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ENERGY EFFICIENCY &
RENEWABLE ENERGY

Industrial Efficiency and Decarbonization Office

2023 Stakeholders Workshop

Decarbonization Challenges and Priorities Across the U.S. Food and Beverage Industry

Summary Report

August 31, 2023

Within the U.S. Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy (EERE), the Industrial Efficiency and Decarbonization Office (IEDO) accelerates the innovation and adoption of cost-effective technologies that eliminate industrial greenhouse gas emissions.

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All of the following individuals deserve a special mention for their efforts, before, during, and after the workshop in providing leadership and invaluable input to the workshop planning and execution efforts as well as to this report:

- Yaroslav Chudnovsky (DOE IEDO) – Workshop planning and execution
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- Stacey Young, Buildings People – Logistics Support
- Simone Hill-Lee, Buildings People – Logistics Support
- Jennifer Ziberna, Buildings People – Logistics Support

Finally, a special thank you is extended to all of those who gave presentations during the workshop plenary and breakout sessions. The presenters are listed below. The presentations were informative, thought-provoking, and set the context for our focused discussions to identify key technology priorities, challenges, and barriers to decarbonization of the Food and Beverage industry.

Plenary Session Speakers

- Isaac Chan, Program Manager, DOE IEDO
- Dr. Yaroslav Chudnovsky, Senior Technology Manager, DOE IEDO
- Keith Jamison, Technology Manager, DOE IEDO
- Dr. Kimmai Tran, Fellow, DOE IEDO
- Joe Cresko, Chief Engineer, DOE IEDO
- Tessa Hale, Director of Corporate Engagement, Good Food Institute
- Blake Harris, Technical Director, Institute of Food Technologists

Breakout Session Speakers

- Kathy Nuñez, Sustainability Engineer, Tyson Foods
- Dr. Olexiy Buyadgie, Chief Executive Officer, Wilson Engineering Technologies, Inc.
- Jerry Barnes, Vice President, BABBCO Tunnel Ovens
- Joseph Zaleski, President, Reading Bakery Systems
- Mike Aquino, Director, ESG, International Dairy Foods Association
- Eric Hassel, Director, Sustainability Measurement and Reporting, Innovation Center for U.S. Dairy
- John Larrea, California Regulator Engagement Director, EcoEngineers

Disclaimer

List of Acronyms

AI	Artificial intelligence
AMMTO	Advanced Materials and Manufacturing Office
ANL	Argonne National Laboratory
ARPA-e	Advanced Research Projects Agency–Energy
AWG	Atmospheric Water Generation
BAU	Business As Usual
CAPEX	Capital Expenditures
CCUS	Carbon Capture, Utilization, and Storage
CHP	Combined Heat and Power
CO_{2e}	Carbon Dioxide Equivalent
CST	Cross-Sector Technologies
DOE	U.S. Department of Energy
EEII	Energy- and Emissions-Intensive Industries
EEIO	Environmentally Extended Input/Output
ESG	Environmental, Social, and Governance
EV	Electric Vehicle
F&B	Food and Beverage
FDA	U.S. Food and Drug Administration
FOA	Funding Opportunity Announcement
FY	Fiscal Year
GHG	Greenhouse Gases
HPC	High Performance Computing
HTHP	High Temperature Heat Pump
HVAC	Heating, Ventilation, and Air Conditioning
IA	International Affairs
IDA	Industrial Decarbonization Analysis
IEDO	Industrial Efficiency and Decarbonization Office
ISO	International Standards Organization
LBNL	Laurence Berkely National Laboratory
LCA	Life Cycle Analysis

LCFFES	Low Carbon Fuels, Feedstocks, and Energy Sources
LDES	Long-Duration Energy Storage
LED	Light Emitting Diode
LEEP	Lab-Embedded Entrepreneurship Program
LPO	Loan Program Offices
MECS	Manufacturing Energy Consumption Survey
ML	Machine Learning
MMT	Million Metric Tons
NAICS	North American Industry Classification System
NETL	National Energy Technology Laboratory
NMR	Nuclear Magnetic Resonance
NREL	National Renewable Energy Laboratory
OCED	Office of Clean Energy Demonstrations
ORNL	Oak Ridge National Laboratory
PNNL	Pacific Northwest National Laboratory
R&D	Research and Development
REBCO	Rare-Earth Barium Copper Oxide
RNG	Renewable Natural Gas
SBIR/STTR	Small Business Innovation Research/Small Business Technology Transfer
SC	Office of Science
SEM	Strategic Energy Management
SME	Subject Matter Expert
TAP	Technical Assistance Partnership
TAWD	Technical Assistance and Workforce Development
TBtu	Trillion British Thermal Units
TEA	Techno Economic Analysis
TES	Thermal Energy Storage
TRL	Technology Readiness Level
UV-C LED	Ultraviolet-C Light Emitting Diode
WRRF	Water Resource Recovery Facilities

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Executive Summary

On August 31, 2023, the U.S. Department of Energy's Industrial Efficiency and Decarbonization Office (IEDO) convened the workshop titled "Decarbonization Challenges and Priorities across the U.S. Food and Beverage Industry" in Las Vegas, Nevada. The workshop aimed to gather insights from a diverse array of stakeholders to inform strategies for enhancing energy efficiency, reducing greenhouse gas emissions (GHGs), and ensuring the long-term competitiveness of the food and beverage industry.

The workshop commenced with a plenary session during which IEDO leadership outlined key DOE programs, portfolios, and initiatives, including the following: Cross-Sector Technologies subprogram; Food and Beverage portfolio; Low-Carbon Fuels, Feedstocks, and Energy Sources (LCFFES) portfolio; Technical Assistance and Workforce Development subprogram; and the Industrial Decarbonization Roadmap. Speakers from industry also presented on the alternative proteins landscape and on global food traceability.

The workshop proceeded with small-group breakout sessions organized by the following specific segments of the food and beverage industry: Proteins; Grains and Oilseeds; Baking and Snacks; Dairy Products; Fruits and Vegetables; and Beverages, Sugar, Confectionary, and Tobacco Products. Discussions in these sessions covered current energy consumption efficiency, GHG emissions profiles, water conservation, waste management, and supply chain sustainability. Participants identified the top technology pathways and associated barriers and challenges for decarbonization within these segments. Section 3 of this workshop report provides further details of the input received from the breakout sessions, but key takeaways from the discussions can be summarized as follows:

- Workforce Development: Addressing the skills gap and workforce training emerged as critical for successful technology adoption and operation, particularly in food and beverage segments requiring specialized knowledge.

- Policy and Regulatory Considerations: Participants highlighted the need for supportive policies such as carbon pricing mechanisms and enhanced regulatory frameworks to incentivize decarbonization investments and foster industry-wide collaboration.

- Supply Chain Integration: Achieving comprehensive decarbonization requires robust integration of sustainability practices throughout the supply chain, supported by improved data transparency and collaboration between suppliers and buyers.

- Technology Opportunities: Identified priority areas for technology investment included smart manufacturing, electrification, enhanced waste management, and expanded circular economy practices. These technological pathways offer significant potential to optimize processes, reduce emissions, and enhance resource efficiency across the food and beverage system.

- Barriers and Challenges: Major impediments cited included high costs of technology deployment, difficulties with scalability, inadequate infrastructure, regulatory complexities, and varying levels of organizational readiness and cultural acceptance of change within the industry.

IEDO encompasses the following three subprograms: Energy- and Emissions-Intensive Industries (EEII), Cross-Sector Technologies (CST), and Technical Assistance and Workforce Development (TAWD). With each subprogram having specific priorities, the following summary below represents the key focus areas for each based on stakeholder input during the workshop breakout sessions:

IEDO's Energy- and Emissions-Intensive Industries Subprogram

The EEII subprogram focuses on the following industrial subsectors with the highest concentration of energy use and carbon emissions: chemicals, iron and steel, food and beverages, cement and concrete, and forest products. Accelerating early-stage investments in decarbonization technologies tailored for specific food and beverage operations is a high priority. Based on stakeholder input, key takeaways highlight the importance of smart manufacturing technologies, such as real-time data monitoring and AI-driven optimization, to enhance energy efficiency and reduce emissions in food and beverage processes. Prioritized strategies include the installation of variable frequency drives and heat integration tools that can significantly lower utility consumption. Additionally, innovations in HVAC systems for cooling and cold storage operations and waste heat recovery present major opportunities for improving overall energy intensity. The need for robust electrification pathways, particularly in drying and baking processes, is emphasized, along with the exploration of alternative heat generation methods like scalable solar thermal technologies. Addressing the challenge of embodied carbon emissions in end products across the supply chain through enhanced data availability and lifecycle assessment is crucial for motivating sustainable procurement decisions. Overall, fostering collaboration across the supply chain and integrating comprehensive decarbonization measures are vital for advancing the food and beverage subsector toward net-zero goals.

IEDO's Cross-Sector Technologies Subprogram

The Cross Sector Technologies program aims to facilitate the readiness of component and equipment technologies that have decarbonization impacts across multiple industries. The report identifies significant opportunities in smart manufacturing, waste management, and alternative fuels for process heating operations, including hydrogen, as essential pathways for reducing carbon emissions. The integration of innovative energy storage solutions and demand response programs can enhance grid stability and support the growth of electrification. Moreover, the program underscores the importance of improving data-sharing mechanisms to better assess and manage life cycle carbon emissions, thus informing more sustainable supply chain practices. Addressing the inherent challenges related to infrastructure limitations and the high-risk nature of emerging technologies will be key to broadening the adoption of scalable solutions. Overall, a collaborative approach that includes investment in R&D, coupled with incentives for technology adoption, is necessary to drive significant decarbonization across the food and beverage industry.

IEDO's Technical Assistance and Workforce Development Subprogram

The Technical Assistance and Workforce Development program focuses on building partnerships and providing the necessary support to industries for adopting energy-efficient and decarbonization technologies. The report highlights the critical need for robust workforce training to effectively implement new technologies, given the complexities involved in the food and beverage sector. Challenges such as segment-specific skills gaps, infrastructure limitations, and regulatory hurdles complicate this transition. Enhanced training resources and support for operational staff are essential for the successful deployment of technologies. Additionally, promoting organizational culture shifts towards sustainability and innovation can facilitate broader acceptance of decarbonization measures. Financial incentives would encourage greater investment in sustainable practices. Ultimately, fostering collaboration among stakeholders and creating a skilled workforce will be pivotal in driving the successful adoption of decarbonization technologies in the food and beverage industry.

Overall, the workshop underscored the importance of collaborative efforts between government; industry; research, development, and demonstration (RD&D); and other stakeholders to advance decarbonization goals in the food and beverage subsector. Insights gained will help to inform IEDO's strategic initiatives, focusing on RD&D investment, analysis, and technical assistance to drive transformative change. IEDO will continue to engage stakeholders, refine RD&D priorities, and seek alignment with industry needs to accelerate the adoption of decarbonized technologies and sustainable industrial practices for the food and beverage industry.

1. Background

1.1. Overview and Purpose

On August 31, 2023, the U.S. Department of Energy (DOE) Industrial Efficiency and Decarbonization Office (IEDO) held a workshop titled "Decarbonization Challenges and Priorities across the U.S. Food and Beverage Industry" in Las Vegas, Nevada. The event brought together 62 participants from government, industry, academia, national labs, trade associations, and utilities to gather input that will inform IEDO decision-making in terms of decarbonizing the U.S. Food and Beverage (F&B) industry.

The overarching purpose of the workshop was to identify and prioritize research, development, and demonstration (RD&D) needs to increase energy efficiency, reduce greenhouse gas (GHG) emissions, and ensure competitiveness and long-term viability of the industry. The objectives of the workshop were to solicit industry feedback:

- To inform IEDO's priority RD&D goals and metrics to accelerate the transition toward a more secure and decarbonized F&B industrial sector.
- To identify the barriers and challenges to developing and adopting transformative, low-carbon technology innovations.
- To identify technical assistance that will support the sector in implementing industrial decarbonization and circular economy technologies and practices.
- To guide IEDO's Energy- and Emissions-Intensive Industries (EEII) and Cross-Sector Technologies (CST) subprogram objectives.

DOE has a long history of partnership and collaboration with the industrial sector to develop innovative technologies and improve efficiency of operations through a variety of RD&D and technical assistance programs. Stakeholder engagement, including workshops and roundtables, provides a direct interface between government and industry. Communication with industry ensures that funding opportunities for specific areas of interest address the most critical technical challenges to reducing industrial energy and GHG emissions.

1.2. Workshop Approach

The workshop began with a series of presentations from DOE leaders, providing overviews of the IEDO programs and subprograms, as well as an overview of the DOE Decarbonization Roadmap. Industry leaders also presented, discussing specific trends and opportunities.

These presentations provided background for the second half of the workshop, which consisted of six facilitated breakout sessions to gather cross-sector input. There was a session for each of the following key F&B segments:

- Proteins
- Grains and Oilseeds
- Baking and Snacks
- Dairy Products
- Fruits and Vegetables
- Beverages, Sugar and Confectionary, and Tobacco Products.

During these sessions, facilitators sought to understand the current state of energy consumption, efficiency, and GHG emissions, along with viable decarbonization pathways. Together, participants reviewed the current energy consumption, efficiency, and GHG emissions profiles of each segment. They then discussed the segments' goals and plans for improving sustainability and environmental compliance, as well as viable options and approaches to reducing energy consumption and GHG emissions. Technology areas of interest included, but were not limited to, the following:

- Improving energy efficiency and increasing material efficiency
  - Innovative process technologies for heating, cooking, and drying applications
  - Waste heat recovery, process intensification, and system optimization
  - Reduction of product loss and recycling
  - Cooling and refrigeration
  - Smart manufacturing and advanced controls
- Fuel switching
  - Low-carbon fuels, feedstocks, and energy sources (LCFFES)
  - Electrification
- Carbon capture, utilization, and storage (CCUS)

DOE also aimed to identify barriers to technological innovations where existing knowledge, technology, and processes are inadequate, hoping to identify strategies to address these barriers, as well as specific targets and metrics for improvement. These discussions also sought to identify potential areas of alignment between industry and government goals that could be fostered through collaboration.

1.3. Industry Snapshot

The F&B industry is a critical component of the U.S. economy and includes all facilities involved in transforming raw agricultural goods into consumer food products, ranging from fresh and processed foods to beverages and packaged snacks. As of 2021, the industry employed 1.7 million workers to produce and ship nearly $920 billion worth of products,[1] and it accounted for an estimated 1,935 TBtu of energy (10% of total energy use for U.S. manufacturing) and 95.7 MMT CO_{2e} of GHG emissions (10% of total energy-related emissions for U.S. manufacturing).[2] The overall energy and GHG emissions footprint of the food (NAICS 311) and beverage (NAICS 312) industrial sector is shown in the table and diagrams below, based on DOE-published Manufacturing Energy and Carbon Footprints.

Table 1.3.1: Food and Beverage Sector Total and Categorical Energy Consumption

U.S. Food and Beverage Manufacturing, 2018	
Category	**Energy (TBtu)**
Total primary energy	1,935
Offsite losses	673
Onsite Energy	1,262
Onsite losses	716
Steam generation and distribution	93
Electricity generation	3
Process energy	431
Non-process energy	81
Energy for all purposes	1,952
GHG emissions	**MMT CO_2e**
Total	95.7
Combustion emissions	95.7
Offsite combustion emissions	50.6
Onsite combustion emissions	45.1
Process emissions	0.0

[1] U.S. Census Bureau. "Annual Survey of Manufacturers: Summary Statistics for Industry Groups and Industries in the U.S.: 2018 – 2021." December 2022. https://data.census.gov/table/ASMAREA2017.AM1831BASIC01?q=AM1831BASIC&n=311:312&nkd=YEAR~2021.

[2] DOE Advanced Manufacturing Office. "Manufacturing Energy and Carbon Footprint, Sector: Food and Beverage (NAICS 311, 312). Primary Energy, 2018." December 2021. https://www.energy.gov/sites/default/files/2021-12/2018_mecs_food_beverage_energy_carbon_footprint.pdf.

