Industrial Decarbonization Roadmap, Pt. 4, Food and Beverages

By John Benson

January 2023

1. Introduction

The first part of this post is described was an Overview and is linked below:

https://energycentral.com/c/cp/industrial-decarbonization-roadmap-part-1-overview

Part 2 was about Iron and Steel Production Industries and is linked below.

https://energycentral.com/c/ec/industrial-decarbonization-roadmap-part-2-iron-steel

Part 3 was about Chemical Manufacturing and is linked below.

https://energycentral.com/c/cp/industrial-decarbonization-roadmap-part-3-chemical-manufacturing

This is the fourth part of this series and is about Food & Beverage Manufacturing.

The source document and section for this paper does not appear to delve into farming and ranching, but only the food and beverage manufacturing process after harvesting.[1]

Although I have occasionally touched briefly on farming practices in earlier posts, I don't believe that I have ever delved into the Food & Beverage Manufacturing Subsector.

2. U.S. Food and Beverage Production

The food and beverage manufacturing industry is a critical component of the U.S. economy. In 2019, the subsector was responsible for adding $412 billion to the economy and employing more than 1.7 million workers.[2] Those workers comprised about 14.7% of all U.S. manufacturing employees and represented over 1% of all U.S. nonfarm employment.[3] In 2019, there were over 38 thousand food and beverage manufacturing plants in the U.S. The states with the most food and beverage manufacturing plants in 2019 were California (6,041), followed by New York (2,611) and Texas (2,485)… Meat processing, beverage manufacturing, and dairy production were the largest components of the industry group's total value added.

2.1. Energy Use and CO_2 Emissions

Food manufacturing is one of the largest energy-consuming and greenhouse gas (GHG) emitting industries in the United States. The subsector is responsible for 6% of total industrial CO_2 emissions, with an estimated 78 million MT CO_2 emissions in 2020.[4] The

[1] Full List of authors, reviewers and supporting groups is contained on this document's front-matter pages xi -- xiv, U.S. Department of Energy, "Industrial Decarbonization Roadmap," September 2022, https://www.energy.gov/sites/default/files/2022-09/Industrial%20Decarbonization%20Roadmap.pdf

[2] "Annual Survey of Manufacturers (ASM)," U.S. Census Bureau, last modified April 21, 2022, https://www.census.gov/programs-surveys/asm.html

[3] "Manufacturing: Food and Beverage Manufacturing," U.S. Department of Agriculture Economic Research Service, last modified December 22, 2021, https://www.ers.usda.gov/topics/food-markets-prices/processing-marketing/manufacturing/

[4] "Annual Energy Outlook 2021 with Projections to 2050," U.S. Energy Information Administration, February 3, 2021, https://www.eia.gov/outlooks/archive/aeo21/ See Table 19. Energy-Related Carbon Dioxide Emissions by End Use.

food manufacturing subsector is critical in furthering industrial decarbonization efforts because of its role in the economy, projected rapid growth, and heterogeneity even within industry. Additionally, in contrast to other carbon-intensive manufacturing subsectors which are often concentrated in a few geographic locations, the food manufacturing subsector is widely dispersed throughout the country, meaning that emissions reductions benefit a larger number of communities. Natural gas accounted for the majority of the 1,185 TBtu energy consumption in the food manufacturing industry in 2020, followed by grid electricity and renewables (Figure 32). Reducing the carbon-intensity of food and beverage manufacturing is important in mitigating emissions from the industrial sector as a whole, especially as industrial volume and resulting GHG emissions are projected to increase in most scenarios. Even though decarbonization of food and beverage manufacturing is challenging and unique because of diversity in the subsector, there is significant GHG emissions reduction potential.

