions due to extreme weather events, allowing stakeholders to proactively mitigate risks while maintaining food security and reducing waste.

Additionally, dietary recommendations and nutritional advice should integrate flexibility to avoid strains on the supply chain and further worsening environmental impacts in climate-sensitive areas. This calls for a shift from promoting specific foods that may be in short supply year-over-year to promoting a variety of foods with similar nutritional values and health benefits. Adapting healthy dietary patterns to locally available foods will also help reduce impacts on climate resulting from the global transport of goods.

> "When we give nutrition advice, we need to increase our awareness of growing conditions in advance of the harvest and check to see if the foods we recommend are likely to be available and affordable. And we need to consider that information before we make a news announcement about the next superfood or super diet. If we do those things, we can be part of the solution."
>
> *Arlin Wasserman, PhD, Changing Tastes*

2. Enhance Resilience in Food Production, Supply Chains, and Safety

Strengthen Resilience Planning through Technology and Collaborations

For many manufacturers in the food supply, a resilient supply chain is key to sustainability. To mitigate systemic vulnerabilities, resilience planning must integrate stress-testing mechanisms across supply chains. Simulations that model the impact of pandemics, extreme weather, or geopolitical disruptions can help food systems adapt and recover efficiently. Collaborative frameworks that involve stakeholders from agriculture, logistics, and retail sectors can ensure a unified response to potential disruptions.

> “At the end of the day, supply chain resiliency is essential for sustainability.”
>
> *Kenzie Bear, ConAgra*

The development of alternative materials solutions can also enhance resiliency to changes in supply chain due to climate or other geopolitical issues. Shared data platforms and resource-pooling initiatives enable stakeholders to learn from one another and respond collectively to challenges such as fluctuating supply or disrupted logistics. For example, when the supply of a particular ingredient is limited, having a knowledge system that enables quick substitutions of similar materials to maintain a steady, affordable, supply would be advantageous. Currently, manufacturers do this primarily in isolation leading to duplicative efforts, but combining the knowledge of food scientists, engineers, and procurement specialists across the industry to provide rapid solutions could lead to greater efficiencies across the middle segment.

Advances in artificial intelligence (AI) can also play a critical role in risk management and contingency planning by providing predictive analyses from numerous inputs and patterns (8). AI-driven surveillance systems can monitor environmental changes, predict the potential proliferation of foodborne pathogens, and provide real-time notifications. When combined with blockchain technology, AI can enable tracking from farm to fork and provide fast detection of food safety concerns, ultimately leading to a safer, sustainable, and higher quality food supply (8).

3. Reduce Food Waste and Loss Across the Supply Chain

[While the topic of food loss and waste was discussed in a previous roundtable, it was also discussed in this roundtable, due to the size and impact of the issue. See the previous white paper on "Reducing Food Loss & Valorizing Food Processing Side Streams."]

Advance Consumer Food Waste Reduction Initiatives and Education

Food waste remains one of the most significant, but solvable challenges with major impacts on mitigating changes in climate. Consumer waste behaviors and patterns are more evident in the Global North with approximately 750 kcals/day wasted compared to 75 kcals/day in the Global South (6). There have been numerous widespread consumer awareness campaigns on the issue of food waste, yet consumer behavior has not substantially changed. Reframing the issue may improve consumer engagement and drive behavior change. For example, citizen science initiatives where individuals measure their own food waste, have been shown to be effective in shifting behaviors (9, 10). Alternatively, making the issue more tangible—such as framing waste in terms of meals lost rather than abstract environmental impact—may alter behaviors. Additionally, incorporating food waste education into school curricula can instill lifelong habits that prioritize sustainability.