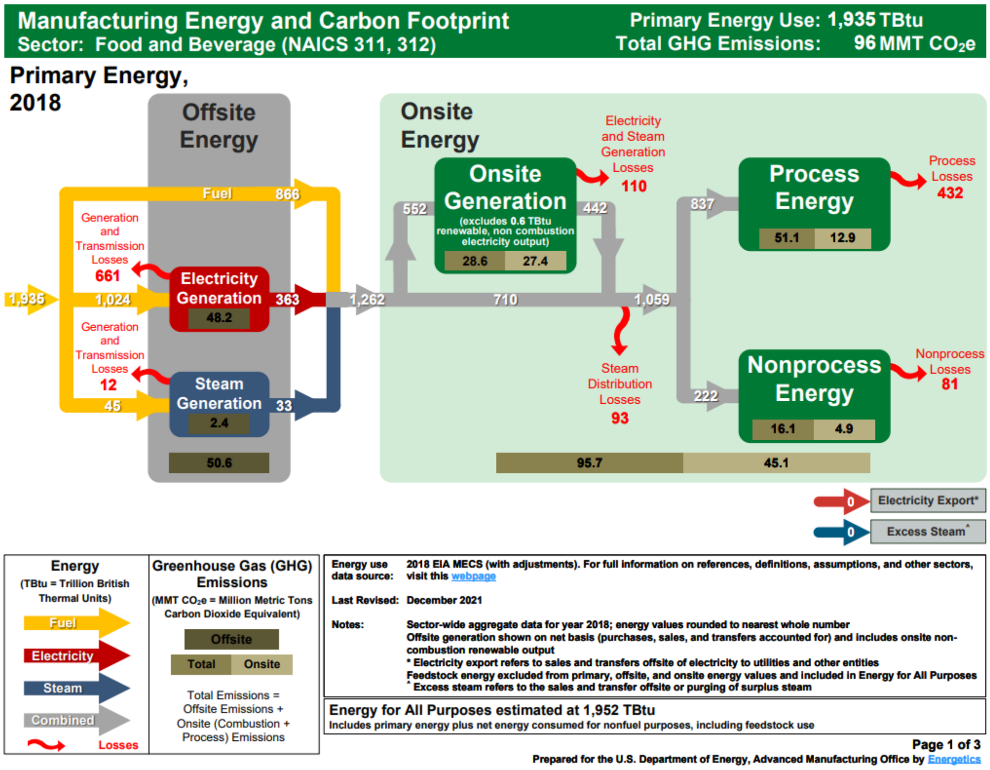


Figure 1.3.1. Carbon Footprint for Food and Beverage – Primary Energy, 2018

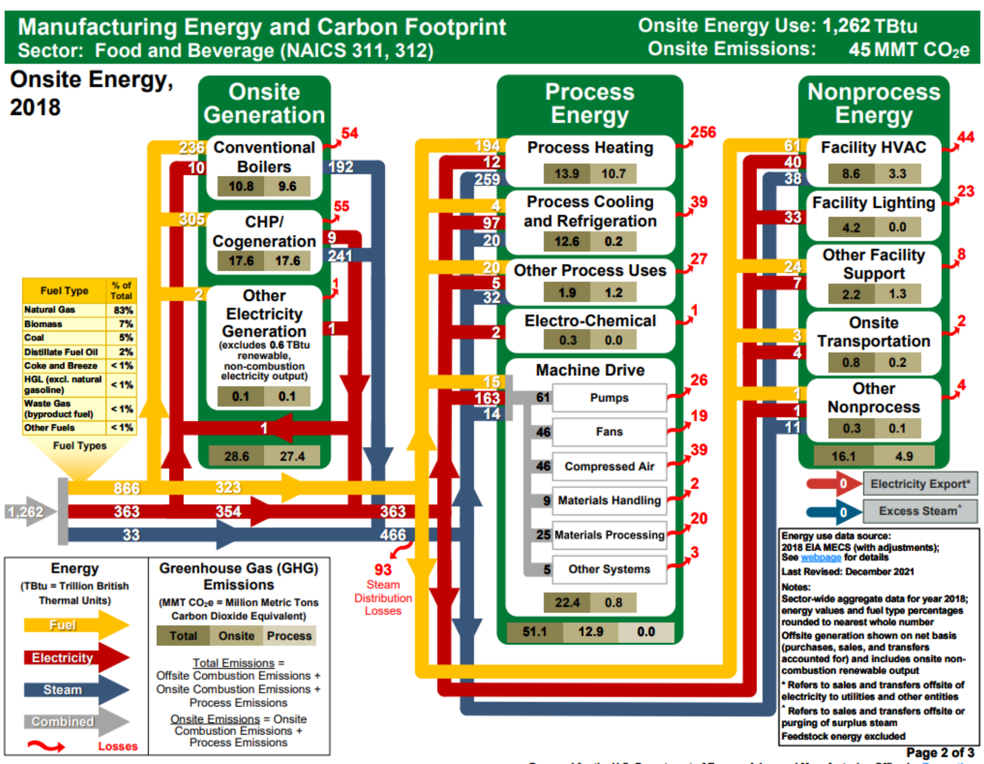


Figure 1.3.2. Carbon Footprint for Food and Beverage – Onsite Energy, 2018

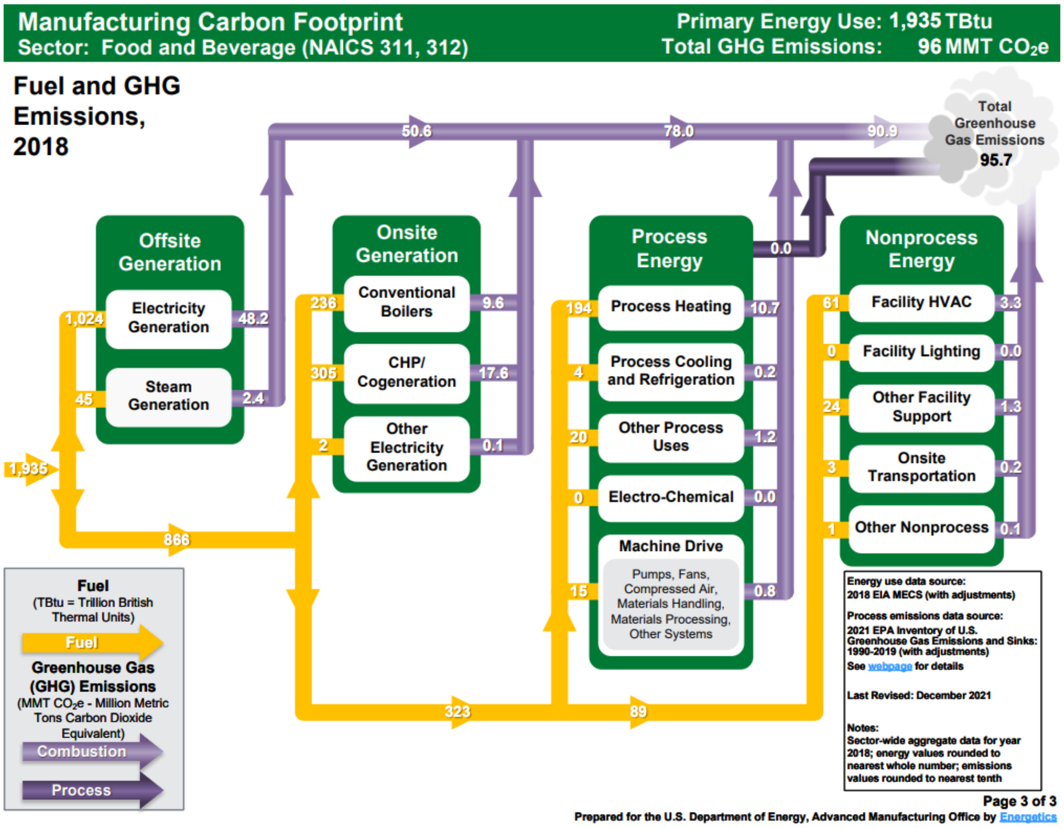


Figure 1.3.3. Carbon Footprint for Food and Beverage – Fuel and GHG Emissions, 2018

2. Plenary Session Summary

The F&B industry workshop began with a plenary session that convened all attendees. This session consisted of a series of presentations. First, DOE leaders provided overviews of programs and subprograms within IEDO and areas of opportunity for impact and collaboration in support of decarbonization efforts. Industry leaders closed the plenary with presentations on two emerging topics: the future of proteins and global food traceability. Each presentation concluded with a question-and-answer period that allowed attendees in the audience to engage with the presenter. The content below summarizes the key points and discussions introduced for each presentation during the plenary session of the workshop.

2.1. Welcoming Remarks and IEDO Program Overview (Linked Here)

Mr. Isaac Chan, Program Manager, DOE Industrial Efficiency and Decarbonization Office

Mr. Chan presented an overview of IEDO's CST portfolio, which targets cross-cutting technologies, including thermal processes, LCFFES, emerging technologies, and water and wastewater treatment. The presentation emphasized the CST mission to establish a net-zero clean energy future across multiple sectors. The industrial sector, constituting 33% of national primary energy use and 30% of CO_2 emissions, faces significant challenges on the path to net-zero. Process heating, crucial in this sector, represents 50% of industrial energy use, with specific requirements for food and beverage heating below 150°C. The industrial sector's top emitters—including Chemicals and Refining, Iron and Steel, Food and Beverage, Cement and Concrete, and Forest Products—have industry-specific decarbonization challenges. McKinsey estimates that a $11–$21 trillion investment will be required for decarbonization of cement, steel, ammonia, and ethylene, with 60% emissions reductions enabled by technologies that will not be commercially available until 2050.[3] IEDO's Fiscal Year (FY) 2023 budget of $266.5 million focuses on conducting applied RD&D and piloting technology development with three subprograms—EEII, CST, and Technical Assistance and Workforce Development (TAWD)—comprising 50 staff members.

[3] Arnout de Pee, Dickon Pinner, Occo Roelofsen, Ken Somers, Eveline Speelman, and Maaike Witteveen. "How industry can move toward a low-carbon future." *McKinsey Sustainability*. 2018. https://www.mckinsey.com/capabilities/sustainability/our-insights/how-industry-can-move-toward-a-low-carbon-future

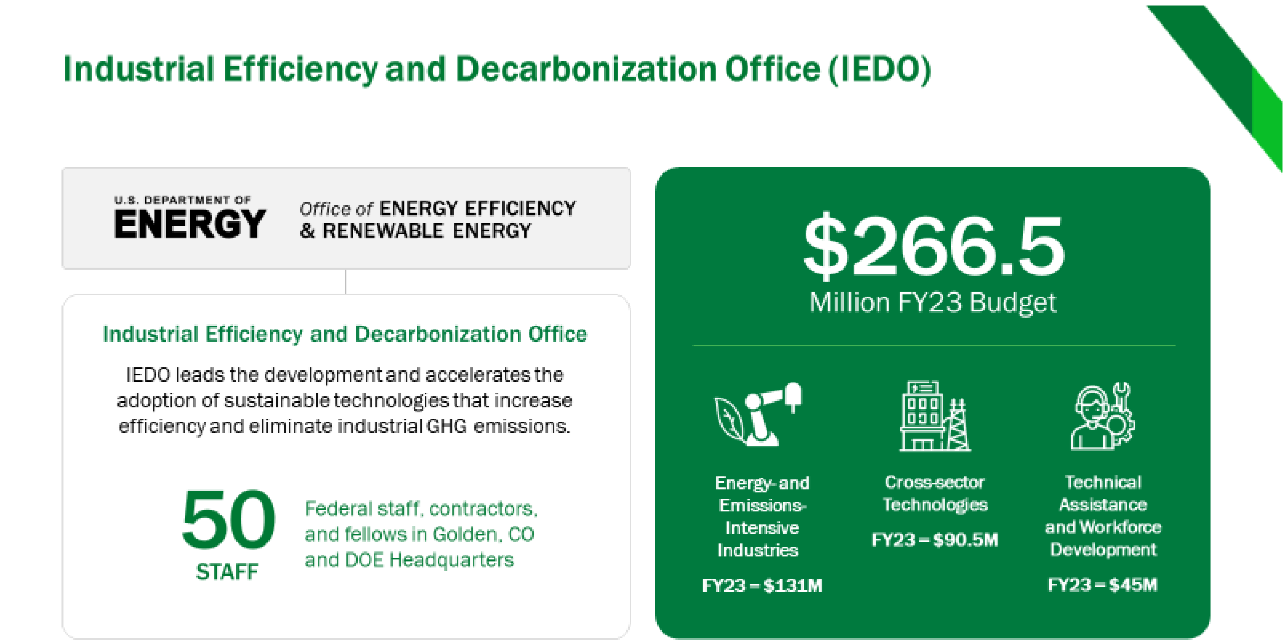


Figure 2.1.1. IEDO Overview

2.2. Energy- and Emissions-Intensive Industries Subprogram: Food and Beverage Investment Portfolio Overview (Linked Here)

Dr. Yaroslav Chudnovsky, Senior Technology Manager, DOE IEDO

Dr. Chudnovsky emphasized the diversity of the F&B industry and the absence of a one-size-fits-all decarbonization solution. The sectorfaces an array of challenges, including industry's conservative mindset toward change, which hinders technology adoption. Dr. Chudnovsky stressed the need for collaboration between the agricultural and manufacturing sectors to address Scope 3 emissions, which constitute 80%–90% of total emissions for the industry. The industry's growth projection of 16% by 2050 underscores the importance of hybrid and modular fuel systems (vs. current centralized heating systems), compliance with environmental regulations, increased workforce training, and supply chain improvements. Dr. Chudnovsky outlined the four pillars for decarbonization, while also highlighting the importance of significant investment and collaboration required for bringing new technologies from ideation to market-ready solutions. The presentation highlighted IEDO's current focus on drying technologies and upcoming areas of interest for funding opportunities, such as alternative proteins, deep waste heat recovery, and advanced separations. Stakeholder engagement, including subsector-specific workshops, is crucial for refining strategies. Dr. Chudnovsky emphasized the urgency of starting investments now to achieve decarbonization goals by 2035, rather than waiting 10–15 years for technology development to progress to commercialization, reiterating the workshop's goal of defining top technology priorities for future IEDO investments.

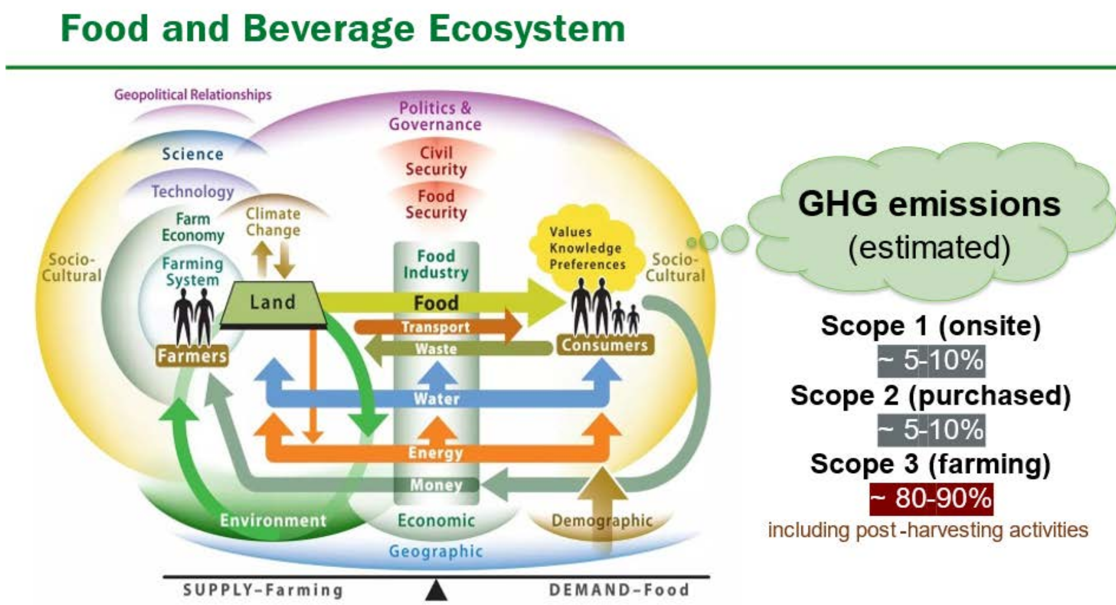


Figure 2.2.1. The Food and Beverage Ecosystem

2.3. Cross-Sector Technologies Subprogram: Drying; Steam Generation; and Low-Carbon Fuels, Feedstocks, and Energy Sources (LCFFES) (Linked Here)

Mr. Keith Jamison, Technology Manager, DOE IEDO

Mr. Jamison emphasized the significance of component and equipment technologies, such as waste heat recovery, thermal storage, and next-generation technologies within the CST program, highlighting their potential impacts across multiple sectors. Reducing emissions from process heating, identified as a significant opportunity for cross-sector impacts, can be achieved by transitioning to electric heating technologies and utilizing LCFFES such as bio-derived fuels, waste, and hydrogen. The FY 2023 budget allocation prioritized thermal processes, with emerging efficiency, wastewater treatment, and LCFFES sharing the remaining budget. The presentation acknowledged barriers in cost, scale-up, and management of a diverse technology portfolio. Key CST technologies include electro-technologies, heat pumps, low-heat processes, non-thermal separations, and advanced furnace systems. Industrial drying, which accounts for approximately 12%–15% of manufacturing process heating energy use, is most significant in F&B, Pulp and Paper, Gypsum, Chemicals, and Textiles manufacturing. Specific CST project portfolios encompass Industrial Drying [Research and Development] R&D, LCFFES, Emerging Technologies, and the Water–Energy Nexus, addressing fit-for-purpose water supplies and wet organic waste streams.