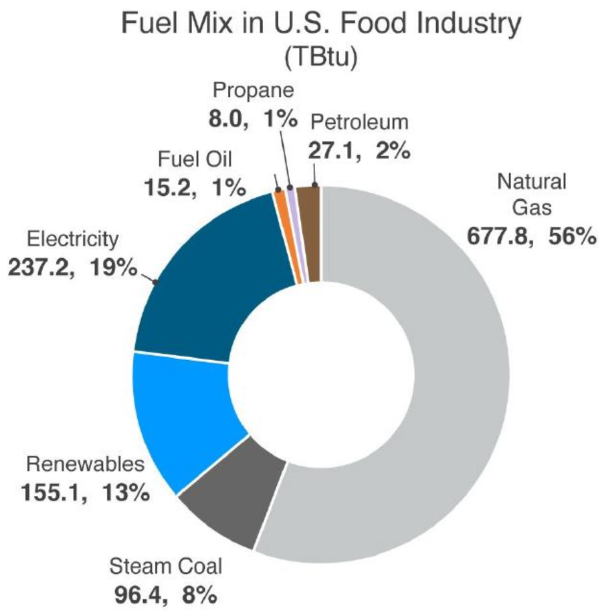

FIGURE 32. FUEL MIX (RIGHT) IN U.S. FOOD AND BEVERAGE MANUFACTURING INDUSTRY IN 2018

DATA SOURCE: U.S. DEPARTMENT OF AGRICULTURE AND U.S. CENSUS 2019 SURVEY OF MANUFACTURERS[242]

3. Decarbonization Pathways

Author's comment: Since this sector mostly uses energy derived from natural gas (methane), and their primary suppliers (farms, ranches, feedlots, etc.) have the ability to produce large amounts of biomethane, this would seem to be a quick fix.

DOE's estimation of the application of decarbonization pillars (energy efficiency, electrification low-carbon fuels, feedstocks, and energy sources (LCFFES), and carbon capture, utilization, and storage (CCUS)) in U.S. food and beverage manufacturing focuses on seven major subsectors of the food and beverage manufacturing industry group. These energy-intensive subsectors account for around a third of total energy use overall in food and beverage manufacturing. They include wet corn milling, soybean oil, cane sugar, beet sugar, fluid milk, red meat product processing, and beer production. Figure 33 shows the estimated CO_2 emissions of U.S. food and beverage manufacturing from those subsectors under the four scenarios.

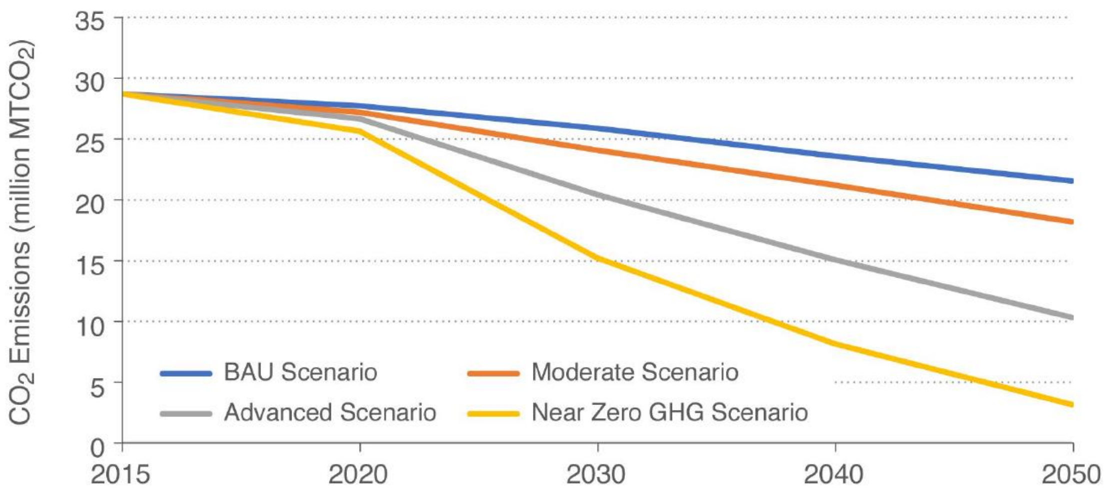

Figure 33. CO_2 emissions forecast for selected subsectors of the U.S. food and beverage manufacturing by scenario, 2015–2050.