> "People may not engage around stories of greenhouse gas emissions or carbon footprint, but they will engage when you tell them you're wasting 144 billion meals worth of food."
>
> *Lara Ramdin, Food X Climate*

Regulatory and incentive structures, such as the Good Samaritan Food Donation Act, which limits liability for food donors, can encourage retailers and manufacturers to redistribute surplus food rather than discard it. However, several barriers remain, including ambiguity around state-level food safety standards for donated foods, which leads some donors to opt for disposal rather than risk liability for foodborne illness. Additionally, managing the cold chain for perishable foods from restaurants or retailers to food banks or shelters increases concerns about liability and the carbon footprint. Implementing digital platforms to connect donors with recipients can streamline and potentially reduce the carbon footprint of the redistribution process.

Valorize Byproducts

Technological innovations that transform byproducts of processing into value-added ingredients also offer a way to increase circularity and minimize food waste. While there are several challenges in this area, such as consumer acceptance, heterogeneity of byproduct streams, and inconsistent supply chains, numerous start-ups have tackled these issues head on to bring new foods to the market. Byproducts can also be used as nutrient-rich animal feed as noted in the case study below. Several additional examples and case studies on upcycling and valorization of processing side streams can be found in IFT's previous white paper.

Case Study

Circular Bioeconomy in Action: Insect Farming as a Waste Valorization Solution in Costa Rica

Costa Rica has taken a proactive approach to food system sustainability, positioning itself as a regional leader in insect farming and waste valorization. A key factor in this progress has been the establishment of a regulatory framework that allows the production of edible insects for human consumption. Recognizing the potential of organic waste as a resource rather than a liability, researchers, entrepreneurs, and government agencies have been exploring how edible insect production can simultaneously address food waste, improve food security, and reduce environmental impact.

A key component of this initiative is the use of organic waste streams, such as fruit peels, spent grain, coffee pulp, purple corn cobs, and sugarcane bagasse, as feedstock for insect farming. The project demonstrates a closed-loop system, where agricultural and food industry byproducts that would otherwise contribute to landfill waste are repurposed as high-quality insect feed. The farmed insects are then processed into sustainable protein sources for both human food and animal feed, while their frass (excrement) is converted into organic fertilizer to support regenerative agriculture.

The environmental impact of this model is significant. Compared to traditional livestock, insect farming requires considerably less feed, water, and land while producing fewer greenhouse gas emissions. Additionally, insect farming generates lower methane emissions and requires significantly less space and water than conventional livestock production, making it a promising strategy for reducing the environmental footprint of protein production.

Beyond sustainability, the economic potential is substantial. By valorizing waste streams into marketable products, Costa Rican entrepreneurs can develop high-value insect-based food and feed ingredients, opening new revenue opportunities for the country's food industry. Moreover, the use of insect-derived organic fertilizer supports regenerative farming practices, improving soil health while reducing reliance on synthetic inputs.

With a supportive regulatory framework, a growing entrepreneurial ecosystem, and a commitment to sustainability, Costa Rica is becoming a model for waste valorization through insect farming. This initiative demonstrates how a circular bioeconomy approach can transform agricultural byproducts into valuable resources, creating a scalable and replicable model for food systems worldwide.

Source (11, 12)

Sugarcane bagasse

4. Overcoming Barriers to Adoption of Sustainable Solutions

Lower Costs and Demonstrate the Sustainability of Emerging Technologies

Advancements in sustainable technologies that use less energy and generate less waste, such as non-thermal processing technologies or cellular agriculture, present significant opportunities to reduce environmental impact while enhancing food and nutrition security. However, two major challenges persist: lowering production costs and convincingly demonstrating the sustainability of these emerging technologies. Addressing these concerns is essential to gaining consumer acceptance, attracting investment, and scaling production to a commercially viable level.

Non-thermal processing methods, such as high-pressure processing (HPP), pulsed electric fields (PEF), and ultraviolet (UV) treatment, provide promising alternatives to heat treatment by reducing thermal degradation of food components. However, these methods are not universally applicable and come with their own environmental trade-offs. For instance, while heat exchangers in traditional thermal processing can recover up to 90% of the thermal energy used, many non-thermal technologies lack comparable energy recovery mechanisms. In the case of HPP, the pressure required for processing is released after use, representing a significant loss of energy that is not currently recaptured.