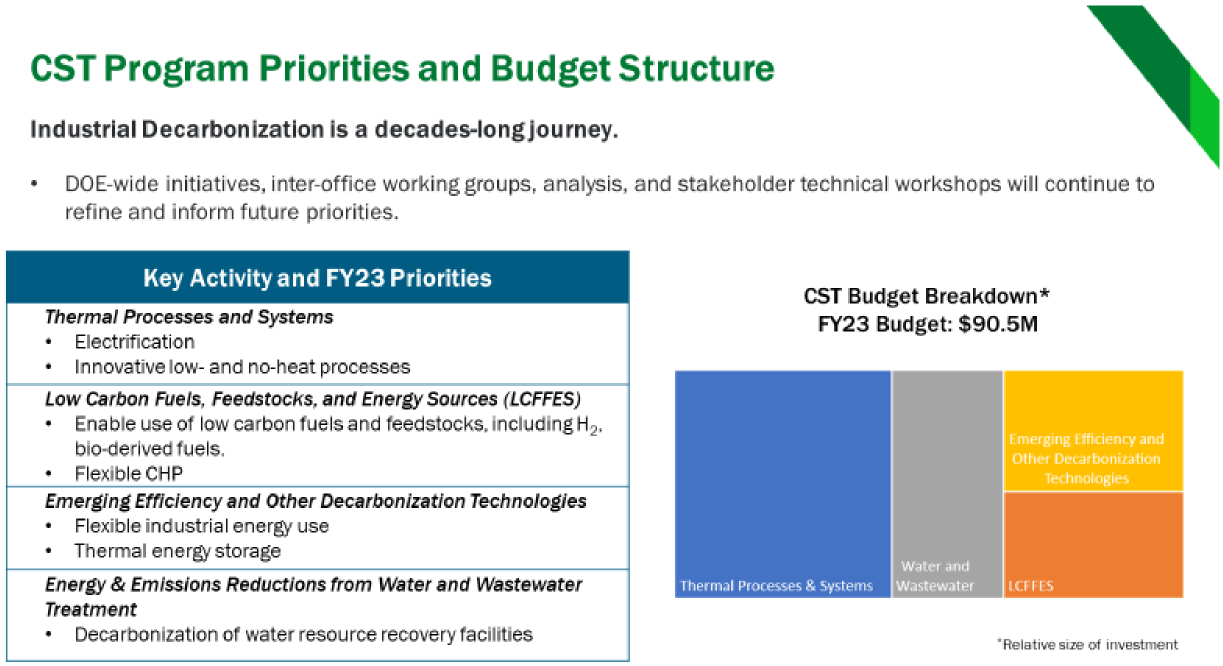


Figure 2.3.1. CST Sub-Program Priorities and Budget Structure

2.4. Technical Assistance and Workforce Development: Better Plants and a Look Into the Controlled Environment Agriculture Accelerator (Linked Here)

Dr. Kimmai Tran, DOE IEDO

Dr. Tran outlined the mission of the TAWD subprogram within IEDO, emphasizing its role as the deployment arm. TAWD's primary goal is to assist industries in achieving energy and emissions reduction goals through public–private partnerships, offering low-cost tools such as energy assessments and peer-to-peer networking. Notable initiatives drive competition among industry leaders, resulting in significant energy cost savings; examples are Better Plants and the Better Climate Challenge, which target a 25% reduction in energy-intensity and a 50% reduction in GHG emissions at industrial facilities. Dr. Tran highlighted TAWD's expanding programs, including combined heat and power (CHP) technical assistance, which now includes onsite energy deployments in areas such as energy storage, solar, geothermal, and heat pumps. The potential translation of manufacturing technologies to agriculture, particularly in controlled environment agriculture, was discussed, emphasizing collaboration with the U.S. Department of Agriculture. Dr. Tran outlined next steps for involvement, encouraging participation in Better Plants and Better Climate Challenges and engaging with various technical assistance programs.

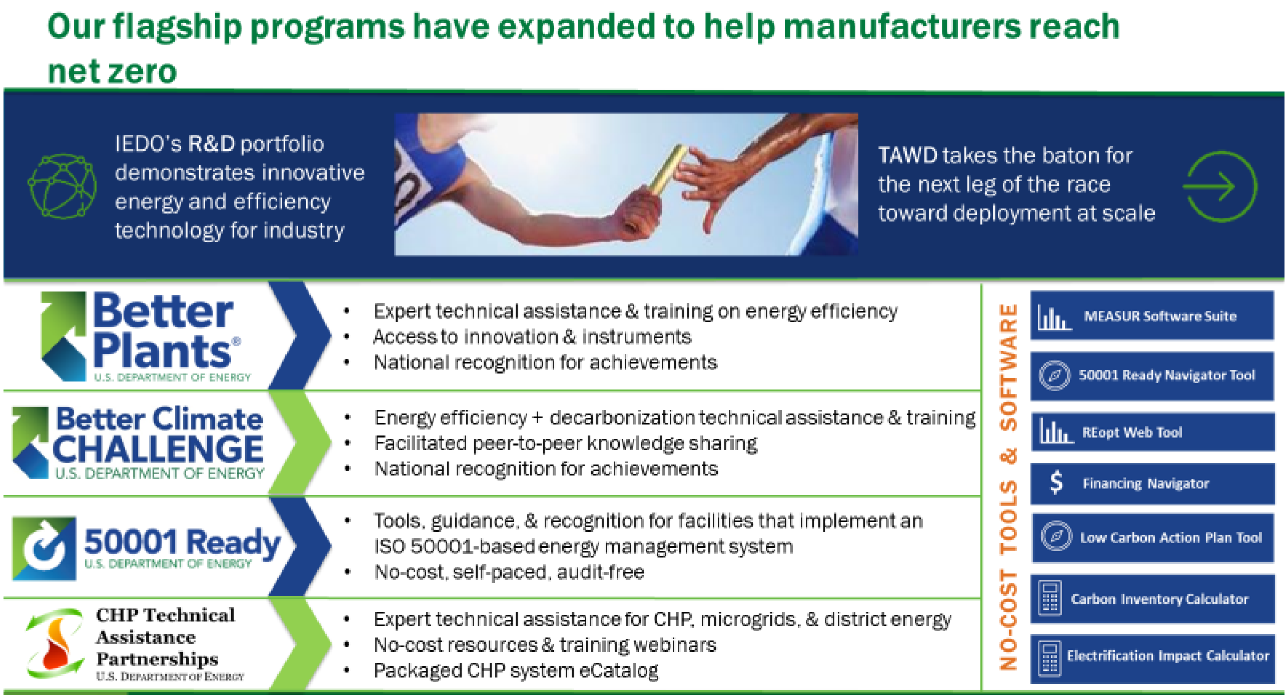


Figure 2.4.1. TAWD Flagship Programs

2.5. DOE Decarbonization Roadmap Overview (Linked Here)

Mr. Joe Cresko, Chief Engineer, DOE IEDO

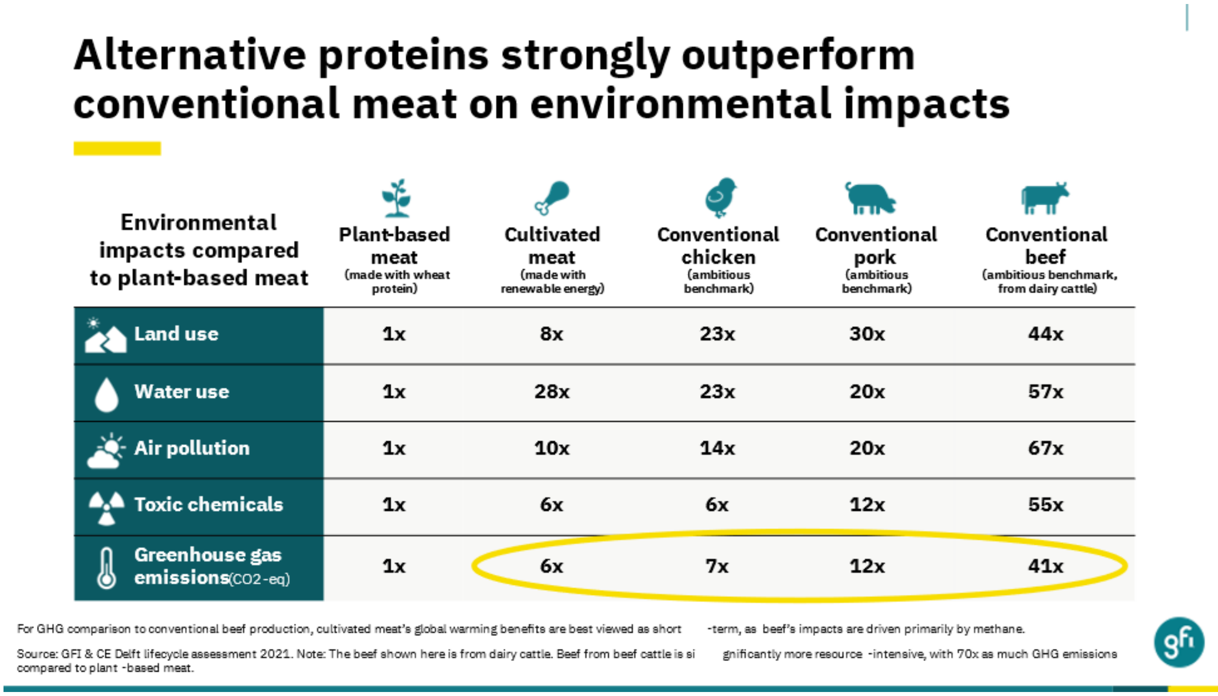
Mr. Cresko stressed the urgency of implementing transformational improvements across all industries, recognizing the complexity of decarbonizing the F&B sector. He emphasized the need for a multifaceted approach, including advancing early-stage R&D, conducting in-depth modeling and analysis of industrial sector emissions, actively engaging communities, and addressing critical issues such as process heating. The Decarbonization Roadmap, organized around four pillars—Energy Efficiency; Industrial Electrification; LCFFES; and Carbon Capture, Utilization, and Storage (CCUS)—serves as a strategic planning guide in shaping refined office goals, multi-year strategies, and actionable plans. Mr. Cresko highlighted the interconnectedness of supply chains, using tools such as the Environmentally Extended Input–Output for Industrial Decarbonization Analysis Tool (EEIO-IDA) to model emissions reduction potential. Mr. Cresko also emphasized the criticality of collaboration and covered various available energy analysis reports available to the public, including the Energy & Materials Resource Flows, Sustainable & Circular Economy, Water–Energy–Carbon Nexus, Extended Pathways Analysis, Integrated Systems & Deep Dives Analysis, EEIO for Industrial Decarbonization Analysis, and Project & Portfolio Impact & Environmental Justice Analysis.

Figure 2.5.1. Strategic Analysis Activities

2.6. Reimagining Proteins (Linked Here)

Ms. Tessa Hale, Director of Corporate Engagement, Good Food Institute

Ms. Hale introduced the Good Food Institute (GFI), a nonprofit think tank of over 180 staff members in six regions globally dedicated to creating a secure, just, and sustainable protein supply. GFI focuses on three pillars: plant-based protein, fermentation, and cultivated protein. Ms. Hale noted that the global population's projected growth to 10 billion by 2050 creates an escalating demand for protein, which will contribute to a 56% food production gap in 2050 based on total calorie consumption. Traditional animal agriculture, responsible for 15% of global CO_2 emissions, faces challenges in meeting nutritional needs sustainably. Specifically, 75% of agricultural land is used to raise and feed livestock but provides only a third of the global protein supply, and the traditional meat production life cycle involves significant emissions production. Thus, a shift to alternative protein production could promote reforestation and reduce the harmful effects of human-induced climate change. Ms. Hale highlighted the challenge to change diets and reduce meat consumption, making alternative proteins akin to electric vehicles (EVs), allowing sustainability without requiring consumers to change their behavior. Alternative protein companies explore sustainable side streams. The presentation emphasized the potential for the United States to lead in this industry, which is estimated to reach as high as $1 trillion in gross value by 2050.



Alternative proteins strongly outperform conventional meat on environmental impacts

Environmental impacts compared to plant-based meat	Plant-based meat (made with wheat protein)	Cultivated meat (made with renewable energy)	Conventional chicken (ambitious benchmark)	Conventional pork (ambitious benchmark)	Conventional beef (ambitious benchmark, from dairy cattle)
Land use	1x	8x	23x	30x	44x
Water use	1x	28x	23x	20x	57x
Air pollution	1x	10x	14x	20x	67x
Toxic chemicals	1x	6x	6x	12x	55x
Greenhouse gas emissions (CO2-eq)	1x	6x	7x	12x	41x

For GHG comparison to conventional beef production, cultivated meat's global warming benefits are best viewed as short -term, as beef's impacts are driven primarily by methane.

Source: GFI & CE Delft lifecycle assessment 2021. Note: The beef shown here is from dairy cattle. Beef from beef cattle is si gnificantly more resource -intensive, with 70x as much GHG emissions compared to plant -based meat.

Figure 2.6.1. Environmental Impacts of Alternative vs. Conventional Protein Production

2.7. Global Food Traceability Center (Linked Here)

Mr. Blake Harris, Technical Director, Institute of Food Technologists

Mr. Harris emphasized the significance of traceability and data management in achieving sustainability goals, citing the Global Food Traceability Center's vision for a fully traceable food system. Recognizing the complexity of current food systems, which are primarily designed for expediency rather than traceability, Mr. Harris highlighted the need for a standardized approach to GHG emissions inventory, as varying data management systems across suppliers, customers, and regulators make it challenging to draw meaningful conclusions from existing data. Overcoming barriers such as coordination, trust, and transparency is crucial for improving traceability and realizing benefits like material efficiency and waste reduction. Mr. Harris stressed that standardized data management would encourage innovation by enabling the tracking and measurement of technological advancements. Collective action involving the private sector, regulators, non-governmental organizations, academia, and technology providers is necessary for setting data standards. Mr. Harris concluded by encouraging attendees to consider their roles in creating data standards to drive sustainability across the food system moving forward.

Figure 2.7.1. Benefits of a Standardized Data Approach

3. Breakout Session Summaries

Each of the six breakout sessions, representing six specific F&B industry segments as noted in Section 1.2, were divided into seven topic areas:

- Topic 1: Energy Consumption and Efficiency Improvement
- Topic 2: Greenhouse Gas Emissions (Scope 1 and 2 Emissions)
- Topic 3: Water Conservation
- Topic 4: Waste Management and Circular Economy
- Topic 5: Supply Chain Sustainability (Scope 3 Emissions)
- Topic 6: Technology Adoption and Associated Challenges
- Topic 7: Goals and Metrics Justification

The first five topics characterized the session's industry segment, including discussions focused on current sustainability opportunities, best practices, technology implementation, associated challenges, and new technologies needed to advance industrial decarbonization.

Topic 6 prioritized the most impactful emerging technologies identified in the previous topics, focusing on those that require further RD&D. Discussions also aimed to identify the associated technical, market, and social/consumer challenges potentially inhibiting widescale market adoption of those technologies. The intent of this prioritization exercise was to help inform IEDO's F&B portfolio of future areas of interest for investment based on current industrial needs.

Topic 7 identified top key metrics and performance indicators essential for measuring the success of technology development and implementation. This information will inform IEDO of potential metrics that can be used to better assess project proposals for future funding opportunities respective to the F&B industry. Such metrics are important tools in holistically, comprehensively, and quantifiably assessing the potential overall impact and viability of a proposed technology.

Note: The sections below summarize the breakout session discussions, comprising opinions and viewpoints of the session participants. The content does not necessarily reflect the perspective of DOE or the broader F&B industry.

3.1. Breakout Session Summary for Topic 1: Energy Consumption and Efficiency Improvement

3.1.1. Technology Opportunities

Discussions centered on the integration of renewable energy sources and electrification, waste heat recovery, optimization measures to improve energy efficiency, and regulatory incentives. Synthesized results from all six breakout sessions are listed below.