The Subsectors covered are wet corn milling, soybean oil, cane sugar, beet sugar, fluid milk, red meat product processing, and beer production.

In the business as usual (BAU) scenario, the CO_2 emissions of the seven selected subsectors decrease 25% between 2015 and 2050 due to both decarbonization of electricity and naturally occurring efficiency improvements. In the Advanced scenario, the annual CO_2 emissions of food and beverage manufacturing decreased by 65% from 29 million MT CO_2 in 2015 to 10 million MT CO_2 in 2050. During the same period, production in the covered industries increases by 25% to meet the needs of a growing population. In the Near Zero GHG scenario, more ambitious assumptions were made, especially for energy efficiency improvement and electrification of heat.

The Moderate and Advanced scenarios are achievable with commercially available technologies and measures. To achieve the Near Zero GHG scenario, more aggressive deployment of current commercialized technologies is needed, complemented by public and private sector research development and demonstration (RD&D). These actions are discussed in detail in the following section on RD&D needs and opportunities (subsection 3.1, below).

Different factors contribute to the realization of significant CO_2 emissions reductions in each scenario. Figure 34 presents the contribution of each of the decarbonization pillars to the reduction in the food and beverage manufacturing's CO_2 emissions. Efficiency and electrification make the largest contribution to CO_2 emissions reduction. CCUS has limited potential in food and beverage manufacturing because of the high number of small-scale, dispersed production plants and lower concentration of point-source CO_2 emissions. The RD&D challenges and opportunities for each of the decarbonization pillars and technical requirements for their adoption in the U.S. food and beverage manufacturing are discussed in detail in the next section.

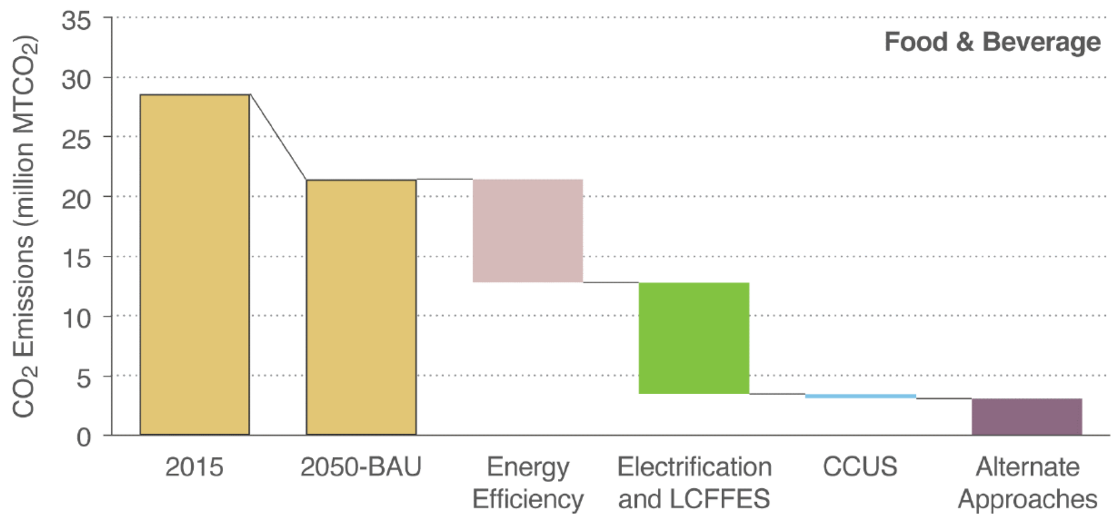

FIGURE 34. IMPACT OF THE DECARBONIZATION PILLARS ON CO_2 EMISSIONS (MILLION MT/YEAR) FOR SELECTED SUBSECTORS OF U.S. FOOD AND BEVERAGE MANUFACTURING, 2015–2050.