Moreover, the material and resource demands for constructing and operating non-thermal processing systems must be considered. HPP, for example, requires massive amounts of steel to manufacture pressure units, contributing to its overall environmental footprint. These hidden resource costs challenge the assumption that non-thermal technologies are categorically more sustainable than conventional methods. As a result, the adoption of these technologies should be guided by detailed life cycle assessments that consider the full scope of resource use, operational efficiency, and long-term sustainability.

> “I don’t think that we know for sure that non-thermal processing technologies are indeed more sustainable than thermal. Indeed, they allow better preservation of nutrients in many cases, but we have to look very carefully at how these technologies work and what their limitations might be.”
>
> *Carmen Moraru, PhD, Cornell University*

Case Study

Advancing Sustainability and Food Quality Through Steam Infusion Innovation

As the food industry continues to explore non-thermal processing technologies for their potential sustainability benefits, it is important to recognize that even small changes in traditional thermal processing can yield significant efficiency gains and reduce environmental impact. Steam infusion, specifically the Vaction™ Pump technology, exemplifies this approach by optimizing thermal energy use, shortening processing times, and enhancing food quality, making it an important innovation for sustainable food manufacturing.

By injecting steam directly into liquid food products, the system eliminates the need for traditional jacketed heating, significantly improving thermal efficiency. This process reduces energy consumption by 17.3% compared to conventional steam heating, translating to an estimated 8.7 tons of CO_2 emissions saved annually per production line. In addition, steam infusion drastically cuts processing times, with batch heating reduced from 60 to 90 minutes to just 9 to 15 minutes, saving approximately 277.8 production hours per year. These gains not only lower operational costs but also increase factory throughput, enabling manufacturers to respond more efficiently to fluctuations in consumer demand.

Beyond its sustainability benefits, steam infusion also enhances food quality. Conventional steam-jacketed kettles often cause scorching and unwanted Maillard reactions due to prolonged heat exposure, leading to flavor degradation and burn-on. In contrast, steam infusion prevents these issues, ensuring more consistent cooking and improved retention of volatile flavor compounds. Trials on curry sauces demonstrated that spice volatiles were better preserved using steam infusion, which could reduce the need for added flavoring while maintaining a more vibrant taste. The process is particularly beneficial for dairy- and starch-based products, where it minimizes overheating and ensures smoother textures.

Another advantage of steam infusion is its modular design, making it easier to integrate into existing processing lines without major factory overhauls. The system's flexibility allows for real-time adjustments to processing conditions, supporting greater agility in production. Additionally, the integration of real-time data tracking supports quality control, traceability, and process optimization.

While steam infusion provides clear benefits, opportunities exist to further refine and optimize the technology. Enhancing steam pressure control could minimize minor heat losses, improving energy efficiency even further. Additionally, continued research into starch gelatinization and fat reduction could unlock new applications, particularly for reformulated or lower-fat food products. As steam infusion technology evolves, its role in improving efficiency, reducing emissions, and maintaining food quality will continue to shape the future of sustainable food manufacturing.

Source (13)

One of the most substantial cost drivers in cellular agriculture growth media, which generally accounts for half or more of total production costs (14). Thus, efforts are being directed toward replacing expensive animal-derived growth factors with more sustainable and cost-effective alternatives, such as engineering cells to generate their own growth factors or using precision fermentation to generate media components. AI-driven media formulations and circular resource utilization strategies are also being explored to create more efficient and cost-effective production systems. By leveraging computational modeling, researchers can design media compositions that maximize nutrient uptake while repurposing metabolic waste into usable compounds. These closed-loop approaches reduce both material costs and environmental impact by transforming byproducts into valuable inputs within the production cycle.