- Integration of **renewable energy sources** and low-carbon fuels can help offset the consumption of fossil fuel sources. **Electrification** technologies can offer higher efficiencies while also offsetting the use of fossil fuels. Baking and drying equipment were specifically identified as priorities for deployment of electrified equipment, in addition to advanced steam generation technologies, such as electric boilers, to facilitate transitioning away from fossil-fuel based combustion systems to meet plant heating demands.
- There are also electrified technologies, such as heat pumps, that enable **heat recovery** and reuse. Opportunities for heat capture are especially relevant to flue gases and exhaust streams where a large amount of heat could be recouped through equipment such as condensing economizers for boiler and CHP operations. Another prime application is for ammonia refrigeration systems where the heat of compression generated presents further thermal reuse opportunities. Finally, waste heat recovery technologies could be paired with thermal energy storage for pre-heating, while insulation improvements can reduce heat loss.
- Plant efficiencies can be improved through **equipment optimization**, which was noted to be "low hanging fruit." For instance, retrofitting **natural gas boilers** would enable streamlined and cost-effective integration of high-efficiency furnaces and combustion equipment in the near term, whereas complete equipment replacement would require large capital investments.
- As part of smart manufacturing, the expanded use of **sensors** on equipment and processes enables advanced **process automation** for real-time decision-making to boost performance and throughput. Additionally, digital twin models, developed using artificial intelligence (AI), can be used to identify efficiency improvement opportunities. In addition, pinch analysis can be used to improve heat integration between operations to facilitate **process optimization**. Enhanced combustion systems for ovens can enhance **energy efficiency of equipment**.
- **Upgrading light emitting diode (LED) lighting** is another strategy for reducing electricity usage. PepsiCo uses a staggered approach (referenced in the baking and snacks breakout session): after a lighting fixture has failed, replace it with an LED

upgrade. This strategy allows the organization to avoid making the entire capital investment up front and performing all the maintenance at one time.

- Additional **regulatory incentives and commitments** are crucial to further drive implementation and adoption of energy-efficient technologies within industry.

Table 3.1.1 summarizes the results of the discussion on technology opportunities for energy efficiency improvements across all six breakout sessions.

Table 3.1.1: Technology Opportunities for Energy Consumption and Efficiency Improvement Identified in All F&B Breakout Sessions

Technology Opportunities Identified for Energy Efficiency Improvements
• Renewable energy sources • Electrification technologies • Heat recovery systems • Equipment optimization (e.g., natural gas boilers and processes) • Smart manufacturing (e.g., digital sensing) • Process automation and optimization • Process intensification • Energy-efficient equipment • LED lighting • Regulatory incentives

3.1.2. Challenges and Barriers

Challenges focused on insufficient data monitoring, as well as equipment limitations, including difficulties in improving the performance of legacy equipment. Additionally, adoption of new technologies poses challenges related to industry training and awareness, cost, and supply chain. Finally, there are notable constraints related to the grid and alternative fuels that inhibit the transition away from fossil fuels, along with market and policy challenges that must be overcome to further encourage widescale adoption and deployment of emerging decarbonization technologies. Combined session results from all six breakout groups are summarized below.

- **Lack of data monitoring and analysis** weakens the ability—driven by the availability of real-time information—to quickly and adaptively address performance and optimization needs. This lack especially inhibits creation of AI/physics-based models, which can be used to better identify areas of improvement within production processes. From an organizational standpoint, the absence of a single point of contact for **data traceability** and energy efficiency within companies poses a communication challenge. This challenge arises when there are different departments or teams that operate independently within an organization without a shared understanding of data flow or energy usage, leading to siloed information and suboptimal decision-making.

- Existing **equipment inefficiencies** can be difficult to overcome based on equipment and process limitations that can make **retrofitting** new technologies difficult in terms of technological obsolescence, compatibility issues, and downtime and disruptions. Combustion processes were specifically noted within the baking and snacks breakout as especially challenging, given the significant level of enhancement required; even advanced ribbon burner retrofits currently available are not advanced enough compared to emerging technologies. Also, many boilers are oversized, resulting in excess boiler cycling. This frequent starting/stopping of operation results in thermal energy losses and has negative impacts on equipment reliability, given the excessive starts/stops. Another major challenge is microbial growth under insulation on pipes in dairy operations, as it can degrade insulation and corrode pipes over time if left unaddressed, sometimes leading to excessive heat loss and product loss.
- Large organizations with many sites encounter challenges with **scale-up** and rolling out new efficiency strategies and/or equipment optimization measures. The grains and oilseeds breakout session specifically identified advanced sensors, given the resources, cost, and timing involved in ensuing sensors are used consistently and integrated into existing process controls throughout a variety of industrial sites in various locations.
- **Equipment standardization** ensures aspects such as standard fittings and other considerations are consistent for new technologies made commercially available for ease of install, operation, and maintenance. **Integration challenges** arise with industrial heat pumps. Stakeholders expressed that industrial heat pumps are not ready for integration in every process, and simple subsidies to organizations that purchase and install this equipment are not enough to promote further deployment. Further technical assistance is needed to guide industry on strategies to ensure successful integration of this equipment.
- **Industry's lack of awareness** of new technologies on the market, in addition to **lack of trained manpower** to operate and maintain these technologies, can inhibit widescale adoption and deployment. Industry hesitation is further compounded by **quality concerns**, given consumer sensitivities to changes in products associated with exchanging legacy equipment and processes for new technologies that either are unproven or lack sufficient demonstration. Related to this aspect is the **lack of a guarantee of reliable functionality** for novel technologies, which leads to additional concern over potential disruptions to manufacturing processes and adverse impacts on product quality.

- Deployment of new technologies is challenging, as they often have **longer payback periods** and internal rates of return that may not meet an organization's requirements for capital expenditures and thus deter investment. Further compounding this problem are high electricity prices, which were specifically noted as a barrier toward adoption of electrification technologies. Electricity costs contribute to extended payback periods that make large equipment expenditures unattractive. Furthermore, the seasonality of the Fruits and Vegetables segment further intensifies the payback period duration. For existing technologies such as LED lighting, there is also the challenge of **diminishing returns**, meaning that most organizations have already "plucked" the low-hanging fruit.
- **Supply chain** issues can result in delays or **limited availability** of equipment and/or instrumentation to support reduction strategies. Technologies like industrial heat pumps were specifically noted as lacking both a standard evaluation methodology for assessing applicability and sufficient equipment options available for purchase, as multiple original equipment manufacturers are needed to ensure a consistent supply with wide-ranging capabilities for maximum impact across a diverse set of processes. In the Baking and Snacks session, a stakeholder working on an optimization project to improve measurement and process control noted that specific sensors and actuators were needed for the effort, yet none were available on the market for purchase.
- Electrification technologies present a range of challenges – increasing demand, **grid reliability and stability issues**, and limitations with local electrical infrastructure – that contribute to industry hesitation in transitioning to electrification technologies. While such technologies could reduce energy consumption and contribute to overall energy efficiency improvements, there are concerns regarding the compatibility of the grid with nascent technologies. Limited availability and affordability of low-carbon energy sources, such as hydrogen and green electricity, make it particularly challenging for smaller companies to implement new energy-efficient technologies and strategies.
- The **lack of a waste-to-energy strategy**, especially for processing dairy food waste and wastewater, can result in missed opportunities for biogas and renewable natural gas (RNG) generation to offset the use of fossil fuel sources. A collective digester strategy would ideally utilize urban food waste, industrial food waste, and manure waste from farming based on proximity of operations to generate biogas and electricity that could be distributed and utilized by multiple sites. A collective strategy for waste-to-energy production would likely be most impactful, given the economies of scale in waste treatment.
- **Regulatory aspects**, such as **lengthy permitting**, can be challenging to navigate when attempting to deploy a new technology. Concentrated solar power was specifically identified in the grains and oilseeds breakout session as a means to integrate

renewable energy; associated regulations can differ by application (e.g., commercial vs. industrial) and by state, which can cause confusion in terms of knowing which standards to follow.

- The **market transformation plans** for new technologies were identified as **needing additional support for both development and execution**. Emerging technologies are rarely, if ever, plug-and-play solutions, so stakeholders expressed a need to know what resources and personnel, with specific skillsets, are required onsite to ensure safe and reliable operation of the new equipment. Additionally, agreements between service providers and suppliers must be established to ensure routine maintenance and parts are available to support the sites where new (but high-technology-readiness-level [high-TRL]) solutions are deployed. Overall, the **absence of a comprehensive roadmap** that spans the F&B sector makes it difficult for organizations to identify which technologies should be prioritized based on maximum decarbonization and energy impacts in order to meet the Administration's long-term carbon reduction goals.

Table 3.1.2 summarizes the results of the discussion on challenges and barriers for energy efficiency improvements across all six breakout sessions.

Table 3.1.2: Challenges and Barriers for Energy Consumption and Efficiency Improvement Identified in All F&B Breakout Sessions

Challenges and Barriers to Energy Efficiency Improvements
• Lack of data monitoring, analysis, and data traceability • Equipment inefficiencies • Challenges retrofitting old equipment with new technologies • Difficulty with scale-up of technologies (e.g., different regulations in different states) • Lack of equipment standardization • Integration challenges • Lack of awareness of new technologies • Gap in training for new technologies • Quality concerns with new technologies • High equipment costs (not meeting internal rate of return) • Diminishing returns on existing technologies, particularly LED lighting • Supply chain issues (e.g., heat pumps, sensors) • Grid instability • Limited availability and affordability of low-carbon fuels • Absence of a collective waste-to-energy strategy • Permitting/regulatory delays/challenges (e.g., interconnection standards)

- Lack of assistance in market transformation for energy efficiency products
- Lack of clear mechanism and roadmap

3.2. Breakout Session Summary for Topic 2: Greenhouse Gas Emissions (Scope 1 & 2 Emissions)

3.2.1. Technology Opportunities

Discussions focused on efficiency measures, waste management and waste-to-energy solutions, combustion advancements, electrification, and carbon capture and utilization as means to reduce GHG emissions. Synthesized results from all six breakout sessions are provided below.

- From an efficiency standpoint, **strategic energy management (SEM) programs** can help industry stakeholders implement continuous improvement initiatives that systematically address energy usage and achieve energy performance improvements, resulting in a reduction in GHG emissions. More sophisticated **automation**, through enhanced data availability via the installation of more **sensors**, can allow for better process and equipment optimization.
- **Improved effluent management** and treatment offers **waste-to-energy solutions** to offset fossil fuel consumption, including biogas and RNG production from anaerobic digestion of organic wastes. For the dairy industry specifically, waste digesters can be distributed, given high concentrations of organic materials in dairy wastewater. Waste digesters were also identified specifically as a means to support **microgrid development** among dairy farmers, producers, and processors through generation of cleaner electricity, which could then enable facilities to provide grid services. The ideal microgrid, per stakeholders in the dairy segment, would include **integration between waste digesters** among facilities and farmers within a region as well as energy storage capabilities to modulate output during times of low energy demand. Moreover, facilities connected to a microgrid, assuming they are also tied to the main electrical grid, would benefit from improved reliability of operations should unexpected outages occur, given the enhanced redundancy in electrical supply.
- On the farming side, improved **manure management practices** should be prioritized. Solutions like enhanced **feed additives** and **methane inhibitors** can improve nutrient optimization while reducing enteric emissions of livestock.
- **Combustion improvements** can also be made through upgrading/retrofitting older equipment with **higher-efficiency furnaces**, which was noted to be a common industry

practice that should continue. From an R&D standpoint, there is a need for **fuel-flexible burners** to be able to accommodate low-carbon fuels like **hydrogen** to offset natural gas usage. **Biomass** also offers an alternative fuel source to traditional combustion of fossil fuels to generate process heat. Additionally, improved automation and control systems can help to **reduce NO_x emissions**—a particular benefit when using hydrogen combustion, which increases them. Finally, combustion equipment that supports **CHP** and, on a larger scale, **district energy systems** can provide clean heat and electricity to centralized industries that can share resources. There are large industrial parks in China that follow this model.

- **Electrification technologies** also can reduce emissions intensity of food and beverage operations by transitioning away from fossil fuel sources as a means to generate process heat. Specifically, **electrified high-pressure steam generation** technologies, such as electric boilers, offer a widely applicable means of generating clean and affordable process heat used in many food and beverage processes to eliminate fossil-fuel-combustion-based technologies.
- Electrotechnologies that **combine heat recovery with high-temperature heat pumps (HTHPs)** also offer an alternative to fossil fuels for steam generation. **High-pressure processing technologies** can also be employed to extend the shelf life of perishable foods, both packaged and unpackaged. This non-thermal preservation method can both reduce waste on the supply chain and consumer sides and eliminate traditional process heating technologies that result in emissions from fossil fuel consumption.
- CO_2 shortages and overall lack of availability of purchasable CO_2 on the market for food and beverage operations were noted. Deploying more **carbon capture technologies** can both reduce emissions and help address the market shortages of this commodity. Boilers, specifically, are very large CO_2 emitters, owing to the flue gases traditionally released/vented to the atmosphere. A participant the proteins breakout mentioned **$CleanO_2$**, a newer technology that converts CO_2 in the boiler stack gases to soda ash for subsequent capture. **$CleanO_2$** will soon be in the commercialization phase.

Table 3.2.1 summarizes the results of the discussion on technology opportunities for GHG emissions reductions across all six breakout sessions.

Table 3.2.1: Technology Opportunities for GHG Emissions Reductions Identified in All F&B Breakout Sessions

Technology Opportunities Identified for GHG Emissions Reductions
• SEM programs • Automation technologies, e.g., sensors for issue detection and response • Solid waste and effluent management for waste-to-energy • Wastewater digesters for RNG • Microgrid development via waste digesters • Manure management and feed additives • Combustion equipment/burners with the ability to utilize hydrogen as a fuel • Biomass combustion • Efficient combustion and burner designs to target low NO_x emissions • CHP and centralized industries for district energy systems • Electrified high-pressure steam generation technologies to produce affordable process heat • Electrification • Combined heat recovery and HTHPs • High-pressure, non-thermal processing technologies to extend shelf life of perishable foods • Carbon capture opportunities coupled with shortage of purchasable CO_2 on the market • CleanO_2 technology designed to produce soda ash from CO_2 in the flue gas from boilers

3.2.2. Challenges and Barriers

Challenges identified in the breakout session for GHG emissions reductions were wide-ranging and focused on baselining of emissions, limitations in industry capabilities with regard to workforce training and legacy equipment upgrades, and limited infrastructure. Additionally, lack of technology options on the market and current electricity pricing were identified as barriers to new technology adoption. Finally, certain factors contribute to industry hesitation and, when coupled with certain regulatory aspects, can complicate and slow the execution of industrial decarbonization strategies. Consolidated results from all six breakout sessions are summarized below.

- **A reliable and standardized approach for establishing baseline emissions** would better ensure credibility and transparency and also enable effective benchmarking so companies can accurately identify areas in which they may be lagging or excelling. The **lack of current mechanisms** is also an obstacle in regulating businesses from a policy standpoint, adding to ambiguity in consistently and accurately baselining emissions.

- The current workforce requires **training** on deploying, operating, and maintaining new decarbonization technologies to ensure overall process reliability and product consistency. Additionally, the baking and snacks breakout session noted specific training is required to address the **safety aspects** related to hydrogen utilization. To further complicate this challenge, there is a **disparity among industry capabilities**. As a result, smaller facilities and/or facilities with fewer resources may not be sufficiently prepared to adopt new technologies to facilitate emissions reductions.
- There is often simply a **limited number of engineers** to manage and execute the installation and/or retrofits of new technologies. This is especially true for larger organizations that seek to scale and standardize emerging technologies and strategies across a range of industrial sites, given the sheer number of units requiring upgrades.
- **Upgrading legacy equipment**, such as large industrial boilers, is also very costly and requires extensive resources. Additionally, **integration challenges** may arise when deploying certain technologies. Combinations of waste heat and HTHP technologies, in particular, require precise amounts of heat at exact temperatures to satisfy process demands for successful integration. For onsite generation technologies such as CHP, **balancing heat and electricity** can be challenging, especially for industrial sites where process demand varies for both.
- From an **infrastructure** standpoint, industrial sites often have limitations. For example, when considering integration of carbon capture technologies for boilers, there are often **spatial constraints**, as boiler rooms are typically not built to accommodate new technologies with larger footprints.
- Infrastructure is also a limiting factor in **hydrogen integration** and utilization for combustion operations, as noted in the baking and snacks breakout. Hydrogen combustion is complex and entails additional safety considerations that must be addressed both at the distribution level and within the plant. Hydrogen is not widely available as a fuel source, so there is currently very limited opportunity for integration.
- There is also insufficient **electrical infrastructure** to support commissioning of additional electrification equipment. This limitation is not only at the distribution level; plants often do not have their own infrastructure to supply the amount of electricity required for heat generation to support process operations. Thus, deploying electrified ovens in the baking industry or expanding the use of EVs to reduce Scope 3 emissions, for example, is not feasible for many facilities without significant investment in electrical infrastructure, in addition to the already large equipment investment required.