The subsectors covered are wet corn milling, soybean oil, cane sugar, beet sugar, fluid milk, red meat product processing and beer production. Subsector emissions are estimated for business as usual (BAU) and near zero GHG scenarios. Since industrial electrification and LCFFES technologies and strategies are strongly interconnected, these pillars were grouped for scenario modeling. The "alternate approaches" band shows further emissions reductions necessary to reach net-zero emissions for the subsector. These alternate approaches, including negative emissions technologies, are not specifically evaluated in scenario modeling for this roadmap. The powering of alternate approaches will also need clean energy sources (e.g., direct air capture could be powered by nuclear, renewable sources, solar, waste heat from industrial operations, etc.).

3.1. Research Development and Demonstration (RD&D) Needs

This subsection explores the RD&D needs and opportunities of pillars for decarbonization in the food and beverage manufacturing industry (energy efficiency, industrial electrification and LCFFES, and CCUS). Pursuing opportunities in these three areas is the key to advancing the GHG emissions reduction scenarios of the previous section. Decarbonization of food and beverage manufacturing poses unique challenges that are due to the diversity and dispersion of processes in the subsector, which include energy-intensive processes such as wet corn milling; refrigeration in meat packing; washing, preservation and refrigeration in produce; and cooking and baking of prepared foods. Manufacturing sites vary from small family-run operations that are highly labor-intensive to larger capital-intensive and mechanized industrial processes. This diversity is reflected in differing energy and heat demands, as well as in variability in pathways to decarbonization. Despite this diversity, the three categories of mitigation strategies capture many of the crosscutting, cost-effective opportunities to decarbonize the industry. The technologies covered in this section represent a wide range of options in various levels of maturity and required RD&D investment.

Food and Beverage Manufacturing: Priority Approaches

Technology breakthroughs needed for the food and beverage manufacturing industry include step-changes in non-thermal drying and dewatering, innovative separations, efficient electrification of ovens, fryers, improved produce yields in indoor and outdoor agriculture, and waste reduction (including both food and packaging waste). Priority approaches include:

- *Shift to electric ovens, fryers, boilers, and other electrified technologies where possible, especially as electric prices drop and the electric grid shifts towards generation from clean fuel sources.*

- *Reduce food waste throughout the supply chain through methods identified in LCAs and collaboration between manufacturers.*

- *Increase RD&D into heat pumps to recover and supply process heat in food and beverage manufacturing processes.*

- *Pursue recycling and material efficiency through methods like alternative packaging and packaging waste reduction.*

- *Invest in RD&D into transformative technologies such as cryogenic separation, advanced coatings to prevent ice buildup, advanced enzymes, and low ethanol producing yeast.*

Note that some of the approaches mentioned above the bullets (like "*improved produce yields in indoor and outdoor agriculture"*) encroach on agriculture, and at least one bullet (like "*Reduce food waste throughout the supply chain…*") also seems to do this. Also note similar approaches in the subsection below. This probably is inevitable since agriculture supplies most source material for food & beverage manufacturing.

3.1.1. Energy Efficiency for Food and Beverage Manufacturing

Many energy efficiency technologies and approaches are already being implemented on a commercial scale in food and beverage manufacturing, but significant opportunities remain to expand their adoption. Also, many emerging technologies to improve efficiency could contribute significantly to savings and are nearing readiness. Such emerging technologies include waste heat recovery (WHR), efficient oven burners, improvements to steam generation, and smart manufacturing principles and technologies. Smart manufacturing offers opportunities in this space in process optimization through the integration of thermal systems and in refrigeration and supply chain optimization. The supply chain can be optimized with the intent of both minimizing spoilage and waste and providing continuity for product safety as in traceability of products from farm to retail. However, there are still challenges with the deployment and proliferation of these technologies that RD&D could help address.