As cellular agriculture moves into the mainstream, demonstrating its sustainability is critical for securing regulatory approvals, consumer trust, and investor confidence. One of the key advantages of cultivated meat is its ability to reduce greenhouse gas emissions, land use, and water consumption compared to conventional livestock farming. Early studies indicate that depending on production methods, cultivated meat could lower greenhouse gas emissions by up to 96%, use 99% less land, and significantly cut water consumption (15).

Improve Consumer Awareness of Sustainable Options and Trade-offs

Consumers are increasingly encouraged to reduce their intake of processed foods for health and nutrition reasons. However, these recommendations create tension when considering sustainability, as many food processing techniques can actually reduce waste, improve efficiency, and lower environmental impact. Thus, a nuanced evaluation of the trade-offs is necessary rather than categorizing food processing as all good or all bad. Clear and transparent communication is essential to help consumers find balance in their choices and recognize that reducing intake of some processed foods may sometimes run counter to their sustainability goals.

> "Consumer acceptance of technologies plays a huge role. We can sit in a lab and propose solutions that may not be acceptable to a consumer. Solutions require input from all stakeholders, including consumers."
>
> *Carmen Moraru, Cornell University*

Strengthen Regulatory and Funding Support

Modernizing and streamlining regulatory frameworks are critical for adoption of new sustainable technologies. For example, non-thermal technologies such as HPP may encounter challenges under existing frameworks like the Pasteurized Milk Ordinance (PMO), which requires extensive validation studies to confirm that this method meets established safety standards equivalent to heat pasteurization. Regulatory frameworks for cellular agriculture are also highly complex, often requiring joint oversight by different regulatory agencies. Streamlining these processes could accelerate adoption. Finally, companies will need guidance and enhanced tools to assist with compliance as reporting standards evolve and change, such as with the European Sustainability Reporting Standards.

Securing adequate funding for sustainable food and agriculture technologies remains a significant challenge due to existing funding structures and allocation imbalances. While climate-related funding is available and has increased since 2017, it remains disproportionately focused on the energy sector rather than the food and agriculture sector. An annual analysis conducted by the Breakthrough Institute reported that while the energy sector accounts for 9 times more emissions than agriculture, federal R&D programs allocated 22 times more funding to clean energy innovation than to food and agricultural climate mitigation (16). Within agricultural climate funding, the majority of investment has gone toward soil carbon sequestration, leaving other critical areas—such as emissions reduction technologies in food manufacturing and supply chains—underfunded. Further, research projects that span food and agriculture disciplines, such as a post-harvest innovation that extends shelf life and reduces waste, often struggle to find appropriate funding streams. Agricultural research bodies may categorize such work as food science, while food science researchers may classify it as agricultural research, leaving projects without a clear funding home. A more integrated approach, with clear pathways for interdisciplinary proposals, would help ensure that innovations at the intersection of food and sustainability receive the necessary support. Additionally, considering large-scale, interdisciplinary grants would enable multiple institutions with expertise across agronomy, food science, and climate technology to collaborate on practical solutions.

> “We’ve seen and I’ve heard a real gap from startups, especially thinking about how to scale production beyond the lab stage, beyond the point at which they qualify for R&D grants. Building out processing manufacturing facilities for new types of products or new types of technology that can potentially be disruptive to an existing industry is something that we don’t see a ton of support from on the federal side.”
>
> *Emily Bass, Breakthrough Institute*

One of the most significant barriers for sustainable agrifood startups is the challenge of scaling from lab-stage research to commercial production (17). While research and development grants exist, there is little financial support available for scaling up processing and development of manufacturing infrastructure. This funding gap—often referred to as the “valley of death”—prevents many promising technologies from reaching commercial viability. Federal financing mechanisms, such as grants or public-private partnerships, could help emerging companies navigate this transition and prevent promising innovations from stalling. The Foundation for Food

and Agriculture Research (FFAR) was cited as an example of a successful initiative that leverages both public and private investments to support high-impact food and agriculture research. Expanding similar models for emerging food sustainability technologies could help attract more investment while ensuring that projects addressing climate mitigation and food security receive adequate funding.