- There is a **lack of available technology** suitable for replacing existing equipment within manufacturing facilities. Many mature technologies have been demonstrated and proven and yet are not widely available for deployment (e.g., high-efficiency and hydrogen boilers and furnaces). Commercialization of mature technologies that have been demonstrated is crucial, as businesses and/or financiers may be hesitant to invest in such technologies in the absence of a strong business case or market demand. Reducing GHG emissions requires innovative solutions to address these technological gaps and facilitate a transition toward more sustainable industrial processing and heating systems.
- Stakeholders in the dairy products breakout session noted that producers in rural areas often do not have access to real-time electricity pricing and have **flat-rate pricing** instead. Thus, there is little incentive or financial justification to support improvements in grid services, such as modulating operations or reducing energy usage during peak periods of electrical demand. On a similar note, **electricity** currently costs significantly more than natural gas, which calls into question the cost-effectiveness of electrification technologies. Moreover, the outlook for pricing indicates that natural gas will continue to cost less than electricity, which further disincentivizes investment in this area.
- Multiple factors contribute to overall industry hesitation to adopt new technologies for carbon emissions reductions. From a cost standpoint, **significant capital investments** are often required to deploy new technologies in place of existing processes and equipment. Hesitation toward investment is further compounded when **company culture values short-term profitability** over long-term sustainability gains.
- There is also significant concern for changing legacy processes and equipment, given consumer sensitivity toward **product changes**. Baking and Snacks stakeholders specifically noted that if the industry switched from open-fired ovens to electrified heating solutions, many consumers would notice differences in the **quality** of baked goods. This was also the case for hydrogen-based combustion, given differences in the flame and heating attributes compared to fossil-fuel-based combustion. In the dairy products breakout, cheese producers were specifically mentioned as being especially resistant to changing their production methods. Additionally, implementing new technologies also poses risk to the process in terms of control and consistency. Overall, processors do not seem to be very focused on implementing novel processes to make their products but are likely more open to cross-cutting solutions, such as technologies that focus on drying.
- The term **"green hushing"** characterizes an organization's hesitation to publicize its sustainability goals and targets. Reasons for this may vary, but **public perception** favoring complete neutrality in emissions over incremental improvements can lead to

companies not implementing intermediate strategies or technologies that would achieve partial decarbonization.

- To progress with decarbonization efforts, industrial sites must navigate various regulatory aspects, which pose certain challenges. For instance, from a **policy standpoint**, there are hurdles specifically related to waste feedstock utilization for digesters within local markets, as identified in the dairy products breakout. One stakeholder noted a case where a client was not able to implement a dairy digester at their facility, given that the whey waste product was already being used as a fertilizer in the area. These permitting issues for commissioning waste digesters that can incorporate biomass sources can hinder sites from transitioning away from fossil fuel resources. Specifically, almond shells were noted in the grains and oilseeds breakout as a great biomass feedstock, but obtaining a permit to use this resource is cumbersome.
- In some instances, GHG credits can be negatively affected if **waste feedstocks** other than manure are accepted and processed. Overall, these policy challenges can limit expansion of waste-to-energy solutions. On the supply chain side, the fruits and vegetables breakout noted a **misalignment** between the constrained power capacity of EVs in carrying substantial loads and existing regulations that permit product weights beyond the operational capabilities of EV trucks. This incongruity underscores the necessity for regulatory revisions to align with and incentivize the adoption of EVs equipped to manage larger payloads. Moreover, advancements in battery storage technology are imperative for EV trucks tasked with transporting sizable loads, making regulatory adjustments and technological enhancements mutually integral for the seamless integration of electric transport into freight operations.

Table 3.2.2 summarizes the results of the discussion on challenges and barriers for GHG emissions reductions across all six breakout sessions.

Table 3.2.2: Challenges and Barriers for GHG Emissions Reductions Identified in All F&B Breakout Sessions

Challenges and Barriers to GHG Emissions Reductions
• Difficulty baselining emissions • Lack of mechanisms for measuring emissions • Workforce training needs to adapt to, operate, and maintain new technologies • Disparity in industry capabilities • Legacy equipment – difficulty in upgrading and integrating due to resource challenges • Boiler room limitations that hinder adoption of new technologies with larger footprints

- Limited infrastructure and distribution networks to support a robust hydrogen supply chain
- Electrical infrastructure limitations at the plant level to support implementation of electrified technologies
- Unavailable technologies
- Flat utility pricing rates for rural producers, disincentivizing optimization of grid interactivity
- High cost of electricity compared to natural gas
- Significant capital investments required (i.e. investment, cost savings, and GHG reductions)
- Organizational culture to recognize short-term profitability sacrifices for long-germ sustainability gains
- Product quality concerns and consumer perception associated with hydrogen combustion and electric heating technologies
- “Green hushing” and public perception – hesitation to make incremental improvements when consumers may prioritize complete neutrality
- Permitting limitations for biomass feedstock expansion (e.g., almond shells, which are a great feedstock but hard to permit)
- Misalignment between technology availability and regulation
- Lack of mechanisms for measuring emissions

3.3. Breakout Session Summary for Topic 3: Water Conservation

3.3.1. Technology Opportunities

Breakout discussions focused on improved monitoring related to smart manufacturing practices, along with efficiency measures industrial sites can take to reduce water usage. Additionally, specific technologies that enable improved separation and reuse and electrification technologies to support low- and/or no-process heating operations were identified. Synthesized results among the six breakout groups are described below.

- **Improved water usage and energy consumption monitoring** for various water operations, including boilers, water treatment, and pumping/transport operations, would facilitate improved identification and execution of water reduction measures. **Smart manufacturing** and **improved sensor technology** can help to better inform decision-making in real time to optimize water usages for various processes. Furthermore, the establishment of **leak detection and repair programs** is a proven practice that is important for sustainable industrial water management.
- From an efficiency perspective, there are several strategies facilities can pursue to support water conservation goals. First off, Grains and Oilseeds stakeholders noted that **irrigation efficiency** measures should be prioritized on the farming side for

optimization of resources, especially in regions facing water scarcity concerns. Additionally, **equipment/process efficiency improvements** are a common strategy utilized within the industry to reduce water usage. For example, upgrading to water-efficient fixtures and adopting water-efficient cleaning methods can greatly reduce overall water consumption.

- **Heating and cooling** are the most energy-intensive elements of water operations for the industrial segments in question, so technologies focused on addressing these processing steps are of high interest. On the cooling side, cooling tower operations and evaporative processes to facilitate refrigeration (via heat removal) require large amounts of water. Improved water treatment practices can facilitate reduced usage for these operations. Finally, optimization of traditional **distillation processes**, which are very water- and energy-intensive, is a major opportunity to reduce water consumption of these legacy systems.
- Technologies to enable improved separation processes and water reuse can further improve water conservation efforts and reduce heat traditionally required for certain operations. For instance, **membranes** need to be further developed to improve separation and function at higher temperatures to expand their potential application. In the baking and snacks segment, there is opportunity for **moisture removal in dough before baking**, as this reduces the amount of water that must be "baked off" in the oven, thus lowering the energy intensity of this equipment.
- **Atmospheric water generation (AWG)** could be used to extract water directly from air, given significant levels of moisture present within oven stacks from baking operations that traditionally get vented to the atmosphere. Thus, AWG is a mechanism for condensing the moisture in these exhaust streams, which enables water recovery and reuse opportunities.
- For industrial sites that have **wastewater treatment** capabilities, technology pathways that can facilitate **zero-liquid discharge** should be prioritized, as this enables further water capture and reuse opportunities upstream. This not only limits waste sent to the sewer but also presents valorization opportunities for the remaining solids waste post-water removal. On a similar note, **improved and compact water filtration technologies** that enhance separation processes, such as **ultrafiltration** and **precipitation**, were identified as a priority, as these technologies can improve water cleaning/treatment to expand water reclaim opportunities that offset freshwater consumption. Finally, technologies and strategies should also be implemented that enable **chemical and heat recycling** within a facility, which represent the commodities necessary for a variety of water treatment operations.
- Electrification technologies for water treatment should be prioritized to reduce and/or eliminate process heating traditionally produced through combustion of fossil fuels. **High-pressure and microwave technologies** as part of electrification offer no-heat water treatment options that can boost efficiency and reduce emissions

intensity. Ultraviolet-C LED **(UV-C LED)** water treatment/purification is a newer technology identified that has potential to significantly reduce water consumption and offers an electrified solution to traditional distillation.

Table 3.3.1 summarizes the results of the discussion on technology opportunities for water conservation across all six breakout sessions.

Table 3.3.1: Technology Opportunities for Water Conservation Identified in All F&B Breakout Sessions

Technology Opportunities Identified for Water Conservation
• Improvements in water usage monitoring, including monitoring systems for water use and energy consumption • Smart manufacturing and sensor technology to inform decision-making • Leak detection and repair programs • Irrigation efficiency in response to water scarcity concerns • Equipment/process efficiency improvements, e.g., water-efficient fixtures • Heating and cooling optimization • Optimization of existing distillation systems • Membrane technologies that function at high temperatures • Separation technologies to reduce moisture content in dough before baking • AWG for water recovery in oven stacks • Low-energy zero-liquid discharge systems for water treatment • Improved and compact water filtration technologies to enable reuse practices (e.g., ultrafiltration, precipitation, and enhanced separation) • Technology for chemical recycling and heat recycling within a facility • Electrified technologies, including high-pressure, microwave, and UV-C LED, for no-heat water treatment operations

3.3.2. Challenges and Barriers

During the six breakout sessions, specific barriers were identified that tie to process and equipment limitations. Additionally, challenges associated with infrastructure, quality concerns, industry awareness, and regulatory aspects were also discussed. Synthesized results from the breakouts are detailed below.

- From a process standpoint, many **cleaning operations** require **excessive time and operator setup**, monitoring, and intervention to successfully execute. Reducing or eliminating such manual intervention would both improve productivity and minimize water consumption. On the agricultural side, the grains and oilseeds breakout group noted that there are **peak duration usage requirements** associated with crop survival.

These needs can be temporal or seasonal and can constrain water resources during periods of high demand.

- On the equipment side, **filtration methods** for water treatment can be very costly and **maintenance-intensive**. They pose operational challenges, especially for sites with limited resources and/or manpower. The associated **high capital and maintenance costs** are attributed to limited membrane robustness and longevity, so these methods are not ideal solutions for many separation needs. AWG applications, a potential technology opportunity identified, face certain **climate restrictions**. Specifically, these systems operate most optimally at warmer temperatures and higher humidity levels for maximum moisture separation. Deviations from these environmental conditions can affect the efficacy of water capture, as well as increase energy requirements of an AWG unit. Seasonal variations within a certain region (i.e., summer vs. winter months) can also make it more difficult to use such systems continuously.
- From a facilities/infrastructure standpoint, **spatial constraints** can limit deployment of new technologies with larger footprints. Additional piping requirements for water transport can further exacerbate such spatial limitations.
- Specific quality concerns were identified both from a water treatment and end product standpoint. Regarding source water, sites located by **water sources of poor quality** often must employ additional treatment methods that lead to increased water and energy consumption. A packaging producing company was specifically noted in the grains and oilseeds breakout where well water onsite was of poor quality, which required the need for aeration, a highly energy-intensive process, and chemical additions for proper treatment.
- Regarding industrial operations involving livestock, as discussed in the proteins breakout, **animal welfare considerations** are a potential barrier, particularly in regard to new cleaning technologies that could impact said livestock during slaughtering/meat processing operations. In terms of the end product, the baking and snacks breakout discussed how **product quality concerns** can arise with separation technologies that facilitate removal of moisture in dough before baking. Efforts are underway within this segment to try to better understand the product changes, as well as opportunities to mitigate impacts on the final end product.
- Certain challenges exist with regard to limited industry awareness and increased industry hesitation to adopting new technologies for water conservation. From a high level, an overall **improved strategic understanding of water use** is needed to comprehensively address the water scarcity challenges in specific regions around the United States. Although water scarcity is an issue, water is not often a major cost driver, which can lead to a slower response and/or lack of prioritization on water savings initiatives.

- Industry stakeholders may also have **limited awareness** of how water conservation efforts can lead to subsequent emissions reductions. Even though there is a cost associated with water, industry personnel do not always associate water usage with carbon emissions. Further complicating this problem is the fact that **monitoring energy usage** related to water operations is often ambiguous and complicated. This potential lack of understanding in certain cases may limit the incentive for pursuing water savings initiatives, so a consistent approach for monitoring would better enable industrial sites to identify opportunities for reduced consumption.
- From a technology standpoint, a few significant hurdles were identified. First off, there is a **lack of technological solutions** to assist in increasing water conservation across the industry. More R&D is required to increase the availability of off-the-shelf options and increase widescale adoption. Breakout session participants noted that technological advancements in water conservation are occurring globally, with some countries implementing innovation solutions that are not available for adoption in the United States. Further compounding this problem is limited industry awareness of the R&D space, as it can be challenging for industrial sites to stay abreast of emerging technologies. Finally, cost is a barrier that increases industry hesitation toward investment. Specifically, new technology options identified, such as UV-C LED, are noted to have **high capital costs** that are often unattractive to industry despite water-savings potential.
- **Regulations for wastewater treatment** often vary at the local, state, and federal levels. Navigating these different regulatory frameworks is often confusing and challenging for industry. For example, stakeholders in the baking and snacks breakout noted that California allows a facility to recover water within wastewater treatment operations and reuse it upstream, whereas certain other states do not. From a scalability standpoint, for an organization with facilities across multiple states, use of certain technologies may have limited applicability that is dependent on location.
- Additionally, specific U.S. Food and Drug Administration **(FDA) regulations** were seen as challenging. In the dairy products breakout, stakeholders noted regulatory hurdles regarding the FDA specifically limiting water reuse applications for the dairy sector, which can restrain certain reduction opportunities. Stakeholders in the fruits and vegetables breakout group discussed how the industry typically makes more water than it uses, but this water is not potable and **is subject to FDA regulations.** To bring this water up to FDA standards would require significant capital expenditures (CAPEX), which is intensified by the seasonality and low marginality of the fruits and vegetables segment.

Table 3.3.2 summarizes the results of the discussion on challenges and barriers for water conservation across all six breakout sessions.

Table 3.3.2: Challenges and Barriers for Water Conservation Identified in All F&B Breakout Sessions

Challenges and Barriers to Water Conservation
• Cleaning operations requiring excessive time, setup, and/or intervention • Peak duration usage requirements • High costs, maintenance-intensive operations, and limited lifespans for existing membrane technologies • Limited use of AWG technologies, based on climate • Space constraints for implementing water reuse technologies in smaller plants • Poor water quality • Animal welfare considerations for certain cleaning technologies • Product quality concerns associated with moisture removal before baking • Need for improved strategic understanding of water, especially in regions with water scarcity challenges • Limited awareness on water savings benefits and technology options to enable usage reductions • Inconsistent monitoring of energy related to water operations • Lack of products on the market • High costs • Regulatory hurdles and variability in local regulations on acceptable water treatment and reuse practices

3.4. Breakout Session Summary for Topic 4: Waste Management and Circular Economy

3.4.1. Technology Opportunities

Breakout discussions focused on methods for improving recycling and co-product valorization efforts. Additionally, opportunities were identified that tied to combustion, farming, waste processing, and materials usage related to the supply chain. Consolidated results from the six breakout sessions are presented in detail below.

- From a recycling standpoint, several opportunities exist to reduce waste that traditionally would get sent to landfill. First, the use of **machine learning and/or AI through a recycling application** would be beneficial to industry in guiding and informing on recycling practices for specific materials. Such an app would ensure improved and more streamlined information-sharing on waste streams, locations, best practices, and potential demand for certain materials between organizations and would also provide quick direction on appropriate reuse methods, depending on the specific waste type.