Some of the top challenges in the food and beverage manufacturing's efforts to decarbonization through energy efficiency are common among all industrial subsectors. Such barriers include long investment periods on incumbent technologies and processes, as well as incumbent workforces familiar with those existing technologies and processes. Transitions are capital- and time-intensive and often result in long returns on investments. In addition, the continued use, maintenance, and integration of more efficient technologies require vendor continuity and engagement that have not always existed in the market. In some cases, innovative technology has been deployed in a manufacturing facility only to become stranded when the vendor no longer supports the technology, resulting in a return to the legacy technology at a significant cost to the company with little, if any, benefit. Another significant issue is the lack of technical knowledge and familiarity with new technologies on the user side, which often increases reliance on vendor support, especially if engineering and maintenance staff are reduced to cut costs.

Increasing the efficiency of food and beverage manufacturing also comes with challenges that are unique to the subsector. First, the products of food and beverage manufacturing are typically held to a higher level of quality and safety scrutiny than the products of many other industrial subsectors. Food processing alterations are subject to multiple regulatory reviews on food quality, environmental impact, food health, and safety, as well as worker safety. These regulatory hurdles, while often necessary, typically result in additional costs to meet standards and additional workforce training that can impede the rapid implementation of energy efficiency measures. In addition, food and beverage products are subject to public perceptions of product safety and quality that can influence possibilities for the implementation of more efficient technologies at the process level as well as other transformative technologies. These concerns also increase food waste. Secondly, there are often few opportunities for financially feasible use of low-grade heat in-house, making WHR more challenging and often not cost-effective. This is compounded by the diversity of the subsector, especially in terms of geography, as there are few opportunities to share waste heat and other byproducts among facilities. New technologies, such as heat pipes, advanced air-to-air heat exchangers, and self-cleaning heat exchangers could expand WHR at some facilities. Additionally, heat pumps or booster heat could elevate temperatures of waste heat to a point of greater utility.

Despite challenges, many opportunities exist for further decarbonization through energy efficiency, as well as RD&D needs that would create or expedite new opportunities.

Efficient Oven Burners: *Efficient oven burners are critical to improving energy efficiency in food processing. Oven burners can be optimized by minimizing several components of stack gases. Combustion efficiency can be furthered through such practices as oxygen trim and burner operations. Though it is still an emerging practice, determining the ideal combustion air/fuel ratio has significant potential for reducing energy use and resulting emissions.*

Steam Generation Efficiency: *Because hot water and steam are significant energy users, and sources of energy loss, in food processing plants, efficiency improvements in a steam generation are a critical opportunity that needs to be a focus. DOE estimates a typical industrial steam assessment can identify energy savings of 10%–15% per year. One of the most significant barriers to improving steam generation efficiency in food and beverage manufacturing is the high pressures and large volumes at which steam is typically generated. RD&D is needed in how best to match production with demand and in recovering energy through technologies such as back-pressure steam turbines and turbo expanders. Other potential methods of pursuing energy efficiency in steam generation include improved process integration and energy management, and point-of-use heating versus heat loss and piping expenses for centralized supply of steam.*

Author's comment: one approach that could greatly reduce the CO_2 emissions resulting from steam generation, and also reduce recurring cost of this function would be to repurpose parabolic solar concentrators from concentrating solar power to produce steam. Ideally this would also use thermal storage to allow 24x7 operation. I know that some producers in California's central valley have used at least the former technique.