5. Bridging Workforce Development and Education Gaps

Embedding Sustainability in Food Science Education

Updating educational curricula to include systems thinking and interdisciplinary approaches can prepare the next generation of food scientists and technologists to address complex challenges. Traditional education models emphasize disciplinary depth, often without providing a broader systems view. Courses on topics such as climate-resilient agriculture, circular bioeconomy practices, and sustainable food processing should be prioritized in academic institutions.

In addition to courses, experiential learning opportunities that expose students to farm operations, food manufacturing, and community food networks can help address the disconnect between academic training and real-world challenges. Interdisciplinary collaboration is also essential to ensure graduates can navigate the interconnected challenges of food systems.

Strategic collaboration between universities, industry, and policy makers can also help align research and training with workforce needs. Integrating sustainability metrics into student projects, such as life cycle assessment (LCA) modeling of different production methods, can enhance students' ability to apply scientific knowledge in professional settings.

> "We need more professionals willing to take the risk to work across interdisciplinary boundaries rather than staying in their highly specialized academic environments. We need more scientists willing to break down these barriers."
>
> *Ziynet Boz, University of Florida*

Case Study

Empowering Undergraduates in Circular Bioeconomy through the CD-Skills REEU Program

As the global food system faces mounting challenges related to climate change, resource scarcity, and waste management, the need to educate the next generation of professionals in sustainability and circular bioeconomy principles has never been more urgent. Ensuring that students are equipped with the skills to design regenerative, waste-minimizing systems is critical to transitioning toward a more sustainable and resilient future. The Circularity and Digitalization Skills (CD-Skills) Research and Extension Experiences for Undergraduates (REEU) Program, hosted by the University of Florida in collaboration with the United States Department of Agriculture (USDA) and the National Institute of Food and Agriculture (NIFA), was designed to meet this growing demand by immersing students in cutting-edge research and hands-on training in circular bioeconomy strategies.

The 10-week summer program offered a multidisciplinary approach, integrating circular economy principles with Industry 4.0 digitalization tools. Through weekly hands-on training sessions, students examined topics such as systems thinking, sustainability, and the application of digital technologies in creating regenerative and waste-minimizing food systems. This interdisciplinary approach ensured that participants gain a holistic understanding of the complexities and interconnections within agri-food value chains.

A distinctive feature of the CD-Skills REEU Program was its emphasis on experiential learning. Each student was mentored by a faculty researcher from various sectors of the food supply chain, engaging in over 30 hours of collaborative research. This mentorship model allowed students to apply theoretical concepts to practical challenges, fostering critical thinking and problem-solving skills essential for advancing circular bioeconomy initiatives.

To further enrich the learning experience, the program included field trips to businesses exemplifying circular practices in food processing, dairy systems, and waste management. These visits provided students with real-world insights into the implementation of circular strategies and the role of digitalization in enhancing efficiency and sustainability.

By immersing undergraduates in the principles and practices of the circular bioeconomy, the CD-Skills REEU Program cultivated a new generation of leaders equipped to transform food systems toward greater sustainability and resilience.

Source: https://cdskillsreeu.com/

Students in the CD-Skills REEU Program with Eric Dreyer, Process Engineer at First Magnitude Brewery in Gainesville, Florida.

Embedding Sustainability into Workforce Practices

Food manufacturing remains an underutilized driver of sustainability and engaging employees in climate-focused initiatives can foster a culture of innovation and continuous improvement. Moving beyond passive reporting, providing real-time tracking of carbon, water, or biodiversity footprints allows workforce members to actively engage with the metrics, providing a type of "gamification" of environmental performance to enhance workforce participation. Much like farmers have been engaged in regenerative agriculture, food industry employees can be mobilized to drive waste reduction, resource efficiency, and emissions mitigation.

National demonstrator projects can also showcase real-world applications of sustainability metrics within operational factory settings. These projects offer practical, replicable insights that industry professionals can integrate into their own facilities.