- Strategies to improve reverse logistics are needed to move products more efficiently up the supply chain for reuse and recycling. On a similar note, **colocation of facilities**, where a waste stream from one process can be used as an input/feedstock to another process, improves waste stream utilization and reduces transport costs and associated emissions. Overall, **localization of operations** is a means to reduce waste, as exemplified by Coca Cola in materials sourcing (as noted by beverage breakout participants). Such practices could also enable more local sourcing, tailored recycling programs, and closer supply chains. Finally, **local reuse processes**, combined with incentives (i.e., a carbon tax), would address recycling challenges and encourage purchases of recycled materials over virgin products.
- In terms of waste management, **co-product valorization** offers a means for sites to generate additional revenue. Improved methods of fractioning biomass can expand resource utilization in which each fraction can be used for specific applications, thus maximizing value derived from the biomass resource. Specifically, almond husks were noted in the grains and oilseeds breakout as a suitable feedstock to produce fermented animal feed, for example, while waste husks (i.e., fiber) as a feedstock can benefit many products.
- To enable such upcycling initiatives, **improved separation processes for feedstocks** are needed to segregate waste components so they can be utilized within different processes (e.g., composts and fertilizers). Finally, **enhanced chemical extraction processes** are needed to enable an easier and cheaper means to recover valuable chemicals at very low concentrations within waste streams to enable reuse.
- **Biomass boilers** are needed to provide a further pathway for waste utilization and offset of fossil-fuel-based combustion. A stakeholder in the baking and snacks breakout noted a biomass boiler at their facility capable of burning oat hulls. Similar solutions and/or retrofits are needed for widescale adoption.
- On the farming side, **regenerative agriculture** practices can improve soil health and reduce water requirements, which is especially critical in regions with water scarcity challenges.
- **Food waste processing** presents waste-to-energy solutions that should be a primary focus. **Aerobic and anaerobic digestion systems** provide a means to process this waste and generate biogas as a byproduct that can be used as a fuel source. One stakeholder in the baking and snacks breakout specifically noted their facility's aerobic digestion system to process potato peel waste. Similarly, wastes can be processed and utilized as fertilizers, rather than being directed to landfill. **Drying technology improvements** are needed to remove moisture from waste, thereby

reducing transportation costs and emissions. On the agricultural side, **biodigesters** can enable better processing of waste streams while providing value-added co-products to the farming industry, which was also identified as a potential collaboration opportunity between DOE and the U.S. Department of Agriculture.

- There are several key opportunities for both reducing and improving materials usage across the supply chain. The first priority is technologies or strategies that enable **repurposing of materials** to reduce waste, including onsite pallet rebuilding systems. Methods for **reducing single-use plastics** are also needed. Innovations in packaging would enable this, including expansion of biodegradable packaging, utilization of biomass as a feedstock for plastic packaging production, and eliminating overpackaging of products.
- Sustainable packaging and **reusable packaging** within the supply chain are crucial elements in reducing environmental impact. Similarly, product delivery systems can be revisited to minimize waste. Overall, these measures can reduce long-lasting waste associated with plastics and can reduce the accumulation of waste in landfills. Finally, improvements in material **design for circularity** can minimize waste and make the most of limited resources by keeping products in use for as long as possible. Attributes like recyclability, durability, ease of disassembly, and biodegradability, as mentioned, should be incorporated into material designs.

Table 3.4.1 summarizes the results of the discussion on technology opportunities for circular economy across all six breakout sessions.

Table 3.4.1: Technology Opportunities for Waste Management and Circular Economy Identified in All F&B Breakout Sessions

Technology Opportunities Identified for Circular Economy
• Recycling application using machine learning and/or AI to guide and inform recycling practices • Recycling database with information on waste streams, locations, technologies, and demand for recycling • Colocation of facilities and localization of operations to maximize the utilization of coproducts and waste streams • Local reuse processes and incentives • Coproduct valorization – improved methods of fractioning biomass and utilization of coproducts • Upcycling initiatives to valorize and promote use of biomass waste • Improved separation processes for feedstocks to enable valuable use, such as in composts, fertilizers, and fermented animal feeds • Targeted chemical extraction methods for removal of valuable chemicals in waste streams at low concentrations

- Boilers capable of combusting biomass generated from food waste
- Regenerative agriculture
- Aerobic and anaerobic digestion systems for waste-to-energy conversion (potential collaboration opportunity with the U.S. Department of Agriculture for farming applications)
- Improved drying technologies for waste to lower transportation costs
- Onsite pallet rebuilding to repurpose materials
- Reduction of single-use plastics
- Biodegradable and reusable packaging
- Material design for circularity

3.4.2. Challenges and Barriers

Challenges identified in the breakout sessions were diverse, focusing on limitations of current recycling methods and industrial facilities. Additionally, barriers related to high costs, quality concerns, lack of industry and consumer awareness, and specific aspects of the supply chain were also discussed. Synthesized results from all six breakout groups are provided below.

- **Limitations of current recycling capabilities** on a mass level often lead to recycled materials going to landfill. For instance, dirty and/or contaminated plastics, even if recycled, may not be processable and thus cannot be reused. **Waste streams** for handling the disposal of compostable materials are currently ineffective, as existing methods do not accommodate them constructively, so most waste goes to landfills. U.S. exports are even more problematic, as there is little to no control over **disposal methods abroad**.
- The implementation of circular economy approaches faces issues attributable to **inadequate recycling infrastructure** and the **absence of standardization across jurisdictions**. This poses challenges for producers aiming to establish uniform packaging standards, as well as confuses customers regarding the recyclability of materials in their respective regions. Finally, innovations are required to improve the **recyclability of packaging** while adhering to FDA food-grade requirements and preserving the shelf life of fruit and vegetable products. Specifically, there is a pressing need for innovative solutions in developing **plastics that can withstand thermal processing**, which would contribute to a more comprehensive approach to sustainable packaging solutions.
- At the facility level, depending on an organization's culture, **facility contention** can lead to employees avoiding or overlooking recycling and reuse opportunities if they perceive this as extra work added to their typical job duties. Facility contention can also result if operators feel they had **limited input in the design of systems,** which can

result in disengagement towards organizational goals and/or sustainability practices. Regarding waste processing technologies, systems such as aerobic digestion **occupy large footprints**, and thus it may not be feasible for facilities to install such systems. Therefore, opportunities for waste reuse and waste-to-energy may be lost because of spatial limitations.

- From a cost standpoint, organizations face **high CAPEX investments** required to overhaul legacy waste reduction processes, often resulting in long payback periods. Specifically, the dairy products breakout session noted that the ice cream industry was researching waste reduction mechanisms on the manufacturing side. Legacy processes were not designed with waste minimization as a primary consideration, and mitigating losses requires a major overhaul of these processes and associated equipment. Furthermore, transporting ice cream mix through pipes without creating waste is very difficult, given the product's singular properties, so further research in this area was identified as a priority.
- Virgin products can be less expensive than recycled products, especially when the former are purchased overseas. In the **absence of a carbon tax**, purchasing recycled and reused products is not incentivized, and businesses typically seek the lowest-cost option. Additionally, challenges may arise in implementing a carbon tax to incentivize local recycling, considering potential economic impacts and competitive product costs.
- Localizing operations involves **quality concerns**, such as differing ingredient sources or water availability and quality on a local level that could have negative impacts on product consistency.
- **Lack of industry awareness and education** on circular economy strategies and best practices can lead to excess waste. There is a significant amount of **waste at the consumer level** that most often goes directly to landfill. Consumer behavior is modified through incentives, which can be positive or negative. An example of a negative incentive is charging consumers a small fee for grocery bags to reduce plastic waste.
- **The lack of standardization on shelf life for packaged products** contributes to food waste throughout the supply chain. For example, where nearly 60% of onions are wasted before ever reaching the consumer. Additionally, expiration dates are often inaccurate. One stakeholder in the grains and oilseeds breakout mentioned a study analyzing palm oil. After ten years, the palm oil was close to acceptable, yet the common shelf life for this product is only one year.
- **Temporal availability and lack of robust transportation networks for feedstocks** generated from waste valorization efforts is a major challenge. Often, only certain feedstocks are available in specific regions or time periods throughout the year. This

variability makes it difficult to ensure an adequate feedstock supply to other processes and/or facilities that have a continuous demand for said feedstocks. **Monetizing waste streams** can also be challenging, given the energy and processing requirements to valorize products to be sold on the market. The **limited transportation networks** for waste transport further increase costs, which reduces profitability. Stakeholders from the baking and snacks breakout noted that it is sometimes easier to simply divert food waste to local farms to be used as animal feed vs. trying to process, valorize, and sell to a certain market.

- From a **regulatory** standpoint, the lengthy process of obtaining **FDA approval** for new food-grade packaging compounds the situation, causing frustration and reluctance among stakeholders when transitioning to more sustainable packaging solutions.

Table 3.4.2 summarizes the results of the discussion on challenges and barriers for a circular economy across all six breakout sessions.

Table 3.4.2: Challenges and Barriers for Waste Management and Circular Economy Identified in All F&B Breakout Sessions

Challenges and Barriers to Circular Economy
• Difficulty in recycling dirty and/or contaminated plastics in lieu of limitations on current recycling capabilities • Disposal of compostable materials • Lack of control over global recycling • Recycling infrastructure and lack of standardization • Lack of new technologies • Facility contention – perceived as extra work and/or difficult if plant is poorly maintained • Lack of operator input in design of systems, leading to less commitment/buy-in • Large footprint required for anaerobic digestion (i.e., space constraints) • High CAPEX costs for overhauling legacy processes to reduce waste (e.g., difficulty limiting waste of ice cream mix through pipes) • Financial incentives and product cost • Quality concerns with localized operations • Lack of industry education and awareness on improved circular economy practices • Excessive food waste – need incentives at the consumer level • Lack of standardization in determining shelf life for packaged products (e.g., 60% of onions wasted before reaching the consumer) • Temporal availability concerns and lack of transportation of feedstocks • Difficulties in monetizing waste streams

- Costly and limited transportation networks to support waste management efforts
- Regulatory and permitting challenges

3.5. Breakout Session Summary for Topic 5: Supply Chain Sustainability (Scope 3 Emissions)

3.5.1. Technology Opportunities

Breakout discussions focused on waste reduction and collaboration opportunities between suppliers and customers to boost supply chain sustainability. Additionally, packaging strategies, transportation improvements, and data-sharing mechanisms were discussed. Finally, breakout participants discussed improved farming practices, along with quantifying carbon costs to influence supplier selections. Consolidated feedback from all six breakout sessions is presented below.

- Focusing on **downstream waste reduction** methods will yield the largest impact, as this area accounts for over 75% of total waste in food and beverage manufacturing. Such methods can include **bio-digestion** and **post-production waste management** to divert waste from landfills to being used as alternative feed streams for other processes.
- **Enhanced collaboration among suppliers** can also result in synergies. For instance, organizations within the supply chain can collaborate to improve **raw material sourcing**, aiming to supply and purchase materials with lower embodied carbon emissions. The grains and oilseeds breakout session noted the example of foldable containers, which can allow more storage in a shipping unit on a return journey, thereby reducing transportation costs.
- In terms of **waste management**, stakeholders in the baking and snacks breakout mentioned a recent partnership between Bright Feeds and Ocean Spray: waste from Ocean Spray's processing operations is provided to Bright Feeds as a feedstock to produce animal feed. This collaboration can serve as a model for partnerships to take advantage of waste utilization and reduction opportunities, given the significant amount of food waste within the supply chain and at the consumer level—food waste that currently gets sent to landfill. One participant also referenced collaboration initiatives between their sustainability office and suppliers; the company holds an annual meeting to bring said suppliers together to share best practices. Large organizations that work with many suppliers could have a significant impact through such coordination efforts.
- Suppliers can collaborate with their buyers to implement **customer-driven changes** for improved sustainability. Organizations should set sustainability goals with

suppliers to drive the direction and strategy so suppliers know what actions they should prioritize to meet said goals. Not only can such changes lower embodied emissions of products sold, but doing so can also lead to an improved organizational reputation, which can lead to further opportunities for partnership.

- Packaging innovations can offer a range of sustainability benefits. For instance, advanced technologies to facilitate **cost-effective and streamlined de-packaging** operations enable product waste to be utilized as animal feed, rather than going to landfill. Additionally, innovations for **cheap, waterproof packaging** can help to eliminate waste and pollution associated with plastic-based packaging. Packaging **simplification** would reduce the excess use of materials that result in the over-packaging of certain products. Finally, stakeholders in the baking and snacks breakout session noted that packaging in which products can be baked directly could be a means to reduce material waste. Considerations for not melting any materials or creating a fire in the industrial oven would need to be addressed for such a solution.
- On the transportation side, **reverse logistics** is a means to maximize efficiencies. More efficiently moving goods up the supply chain can also expand reuse, reprocessing, and/or recycling efforts. Without proper coordination, something as simple as an incorrect delivery can cause inefficiencies, so reverse logistics should be prioritized.
- **Transportation innovations** to reduce emissions intensity would have a significant impact, as stakeholders in the dairy products breakout attributed a major portion of Scope 3 emissions to the transportation sector. California was noted for their efforts to reduce fossil fuel usage by replacing diesel engines with electric trucks, which could serve as a model for other states.
- Presently, uniform traceability and standardization are lacking throughout the food and beverage supply chain. Divergent methods employed by various suppliers create a challenge for producers in selecting the most suitable products. Implementing a robust **data management and traceability system** that integrates a standardized approach to GHG emissions inventorying is essential for achieving sustainability goals and mitigating Scope 3 emissions across the food and beverage supply chain.
- The introduction of a centralized database for **expanded data collection and sharing** would foster innovation, enabling stakeholders to readily assess product comparisons and better understand how technological advancements can support organizations in meeting their supply chain objectives and reducing Scope 3 emissions. Additionally, such a platform could aid in the optimization of different metrics within the supply chain, such as energy, quality, and transportation costs. Open-source hardware was noted as a platform that allows for public sharing of designs, so a mechanism with a similar type of structure specifically related to supply chain information-sharing could be used. Furthermore, technological solutions such

as **AI** would be very valuable for selecting preferred suppliers based on sustainability criteria through streamlined AI-based assessments of life cycle carbon emissions for materials.

- On the agricultural side, **improved farming** practices such as **regenerative agriculture** can be employed to better ensure biodiversity, improve soil health for future growing, and reduce water usage. Stakeholders in the baking and snacks breakout also mentioned collaboration with their farmers to share regenerative practices to promote more sustainable farming. Furthermore, additional funding toward **vertical farming** should be considered to reduce land use, promote efficient use of resources such as water, and improve overall resilience of food and beverage production.
- **Carbon costs**, enabled by improved data management, should be integrated within supplier selection, motivating procurement officers to select their suppliers based not only on cost but also on their ability to reduce carbon footprints (thereby allowing incentives at the company level to drive sustainability).

Table 3.5.1 summarizes the results of the discussion on technology opportunities for supply chain sustainability across all six breakout sessions.

Table 3.5.1: Technology Opportunities for Supply Chain Sustainability Identified in All F&B Breakout Sessions

Technology Opportunities Identified for Supply Chain Sustainability
• Downstream waste reduction opportunities, which constitute >75% of total waste in food and beverage manufacturing • Bio-digestion and post-production waste management to divert waste from landfills • Enhanced collaboration with suppliers (e.g., foldable containers for transportation cost savings and waste management) • Improved raw material sourcing • Customer-driven changes to improve organizational reputation • Technologies for de-packaging waste to use as animal feed • Packaging innovations and simplification – low-cost waterproof replacements for traditional plastic packaging • Reverse logistics to maximize transportation efficiencies • Transportation innovations • Expanded data management, traceability, and sharing (e.g., open-source hardware and data optimization) • AI for supplier management • Regenerative agriculture practices in farming • Vertical farming • Carbon costs for supplier selection

3.5.2. Challenges and Barriers

Challenges identified varied considerably with respect to the supply chain, overall collaboration, and standardization. Barriers were also identified relating to alternative fuels, feedstocks, alternative proteins, and regulatory aspects. Consolidated feedback from all breakout sessions is listed below.