By shifting from top-down sustainability mandates to employee-driven solutions, the food sector can activate its largest untapped resource—its workforce—to accelerate climate adaptation and mitigation efforts at scale.

> "When you engage workforce in the manufacturing sector, you augment change. My greatest learning in 25 years is that if I had thought about how to engage workforce and people 15 years ago, I would probably be five years ahead of where I am now."
>
> *Wayne Martindale, PhD, MPC Research*

Case Study

The S3 Project – Engaging the Workforce to Drive Sustainability in Food Manufacturing

As a recognized leader in sustainability, Raynor Foods in the UK has long been at the forefront of innovation in food manufacturing. However, despite significant progress in areas such as carbon footprinting and packaging sustainability, the company faced a critical challenge: how to engage and motivate its entire workforce—from the shop floor to senior management—to drive meaningful, measurable improvements in sustainability. In response, Raynor Foods launched the S3 Project (Smart People, Smart Processes, Smart Factory), a high-tech initiative that integrates real-time carbon tracking, workforce engagement through gamification, and a digital twin factory model to enhance sustainability performance across operations.

At the core of the S3 Project is a workforce engagement and recognition system designed to make sustainability performance visible and rewarding for employees. Using ultra-wide band mesh technology, Raynor Foods created a tracking system with sensors that connect individual employees and operational processes to carbon emissions data. Employees wear digital game links that track their workplace behaviors and performance-based rewards are tied directly to key sustainability metrics. The system was designed to be inclusive and positive, ensuring employees earn points for sustainable behaviors rather than being penalized for inefficiencies.

A key insight from the project was the discovery that financial incentives were not the sole motivator for workforce engagement. Surveys and interviews revealed that employees valued work-life balance, professional development, and recognition as much as monetary rewards. In response, Raynor Foods tailored its incentive structure to include personalized rewards, such as additional paid time off, training opportunities, and community contributions.

The impact of the S3 Project has been significant, with 38 metric tons of carbon emissions already eliminated through improved waste reduction, stock rotation, and energy-efficient operations. By empowering employees with real-time sustainability data and fostering a culture of shared responsibility, Raynor Foods is driving systemic change within its organization.

Beyond its internal success, the S3 Project is positioned as a National Demonstrator, showcasing how digital innovation and workforce engagement can transform sustainability in food manufacturing. By sharing best practices, technology insights, and implementation strategies, Raynor Foods aims to inspire broader industry adoption, reinforcing the principle that sustainability in food manufacturing is not just a technological challenge—it is a people-driven movement.

Source: https://medium.com/@ifmcam/gamifying-sustainability-delivering-worker-engagement-and-environmental-impact-6896a79695c1 and Martindale, et al. (18)

6. Strengthening Resilience Amid Political and Economic Uncertainty

Advocating for Science-Based Policies

Political shifts often lead to uncertainty in climate and food policy, but scientific collaboration and mobilization can serve as a stabilizing force. Rather than communicating and operating in silos, cross-disciplinary alliances—uniting researchers, industry leaders, and advocacy groups—are essential to amplify the role of food systems in climate solutions and protect science and facts amid an increase in misinformation.

Supporting Regional Bioeconomy Hubs

Regional hubs can harness local agricultural strengths to drive economic and environmental benefits. Rather than waiting for top-down regulations to determine sustainability transformations, regions can develop specific strategies that align with domestic policies and stimulate local economies. For example, bioeconomy hubs in grain-producing regions could focus on valorizing cereal byproducts, while coastal hubs could develop seafood processing innovations. By fostering job creation and industry-led innovation, these hubs can ensure long-term economic and environmental resilience.