- The absence of a comprehensive supply chain strategy to guide suppliers and organizations in the most efficient practices makes coordination and collaboration difficult. A **supply chain roadmap** that encompasses best practices and success stories implemented initiatives—including sustainability initiatives—would help industry prioritize the most impactful measures to drive decarbonization efforts.
- There are **industry-specific hurdles** or nuances for certain products that may not widely apply to the supply chain collectively. Therefore, there is a need both for comprehensive or cross-cutting solutions to decarbonize the supply chain and for solutions tailored to specific to industries and/or products, which can be difficult to establish at scale, given the diversity of the F&B sector.
- Establishing collaborations within the supply chain can be challenging, as companies are often in **competition**. One party may be unwilling to share best practices that could give the other an advantage. This tendency to harbor information makes standardization and information-sharing difficult. Stakeholders in the grains and oilseed breakout noted that DOE Tech Assistance could serve as an intermediary, providing shared resources to help all become more sustainable.
- Participants identified cost as one of the most significant barriers to implementing new decarbonization strategies and/or technologies. Organizations across a supply chain do not want to take on all of the costs associated with a sustainability initiative, nor do they want to have costs passed down to them from other companies within the supply chain. The **absence of a cost-sharing model** for supply chains can lead to inertia rather than to aggressive action to reduce embodied emissions of products. On a related note, **lack of innovating financing mechanisms** can often inhibit incentive for investment in the value chain. Financing mechanisms could include exchanges or platforms where different entities within the supply chain interact and collaborate on research opportunities such as technology, sustainability practices, product development, or other aspects that have potential to result in industry growth and mutual benefits for supply chain partners.
- Better alignment is needed regarding **data monitoring and reporting** and **the sharing of best practices for the supply chain**. Moreover, **switching suppliers** can be hindered by the resources (time and money) involved, as many organizations have established long-term agreements and relationships with suppliers.

- Regarding waste-to-feed streams, the current **marketplace is underdeveloped**, meaning there is more waste from sites that could be valorized than there are current buyers/users of said waste products.
- The industry **lacks standardization** in reporting emissions, which poses a challenge in collecting comprehensive emissions data. This makes it difficult to obtain accurate and consistent information, hindering the development of effective emissions reduction strategies. A crucial step toward implementing incentives for supplier selection based on sustainability criteria would require **effective measurement of Scope 2 and 3 carbon emissions** to enable informed decision-making. This could be improved through establishing the **necessary technological infrastructure** for comprehensive tracking of carbon emissions and recycled materials across the food and beverage system. Establishing industry-wide standards from a policy standpoint could also facilitate more effective benchmarking and collaboration.
- Multiple barriers inhibit the transition away from fossil fuel sources to low-carbon fuels and/or electrified technologies:
    - There is a **lack of hydrogen infrastructure and availability** to support moving away from natural gas to hydrogen combustion.
    - Although electrification technologies offset fossil fuel usage, emissions are still significant since the current **electrical grid** is **not fully decarbonized**, limiting potential reduction of embodied emissions of products that move through the supply chain.
    - As noted in the dairy products breakout, dairy farms in rural areas often **lack** access to **charging infrastructure**. The use of electric trucks to transport goods is often very limited at this stage of the supply chain, which inhibits Scope 3 emissions reductions.
- **Feedstock variability** is a barrier to maximizing and valorizing waste-to-feed streams. Better inline sensing and analysis are needed to improve real-time monitoring and control, enabling quick adjustments to processing parameters so that optimal conditions can be maintained when feedstock quality varies.
- The **alternative protein** space represents a **market disruption** and poses integration challenges for the current food system. Achieving economies of scale with these new products is a challenge. Collaboration is needed between the alternative protein and traditional meat spaces.
- Evolving and **inconsistent regulations** related to emissions reporting and reduction can create uncertainty within the industry, which may lead to hesitancy in making long-term investments or adopting comprehensive emissions reduction strategies. For example, stakeholders in the baking and snacks segment noted U.S. Environmental Protection Agency **regulations for waste management** differ compared

to certain state-level regulations. Thus, a technology in one state, even if determined to be an impactful solution, may not be able to perform at a level congruent to regulations within another state. This makes standardizing waste reduction strategies and technologies complicated.

Table 3.5.2 summarizes the results of the discussion on challenges and barriers for supply chain sustainability across all six breakout sessions.

Table 3.5.2: Challenges and Barriers for Supply Chain Sustainability Identified in All F&B Breakout Sessions

Challenges and Barriers to Supply Chain Sustainability
• Absence of an industry roadmap to maximize sharing of best practices and guide industry in the most sustainable practices • Site-specific hurdles beyond industry norms and challenges specific to individual organizations • Competition between potential collaborators inhibiting sharing of best practices • Lack of a cost-sharing model within supply chains between suppliers and buyers related to sustainability efforts • Lack of innovative financing mechanisms to spur investment • Time and cost impacts for switching suppliers • Lack of developed marketplace for waste-to-feed streams for better resource utilization • Lack of standardization and effective ways to measure Scope 2 and 3 emissions • Lack of systems to analyze recycled materials • Limited availability of green hydrogen to support low-carbon fuels integration • Lack of a clean/decarbonized electric grid to reduce embodied emissions of products • Lack of charging infrastructure in rural communities • Need for improved inline sensing and analysis (i.e., AI) to address feedstock variability • Integration challenges of alternative proteins (i.e., “system disruptors”) into the current food system • Lack of industry standards/universally accepted standards • Regulatory challenges • Varying regulations for waste management by region affecting applicability of certain technologies

3.6. Breakout Session Summary for Topic 6: Technology Adoption and Associated Challenges

3.6.1. Technology Opportunities

Top technology opportunities identified for maximum decarbonization impact across all six breakout sessions focused on the following areas: smart manufacturing, efficiency measures, electrification and alternative pathways for process heat generation, data monitoring, grid support and renewables, waste management and circular economy, agriculture, and policy.

Smart manufacturing technologies enable optimization of energy consumption to reduce emissions impacts. Installation of **sensing devices** provides an array of data that can be coupled with control system optimizations to quickly adjust processing parameters in real time. **Edge computing**, AI, and advanced automation can also be incorporated to improve decision-making in order to boost performance and throughput. Smart manufacturing practices can also be applied to **water** treatment to measure and track **energy and emissions** associated with these operations more effectively.

There are multiple decarbonization strategies that can boost industrial efficiency. The installation of variable frequency drives represents "low-hanging fruit" to improve the **efficiency of machine drives** for a variety of equipment. **Heat integration tools** such as pinch analysis can be used to better integrate heating and cooling needs between food and beverage processes to reduce overall utility usage associated with heat/steam generation and refrigeration. **HVAC innovations** specifically can make a significant impact in lowering industrial energy intensity. Equipment such as cooling towers can be optimized to reduce energy and water usage, while alternative processes to traditional ammonia refrigeration, such as **non-vapor compression cooling** approaches, can improve both efficiency and safety of cooling operations. Moreover, **improving condensate recovery** associated with steam generation reduces boiler fuel usage while also lowering water consumption and chemical costs for boiler feedwater treatment. Similarly, exhaust streams from processes like baking and oven operations that vent to atmosphere represent a significant amount of heat and moisture lost. Thus, there is great opportunity for **waste heat capture solutions** to enable integration and reuse of the heat in other lower-temperature processes within a facility. There are also a range of opportunities to **improve combustion** processes associated with both boiler and process heating operations (e.g., baking). Enhanced and highly **efficient combustion** systems that can be **retrofitted** to existing equipment are a top priority to reduce energy consumption and lower emissions. Optimization methods that move systems toward **stoichiometric combustion** limit the amount of excess air required, which ultimately reduces process energy intensity and heat loss.

In terms of reducing consumption of fossil fuels traditionally used to generate process heat, **improved filtration options** requiring less maintenance and operator intervention are a top priority, as these approaches will also improve and expand water treatment capabilities to enable further water reuse opportunities. Additionally, operating cost savings will be realized as a result of more robust filtration systems associated with water treatment activities. **Scalable solar thermal technologies** can provide an alternative pathway for process heat generation, especially in facilites located in rural areas (e.g., crop and dairy farms). **Electrification** efforts also provide a key pathway to transition away from fossil fuels for process heat generation. Drying and baking operations are top processes for such solutions, including **non-resistive heating** and **dielectric heating** technologies. Retrofits enabling electrification should also be prioritized, given lower capital investment compared to purchasing and installing new technology options, which provide an intermediate decarbonization solution toward the path to reaching net-zero. Additionally, **direct electrification** for boilers, innovations to replace technologies for **steam heat**, and combination technologies for waste heat recovery can facilitate transition from fossil fuel usage associated with combustion processes. Overall, R&D is required to increase the availability of off-the-shelf technologies that can achieve cost and emissions reductions. For instance, increased commercialization of **industrial heat pumps** that can reach higher sink temperatures is needed to ensure more market options. **UV-C LED** is another electrified solution that could replace traditional water distillation, while **electromagnetic technologies** could be developed to generate clean heat needed to support pasteurization processes.

Embodied carbon emissions for end products sold are not well measured and, in most cases, are unknown to the buyer/consumer. There is a critical need for strategies to **enhance data availability** to assess and measure life cycle carbon emissions at each stage, both at the industrial level and across the supply chain. Thus, a **mechanism to measure GHG emissions** and embodied CO_2 would more easily allow organizations to incorporate these factors into purchasing decisions as part of their procurement operations. Developing a framework for data-sharing and **utilizing AI** can streamline distilling and assessing information. This use of AI would enable industries to make quick but informed supply chain decisions that consider sustainability aspects. Such information-sharing can also be applied to develop mechanisms to **monitor the reuse of recycled materials**, as well as **water** treatment, to measure and track **energy and emissions** associated with these operations more effectively.

The increasing demand for electrification driven by the imperative to decarbonize the F&B sector necessitates a substantial energy supply, with manufacturers dependent on the electrical grid. However, current and emerging technologies do not yet facilitate the **grid's operational stability and reliability**. Breakout session participants underscored the pressing need to enhance grid dependability to foster and sustain the growth of electrification. Strategic interventions—including infrastructure upgrades, enhanced maintenance protocols, and the integration of smart technologies—are required to ensure a robust and reliable power supply. In terms of **onsite wind and other renewables**, they should be prioritized from a deployment standpoint to further decarbonize and reduce the costs of purchased electricity. **Grid integration and interactivity** can also enhance efficiency and support sustainability. There are existing technological means to address grid shortcomings and support further renewables penetration. For instance, demand response programs can help modulate processes in line with peak demand periods to support grid stability. Energy storage technologies can be used to address renewables' variability issues. Large **district energy systems** make use of **CHP** to flexibly meet changing demand while improving efficiencies for heat and power generation.

Aside from electrification, incorporation of low-carbon fuels, such as hydrogen, can fuel combustion processes directly in place of fossil sources. However, hydrogen incorporation would require large-scale and reliable hydrogen equipment, along with a robust infrastructure to ensure an adequate supply to meet industrial demands.

Effective waste management can provide waste-to-energy and waste-to-coproduct solutions that can reduce an organization's environmental footprint, save on operating costs, and boost revenue. **Onsite bio-digesters** for processing organic wastes and industrial wastewater not only minimize the amount of waste sent to landfill but also produce an alternative energy source to offset fossil fuel consumption. For instance, anaerobic digesters consume organic waste and produce biogas as a byproduct, which can be used as a low-carbon fuel source for generating process heat. These biodigesters should be distributed and small-scale in order to effectively process lower-volume waste streams from smaller industrial sites. On the other hand, facilities in close proximity would benefit from a **collective digester strategy**, which would facilitate better utilization of wastes from farming, industrial, and commercial operations and expand potential for biogas and/or RNG generation to offset fossil fuel consumption. Additionally, such waste streams can be valorized and converted to useful **co-products** that can be sold on the market. Not only is waste-to-landfill avoided, selling these byproducts yields an additional revenue stream. At a higher level, **food waste diversion strategies** across the supply chain overall can divert wastes typically sent to landfill through other means, such as food donation programs or conversion to animal feed. Also worth considering are cost-effective **local or in-house reuse processes** to improve recycling and the establishment of mechanisms to **monitor the reuse of recycled materials**. Overall, **circular economy practices** must be further implemented throughout the supply chain to enable resource-sharing and waste reduction. For instance, bioprocessing equipment for medical grade applications are often more precision-based and can be repurposed for food grade applications to promote the circular economy. Both industrial awareness and consumer education are critical to furthering circular economy strategies.

On the farming side, practices such as **regenerative agriculture** can promote biodiversity and improve soil health to increase water-holding capacity, which can reduce irrigation requirements and make farming overall more resilient to drought. This is especially important in regions with water scarcity challenges where traditional farming practices are unsustainable.

From a policy standpoint, breakout session participants also emphasized the use of **carbon credits** to steer industry toward decisions based on sustainability considerations, including those made at the supply chain level for material sourcing.

Table 3.6.1 summarizes the results of the discussion on top technology opportunities for maximum decarbonization impact across all six breakout sessions.

Table 3.6.1: Top Technology Opportunities for Decarbonization of All F&B Breakout Sessions

Technology Opportunities Identified for Maximum Decarbonization Impact
• Smart manufacturing technologies • Sensing, control system optimization, edge computing • Machine drive efficiencies – fans/variable frequency drives/motors/drives/conveyors • Heat integration tools/engineering • HVAC innovations, e.g., evaporative cooling systems • Non-vapor compression cooling • Improved condensate recovery • High-temperature heat and moisture captured from exhaust streams • Enhanced combustion-based baking/drying technology (e.g., indirect fired), including retrofits • Better filtration options that require less maintenance • Scalable solar thermal technologies for process heat generation • Electrification of baking and drying processes (e.g., non-resistive heating, dielectric heating technologies), including retrofits • Direct electrification of equipment beyond heat pumps (e.g., electrified boilers) and combination technologies (e.g., waste heat recovery + HTHPs) • Commercialization of industrial heat pumps • UV-C LEDs to replace traditional distillation of water • Electromagnetic technologies for pasteurization • Mechanism to easily measure GHG emissions for end products • Data availability to assess and measure life cycle carbon emissions in each step of the life cycle: framework to share data; enabling AI to distill/assess data; enabling AI to select suppliers based on sustainability level • Strategies to monitor water and energy use • Mechanism to monitor reuse of recycled materials • Onsite wind and other renewables for decarbonizing the electric grid

- Grid integration and interactivity
- Use of district energy systems and CHP to improve energy efficiency
- Hydrogen fuel; large-scale, reliable, and affordable equipment (hydrogen furnace and boiler); hydrogen-compatible/flexible equipment
- On-site biodigesters (distributed, small scale)
- Collective digester strategy
- Waste and coproducts marketplace – sources and uses of waste
- Food waste diversion and supply chain technologies
- Cost-effective local or in-house reuse processes
- Biotech processing equipment (medical grade), repurposed for food grade (less than medical grade) to promote circular economy
- Regenerative agriculture
- Carbon credits

3.6.2. Challenges and Barriers

The main challenges and barriers identified by the six breakout groups center around factors relating to cost, training and resources, infrastructure and facility limitations, market and supply chain, industry concerns, and regulation.

From a financial standpoint, there is currently a **lack of incentives** to encourage industry to aggressively prioritize decarbonization measures. A cost for carbon or **carbon tax** would provide such an incentive for both food and beverage producers and suppliers to avoid this extra cost by lowering embodied emissions. On a similar note, an established system and **comprehensive guidelines to track carbon credits** is needed to more effectively motivate industry and organizations across the supply chain to execute further sustainability initiatives, especially when it comes to prioritizing investment in sustainability. Additionally, deploying new technologies results in large **up-front costs**, often with long payback periods. Short-term gains are often prioritized over long-term sustainability benefits, detering investment in decarbonization technologies and contributing to overall industry hesitation. This challenge is further compounded for **smaller companies** that have **limited resources** to support such efforts, which makes decarbonization of the F&B sector very difficult, given how heterogenous and distributed facilities are in terms of size and capabilities. In addition, the investment in decarbonization technologies required to aggressively reduce emissions would result in increased costs of goods, and the industry has concerns with **consumer acceptance** of these cost increases. Finally, investment is needed to facilitate RD&D of emerging technologies, but widespread adoption is needed to attract investment—it is a classic **chicken-and-egg problem**. Therefore, technologies and techniques with broad applicability are seen as the most likely to advance.

Incentives to encourage suppliers to lower embodied emissions are insufficient. In addition, there is a lack of clear data and information-sharing on embodied emissions of products. These factors combined discourage organizations in the supply chain from prioritizing sustainability as a key consideration in procurement activities. To advance decarbonization across the supply chain, strategies are needed to strengthen motivation and promote collaboration opportunities between suppliers and buyers.

Implementing and integrating new technologies into existing production processes requires **strong workforce development** to support the installation, operation, and maintenance of the associated equipment to ensure successful, reliable, and safe operation. This requires significant **training**, resources, and manpower to ensure successful implementation and continuous operation of new technologies. Additionally, there are segment-specific challenges that further complicate expanding workforce development and training efforts. Fruits and vegetables stakeholders, for example, noted that the short growing season for certain agricultural products presents challenges in **recruiting and retaining the required workforce**, as most individuals prefer year-round employment. Additionally, this sector grapples with the need for specialized skills, as the work demands an unconventional skill set. Moreover, many people are reluctant to reside in rural areas.

There are inherent infrastructure and facility limitations that make deploying new technologies all the more difficult for certain facilities. For instance, there are often inherent physical **footprint limitations** that impede technological adoption. Boiler rooms are a prime example, as these areas are typically not built to accommodate additional equipment. Thus, retrofits for more efficient and/or clean combustion or carbon capture technologies can be very difficult to integrate, given these spatial constraints. **Insufficient electrical infrastructure**, at both the grid and plant levels, is a barrier to expanding electrification efforts. Electrifying energy-intensive operations (e.g., baking) is often infeasible with current facility electrical infrastructure, which cannot support the energy required to generate the necessary process heating. Investment into energy storage and advanced control systems is required to address **grid shortcomings**. **Scalability** is also a concern, especially for large organizations, where implementing a technology or strategy across a range of industrial sites is very difficult, resource-intensive, and time-consuming. An additional factor influencing the feasibility of certain decarbonization strategies is **climate conditions**, particularly related to water availability to support water-intensive technologies. Finally, stakeholders noted that plant designs often **lack inclusion of carbon reduction mechanisms** and focus primarily on optimizing productivity and ensuring safety. If functionality for emissions reductions is not prioritized in the design stage, it becomes much more difficult and costly to optimize these legacy processes down the road.

Broadly speaking, overall **supply chain robustness** of newer technologies on the market is lacking in terms of ensuring equipment, parts, and overall resource availability. For example, equipment availability is a concern with regard to the **lack of commercially available heat**

pumps that can operate at high temperatures (above 180°C), which makes it difficult to capture and upgrade waste heat to enable reuse in other industrial processes. Additionally, **unproven technologies** or technologies with low TRLs are considered high-risk and often unattractive from an investment standpoint. Industry stakeholders have communicated that no one wants to be the “guinea pig.” New technologies often have **limited commercial proof of concept**, and senior managers in control of capital investments are often very risk-averse; the preference is to mitigate risks to plant operations by opting for proven and trusted technologies. Managers are especially wary when such new solutions have longer payback periods. On another note, many **alternative fuels** (such as hydrogen combustion for process heat generation) have **limited availability** and/or are cost-prohibitive, constraining the range of decarbonization solutions outside of electrotechnologies.

There are a variety of industry concerns surrounding adoption of emerging decarbonization technologies. **Organizational culture** plays a major role in determining how much a company emphasized change and innovation of legacy processes and equipment. Different organizations vary in how quickly and easily they perceive, accept, and **adapt to change**. As mentioned earlier, given the diversity of the F&B sector, there is a wide range of organization sizes, capabilities, and resources. Smaller facilities often have limited access to newer technologies. This can further complicate **integration** of sustainability measures in lieu of complex legacy processes that are difficult to modify. Because of the high degree of **diversity in materials and processes** within food and beverage operations, there is no one-size-fits-all solution to achieve comprehensive decarbonization. In terms of segment-specific challenges, most dairy facilities have **24/7 operation**, so there is little opportunity to execute capital improvements during the limited shutdown time available. Finally, the “not in my back yard” perspective, reflecting concerns about **social license to operate**, can also restrain widescale adoption.

Regulatory and permitting challenges make it difficult for this sector to adopt decarbonization technologies, as they may require changes to land use. In addition, organizations adopting new technologies may become subject to new permitting requirements, and the permitting process may be costly and lengthy. This challenge is exacerbated by the varying and fragmented regulations across regions, which are subject to continuous change.

Table 3.6.2 summarizes the results of the discussion on top challenges and barriers for maximum decarbonization impact across all six breakout sessions.

Table 3.6.2: Top Barriers and Challenges for Decarbonization of All F&B Breakout Sessions

Technology Challenges and Barriers to Maximum Decarbonization Impact
• Lack of carbon incentives (i.e., increased tax incentives and/or carbon tax and/or carbon market) • Lack of comprehensive guidelines for claiming carbon credits

- Initial upfront cost/investment with extended payback periods
- Capital costs/limited scalability
- Consumer resistance to increased costs associated with required investment in decarbonization technologies
- Need for broad applicability to facilitate necessary investment (chicken-and-egg problem)
- Lack of incentive for supply chain to reduce embodied emissions
- Workforce training development needs
- Physical footprint limitations relating to equipment upgrades
- Grid reliability and lack of electrical infrastructure to support electrification efforts
- Scalability issues for technology implementation
- Climate impacts (e.g., water availability related to water-intensive technologies)
- Lack of inclusion of carbon reduction mechanisms within plant designs (more focus on concerns like safety and throughput)
- Lack of commercial availability of HTHPs (>180°C) to support waste heat recovery and reuse
- Industry hesitation to adopt low-TRL technologies (i.e., not wanting to be the "guinea pig")
- Reliability concerns about emerging technologies
- Limited availability of alternative fuels
- Lack of supply chain robustness
- Cultural context for bringing change and organizational inertia
- Small companies' limited access to newer technologies
- Complex process integration
- Not-in-my-backyard perspective; social license to operate
- 24/7 operation in dairy industry inhibiting shutdown/time for retrofits
- Diversity of materials and processes within the dairy industry (i.e., no one-size-fits-all solution)
- Regulatory and permitting challenges

3.7. Breakout Session Summary for Topic 7: Goals and Metrics Justification

In all six breakout groups, discussions of top metrics and performance indicators centered around energy and emissions, quality, supply chain, facility/process, and costs.

From an emissions and energy standpoint, **normalizing carbon, water, and energy intensities** at the product level will provide further granularity on usage levels while also ensuring a standard framework of measurement to facilitate cross-product comparisons and benchmarking initiatives. **Emissions metrics at the plant level** will also help in determining a decarbonization technology's overall impacts on a facility as a whole, helping to assess overall performance in terms of sustainability goals. Additionally, **efficiency and emissions reduction metrics** should be compared to a standard baseline that is **site-specific** to ensure targets are realistic for a facility implementing a decarbonization technology.

From a quality perspective, participants emphasized **consumer acceptance** associated with implementing new technologies in changing legacy processes and equipment. Consumers are often very sensitive to any product changes, so food and beverage producers tend to be quite hesitant to adopt new technologies that may pose a risk to end products. Thus, metrics that assess **product quality** to maintain consistency are critical in ensuring end products are not negatively impacted by any process or equipment changes. From a regulatory perspective, **adherence to FDA standards and state and federal regulations** is also of paramount importance and must be considered when assessing the implementation of decarbonization technologies.

With regard to the supply chain, **commercial availability** of emerging technologies is indicative of their maturity and readiness for widespread adoption in the market. Given industry's hesitation to change processes and equipment, technologies with strong demonstrations and proven results are more attractive from an investment standpoint. Therefore, metrics centered around this aspect should be prioritized to better identify which decarbonization technologies have the highest potential for widescale deployment. Additionally, improved **GHG accounting and reporting** is needed for new technologies, especially on the supply chain side, to better assess embodied carbon emissions of end products. Data availability and sharing are critical in order to facilitate improved reporting mechanisms and material sourcing.

On the facility and process side, metrics that indicate the degree of **complexity** added to a process for an emerging technology should be prioritized. Increasing complexity of operations generally requires more resources to manage and increases the risk of deviation, so added complexity should be minimized where possible. Additionally, **productivity and throughput** are vital metrics for assessing the operational efficiency of new technologies, as these metrics would provide insights into resource use, productivity, and capacity to meet market demand sustainably and efficiently. Specifically, a **scorecard system** was proposed to facilitate facility-to-facility or company-to-company comparisons, streamlining the assessment process.

Participants also identified cost metrics to evaluate profitability of decarbonization technologies: **internal rate of return, internal rate of investment,** and **payback period**. The **levelized cost of avoided carbon** metric more specifically quantifies emissions reduction benefits by representing the specific cost required to avoid emitting a unit of carbon associated with a new technology. Stakeholders also noted the need for **assessment**

methodologies relating to return on investment to better account for technology changes; such evaluation metrics help address industry hesitation related to risk aversion. On another note, consumers are highly sensitive to product pricing, so it will be critical to evaluate **costs to the consumer**, i.e., how and to what degree a new technology will impact **final product pricing**. Ideally, decarbonization solutions should reduce operating costs as well as emissions, so there is a need to quantify these impacts on a **dollar-per-mass-of-product basis**.

Table 3.7.1 summarizes the results of the discussion on top performance indicators for effective evaluation of emerging decarbonization technologies to be developed and deployed across all six breakout sessions.

Table 3.7.1: Key Metrics for Measuring Success of Decarbonization Technology Implementation and Deployment for the F&B Sector

Top Performance Indicators Identified for Most Effective Assessment of Development and Deployment of Emerging Decarbonization Technologies
• Normalize carbon/energy/water intensity per product output (depends on product) • Plant-wide emissions reductions (site-specific, normalized, standardized) • Consumer acceptance • Product quality metrics • Adherence to quality and safety standards • Commercial availability of emerging technologies • Process complexity • Productivity and throughput • Scorecard to compare facility to facility or company to company • Internal rate of return or return on investment (made difficult by conflicting utility rate projections from the U.S. Energy Information Administration) • Payback period • Levelized cost of avoided carbon • Costs to consumer • Dollar per pound/ounce of product, including production cost

Appendix A: Workshop Agenda

U.S. DOE Industrial Efficiency and Decarbonization Office
Stakeholders' Workshop: Decarbonization Challenges and Priorities across the U.S. Food and Beverage Industry

The Hampton Inn Tropicana –4975 Dean Martin Drive, Las Vegas, NV 89118; Main Session: Salon A

Thursday, August 31, 2023

8:00 AM – 8:30 AM	Registration and Check-in – *Event Center Foyer*
8:00 AM – 9:00 AM	Continental Breakfast and Networking
9:00 AM – 9:10 AM	Workshop Introduction – Room: *Salon A*
9:10 AM – 9:25 AM	Welcoming Remarks and IEDO Program Overview **Isaac Chan**, Program Manager, U.S. DOE Industrial Efficiency and Decarbonization Office
9:25 AM – 9:30 AM	Questions and Answers
9:30 AM – 9:45 AM	Energy and Emissions Intensive Industries Subprogram: Food and Beverage Investment Portfolio Overview Yaroslav Chudnovsky, Senior Technology Manager, U.S. DOE Industrial Efficiency and Decarbonization Office
9:45 AM – 9:50 AM	Questions and Answers
9:50 AM – 10:05 AM	Cross-Sector Technologies Subprogram: Drying; Steam Generation; and Low-Carbon Fuels, Feedstocks, and Energy Sources (LCFFES) *Keith Jamison, Technology Manager, U.S. DOE Industrial Efficiency and Decarbonization Office*
10:05 AM – 10:10 AM	Questions and Answers
10:10 AM – 10:25 AM	Technical Assistance and Workforce Development: Better Plants and a Look Into the Controlled Environment Agriculture Accelerator Kimmai Tran, Fellow, U.S. DOE Industrial Efficiency and Decarbonization Office
10:25 AM – 10:30 AM	Questions and Answers
10:30 AM – 10:50 AM	Break
10:50 AM – 11:05 AM	DOE Decarbonization Roadmap Overview Joe Cresko, Chief Engineer, U.S. DOE Industrial Efficiency and Decarbonization Office
11:05 AM – 11:10 AM	Questions and Answers
11:10 AM – 11:25 AM	Reimagining Proteins Tessa Hale, Director of Corporate Engagement, Good Food Institute
11:25 AM – 11:30 AM	Questions and Answers

11:30 AM – 11:45 AM	Global Food Traceability Center Blake Harris, Technical Director, Institute of Food Technologists
11:45 AM – 11:50 AM	Questions and Answers
11:50 AM – 12:00 PM	Breakout Session Instructions
12:00 PM - 1:00 PM	**Lunch**
1:00 PM – 4:30 PM **(Break: 3:00 PM – 3:30 PM)**	Breakout Sessions Session #1: Proteins – Room: *Bora Bora A* • **Kathy Nunez**, Tyson Foods, "Cutting Cost with Decarbonization" • **Sanjay Sethi,** Plant Based Foods Industry Association, "Plant Protein Cluster: Catalyst for Decarbonizing the Food Chain" Session #2: Grains and Oilseeds – Room: *Bora Bora B* • **Olexiy Buyadgie,** Wilson Engineering Technologies, Inc., "Energy Efficiency and Decarbonization for Grain and Oilseeds Industries as Elements of Circular Economy" • **Zhongli Pan,** University of California, Davis, "SmartProbe Technology for Reducing Food Loss and Chemical Use" Session #3: Baking and Snacks – Room: *Tahiti* • **Jerry Barnes**, BABBCO Tunnel Ovens, "CleanBake Multi-Fuel Zero Emissions-Capable Tunnel Oven" • **Joseph Zaleski,** Reading Bakery Systems, "U.S. Department of Energy Goals for the Food and Beverage Las Vegas Workshop" Session #4: Dairy Products – Room: *Fiji* • **Mike Aquino**, International Dairy Foods Association, "Dairy's Decarbonization Journey" • **Eric Hassel**, Innovation Center for U.S. Dairy, "Dairy Processing Decarbonization Efforts" Session #5: Fruits and Vegetables – Room: *Salon B* • **John Larrea**, EcoEngineers Session #6: Beverages, Sugar and Confectionary, and Tobacco – Room: *Salon A*
4:30 PM – 5:00 PM	**Break**
5:00 PM – 5:30 PM	Breakout Session Report Outs – Room*: Salon A*
5:30 PM – 5:45 PM	Closing Remarks Yaroslav Chudnovsky, Senior Technology Manager, U.S. DOE Industrial Efficiency & Decarbonization Office
5:45 PM	Adjourn Workshop

Appendix B: Workshop Participants

First Name	Last Name	Company
Kristen	Ajmo	Energetics
Mike	Aquino	International Dairy Foods Association
Zach	Bagley	California Prune Board
Andrew	Bailey	National Pork Producers Council
V.M.	Balasubramaniam	The Ohio State University
JERRY	BARNES	BABBCO Tunnel Ovens
Jocelyn	Bridson	Tillamook County Creamery Association
Phoebe	Brown	Energetics
Sabine	Brueske	Energetics
Olexiy	Buyadgie	Wilson Engineering Technologies, Inc
Isaac	Chan	DOE
Yaroslav	Chudnovsky	U.S. Department of Energy
Joe	Cresko	DOE
Eric	DeBlieck	Grain Millers, Inc.
Tracy	Evans	Energetics
William	Foran	BABBCO
Greg	Forton	Leprino Foods Company
Jesse	Geiger	Energetics
Matt	Gregori	SoCalGas RD&D
Arun	Gupta	Skyven Technologies
Logan	Guy	Energetics
Tessa	Hale	The Good Food Institute
Blake	Harris	Institute of Food Technologists
Eric	Hassel	Innovation Center for U.S. Dairy / Dairy Management Inc.
Guangwei	Huang	Almond Board of California
Shea	Hughes	Scale Microgrids
Trudi	Hughes	California League of Food Producers
Keith	Jamison	DOE - Industrial Efficiency and Decarbonization Office
David	Johnson	PARC, Part of SRI International
Frank	Johnson	GTI Energy
Rohit	Karnik	Massachusetts Institute of Technology
Maria	Keane	Energetics

Kelly	Kissock	UC Davis Energy and Efficiency Institute
Austin	Kozman	PepsiCo
Sreenidhi	Krishnamoorthy	Electric Power Research Institute
John	Larrea	EcoEngineers
Alan	Leung	SoCalGas
Hailin	Li	West Virginia University
Sarah	Novak	American Feed Industry Association
Kathereen	Nunez	Tyson Foods, Inc.
Zhongli	Pan	University of California, Davis
Kody	Powell	University of Utah
Thomas	Price	Energetics
Sheyla	Ramsay	PepsiCo R&D Global Foods
Prakash	Rao	Lawrence Berkeley National Laboratory
Srinivasa	Salapaka	University of Illinois at Urbana-Champaign
Diane	Sellers	Energetics
SANJAY	Sethi	Plant Based Foods Industry Association
Greg	Spragg	Solve For Food
Darlene	Steward	National Renewable Energy Lab
Juming	Tang	Washington State University
Emmanuel	Taylor	Energetics
David	Thaller	Energetics
Mai	Tran	U.S. Department of Energy
LAUREN	Vahle	Cargill
David	Voss	Energetics
Erick	Watkins	Pacific Coast Producers
Sophia	Weiss	Grain Millers, Inc.
Zak	Weston	BERA
Stanley	Wetch	Flor De Mexico Foods
Jamal	Yagoobi	Worcester Polytechnic Institute
Joseph	Zaleski	Reading Bakery System