Stabilizing Investment Funding in Climate-Focused Food Innovation

The shifting investment landscape has made it increasingly difficult for food startups and small businesses to secure funding for sustainable food solutions. Advocacy for food system innovation within broader climate investment frameworks can ensure that food solutions remain a priority within climate funding. Additionally, positioning food system innovation within a context of research in extreme environments—even extraterrestrial settings such as Mars—can open pathways to new funding streams that may be less vulnerable to political and economic shifts. Leveraging public-private partnerships can also provide more stable funding streams, buffering against political and economic uncertainty. Importantly, innovation within companies often continues despite political turbulence. While external funding may fluctuate, companies that internalize sustainability initiatives as core business strategies will be more resilient to shifts in government priorities.

Call to Action

Advancing Climate-Resilient and Sustainable Food Systems

The challenges facing the middle segment of the food system—resource inefficiencies, systemic vulnerabilities, food waste, economic and regulatory barriers, workforce gaps, and evolving geopolitical uncertainties—are complex and interconnected. Addressing them requires urgent, coordinated, and science-driven action across the food supply chain. The solutions outlined in this white paper provide a road map for mitigating climate risks and building a more resilient and sustainable food system. However, achieving meaningful progress will require collaboration, investment, and strategic policy support.

To catalyze change, industry leaders, policymakers, researchers, and other key stakeholders must take immediate steps to:

1. Address Resource Inefficiencies Through Circularity and Systems Thinking

The food system must move beyond linear production models toward integrated models that maximize resource efficiency and minimize waste. This shift requires embedding circular bioeconomy principles alongside systems thinking approaches that connect food production, processing, and dietary guidance with climate and sustainability considerations. To achieve this there is a need for:

- **Investment in scalable processing infrastructure** that enables the valorization of byproducts into high-value food ingredients, biomaterials, and alternative protein sources, while adapting to variable inputs across regions and seasons.
- **Expansion of regional bioeconomy hubs** to support localized solutions, reduce transportation emissions, and create economic incentives for waste valorization.
- **Integration of climate and sustainability data into decision-making**, such as predictive modeling for supply chain resilience, life cycle assessments for new products and processing technologies, and tools to evaluate the climate impact of dietary recommendations.
- **Cross-sector collaboration** to develop industry standards for waste stream utilization, ensuring consistency in supply chains and reducing barriers to adoption.

Stakeholders across the food sector—including processors, ingredient suppliers, and technology developers—must work together to establish new markets for upcycled food products, sustainable packaging, and bio-based materials. Dietary recommendations should also be aligned with climate realities by incorporating data on resource availability, regional growing conditions, and environmental impact. Policymakers should further support these efforts through financial incentives, regulatory clarity, and public-private partnerships.

2. Strengthen Resilience in Food Supply Chains and Safety Protocols

As climate-related disruptions intensify, food manufacturers must integrate risk mitigation and stress-testing mechanisms into supply chain planning. To enhance resilience:

- **Companies must adopt AI-driven modeling and digital tools** to forecast supply chain disruptions, optimize procurement strategies, and enhance food safety monitoring.
- **Regulatory agencies should update food safety frameworks** to account for climate-related risks, such as the increased prevalence of foodborne pathogens and mycotoxins due to temperature fluctuations.
- **Industry consortia should establish shared databases** to enable rapid ingredient substitutions and improve supply chain agility in response to extreme weather events or geopolitical instability.

Ensuring food safety and security in a changing climate requires proactive, data-driven strategies that integrate food science, technology, and policy. Collaborative frameworks between food manufacturers, logistics providers, and agricultural producers must be established to create a more adaptive and resilient food system.

> "Just like food safety, building resiliency in the food supply should not be a competitive thing."
>
> *LeeAnn Jaykus, former William Neal Reynolds Professor in the Department of Food, Bioprocessing, and Nutrition Sciences at North Carolina State University, USA*

3. Reduce Food Waste and Improve Waste Valorization

Food loss and waste remain one of the most solvable contributors to climate change. While consumer education campaigns are essential, food manufacturers, retailers, and policymakers must take bolder steps to:

- **Expand food donation programs** by aligning liability protections and regulatory requirements across states and regions.
- **Invest in food waste tracking and reporting systems** that provide real-time data on waste hotspots across the supply chain.
- **Support R&D in upcycling technologies** that transform side streams—such as fruit and vegetable peels, dairy co-products, and spent grains—into functional food ingredients.

The food industry must embrace a waste-free mindset by integrating food loss prevention measures into standard operating procedures, while policymakers should provide incentives and funding mechanisms for businesses that actively reduce and repurpose food waste.

4. Overcome Economic and Regulatory Barriers to Sustainable Innovation

Scaling emerging food technologies—including non-thermal processing, cellular agriculture, and precision fermentation—requires addressing economic and regulatory hurdles that hinder commercialization. To realize the full potential of these innovations:

- **Governments must establish clear and streamlined regulatory pathways** for novel food technologies to accelerate market entry without compromising safety.
- **Financial institutions and public-private partnerships should expand funding models** that bridge the "valley of death" between R&D and commercialization, ensuring that promising innovations reach industrial scale.

- **New technology developers must collaborate with research institutions** to conduct life cycle assessments (LCAs) that quantify the sustainability benefits of new food processing technologies for broader adoption.

By aligning policy, investment, and industry action, stakeholders can drive cost reductions, accelerate adoption, and demonstrate the long-term value of sustainable food technologies.

5. Modernize Workforce Development and Sustainability Education

The food industry's sustainability efforts will only succeed if the workforce is equipped with interdisciplinary skills and systems thinking. Educational institutions, industry leaders, and government agencies must:

- Revise food science and technology curricula to include courses on sustainable processing, circular bioeconomy principles, and life cycle assessments.
- Expand industry training programs that expose early-career professionals to real-world food manufacturing, supply chain logistics, and sustainability challenges.
- Integrate sustainability metrics into workforce practices, ensuring that employees at all levels are engaged in achieving climate and waste reduction targets.

Building a skilled, sustainability-focused workforce is essential for accelerating food system transformation and ensuring that climate adaptation strategies are successfully implemented.

6. Strengthen Advocacy and Investment in Climate-Focused Food Innovation

Uncertain investment landscapes and fragmented policies threaten progress toward food system sustainability. To drive long-term innovation and resilience, stakeholders must take action in three key areas:

- Advocate for science-driven policies that support climate-smart food technologies, establish clear regulatory pathways for novel food processing methods, and incentivize food loss prevention.
- Expand regional bioeconomy hubs to decentralize innovation, leverage local agricultural and technological strengths, and create economic incentives for circular food systems.
- Secure long-term investment by aligning food system funding with broader climate action initiatives, expanding public-private partnerships, and creating financial incentives for sustainable food solutions.

Ensuring regulatory clarity, investment stability, and localized sustainability strategies will accelerate climate adaptation, enhance food security, and drive economic resilience in the food sector.

Conclusion

Climate concerns are reshaping global food systems, posing unprecedented challenges to food security, resource availability, and supply chain stability. Rising temperatures, extreme weather events, and shifting ecosystems demand urgent, science-driven solutions to mitigate environmental impact and build resilience. As this white paper outlines, leveraging food science and technology to optimize resource use, enhance supply chain adaptability, and reduce food loss and waste is critical to ensuring a sustainable future.

The path forward requires collaboration across industry, government, and research to implement science-driven strategies that enhance food security while reducing environmental impact. By adopting scalable circular economy practices, leveraging AI and digital tools, removing financial and regulatory hurdles, and embedding sustainability into workforce training, stakeholders can drive systemic change.

In 1931, Winston Churchill envisioned a future where food production would move beyond inefficiency, stating: “Fifty years hence, we shall escape the absurdity of growing a whole chicken in order to eat the breast or wing by growing these parts separately under a suitable medium.” While his timing was slightly off, his vision was prophetic. The challenges ahead are great, but so is the potential for change. If we act decisively today, the solutions in this white paper should not take another fifty years to become reality. With innovation, collaboration, and a commitment to sustainability, we can build a food system that nourishes both people and the planet for generations to come.

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