Food and Beverage Waste Reduction: *Product degradation and spoilage are major problems in the food and beverage manufacturing. Estimates for waste average 31% of all food produced. In many cases, the waste occurs not only at an individual processing plant, but also throughout the supply chain from the agricultural producer through to* *consumers. Opportunities exist to reduce this waste through improved processing, handling, and packaging practices that can significantly reduce the product that is not consumed, with a corresponding reduction in the energy, resources, and emissions that would otherwise be required. Reducing food waste is also a critical component in improving food security and lowering costs. RD&D on the processing practices and technologies to extend the shelf life of food and beverage products and reduce degradation is needed to identify new opportunities, achieve regulatory acceptance, and ensure consumers find products acceptable. In addition, the packaging of food and beverage products is also an energy- and resource-intensive part of the industry; and research is needed to both improve performance and reduce the volume of packaging waste and where possible allow for recycling.*

Other RD&D needs in this space include technologies and processes aimed toward reducing waste through beneficial reuse of waste streams, source reductions, and supply chain visibility. Food waste is lost revenue, so mitigating food waste is typically cost-effective. Processing changes can also mitigate waste, as wastage of processed fruit and vegetables is approximately 14% lower than that of fresh produce and 8% lower than that of seafood. Another avenue to reducing food waste is the use of imperfect produce, which comprises approximately 40% of waste.247 Supporting efforts to address negative public perceptions of such food as well as efforts to introduce new supply streams for unwanted produce (e.g., reuse in feed, soil health, and food service) could be another essential pathway to reducing waste and thereby mitigating emissions.

***Other Technologies:** Other potentially significant technologies that can improve efficiency in food and beverage manufacturing and should benefit from further RD&D include alternate drying technologies and advanced separations in processing and water treatment. There are also more efficient potato peeling and slicing technologies, in addition to opportunities in cryogenic separation, advanced coatings to prevent ice buildup, advanced enzymes, and low-ethanol producing yeast. The U.K. has also identified a low-temperature animal by-product processing technology that aims to demonstrate a 40% thermal energy reduction compared to traditional practices.*

3.1.2. Electrification

Substantial near-term potential exists for energy and cost savings as well as emissions reductions through fostering electrification. Food and beverage manufacturing is well-suited for electrification because of low-temperature process-heating demands and high potential for modularization of heating to replace legacy central steam systems. However, challenges still exist with the deployment and proliferation of these technologies, which RD&D could help address.

Some of the top challenges to the food and beverage manufacturing's efforts to further decarbonization through electrification are common among all industrial subsectors. For example, as with efficiency upgrades, the costs of replacing existing equipment and process connections are likely to be much higher than those associated with maintaining incumbent equipment or like-for-like replacements. In other cases, there is a lack of electric technology demonstration at the site level. Additionally, the low cost of natural gas, which is the most frequently used fuel in the food and beverage manufacturing, has recently been much lower than the cost of electricity. However, EIA projects gas prices increasing faster than electricity prices in future years.

Electrifying the food and beverage manufacturing also comes with challenges that are unique to the subsector. Concerns and consumer perceptions persist that changes in *energy sources could affect product quality. This uncertainty could result in implementation delays that would be needed to prove there is no adverse impact to the product from changes. In addition, production speeds could be slowed because of these technological changes. Despite these challenges, there are many opportunities to realize further decarbonization through electrification in the food and beverage manufacturing. And RD&D would play an important role in identifying or expediting new opportunities.*

As the prices of clean electricity drop, electric boilers, hybrid boilers and the modularization of process heating in food and beverage manufacturing will become important decarbonization strategies. Through the electrification of process heating, ovens and fryers also represent a potential avenue of accelerating decarbonization. Processes in food and beverages manufacturing, such as evaporation and pasteurization, mostly occur at temperatures below 200°C, as do processes in the pulp and paper subsector. Therefore, decarbonization options for these subsectors largely involve replacing fuels in low- or medium-temperature heating applications. More RD&D would be needed on electrification as a decarbonization measure, including refining modeling assumptions, analyzing the impact of technology changes on products, integrating different modeling frameworks, and conducting sensitivity analysis on scenarios.

3.1.3. Carbon Capture, Utilization, and Storage

Some post-combustion CCUS technologies that are relevant to food and beverage manufacturing are closer to commercialization. No single CCUS commercial technology or process design can work for every food or beverage plant, especially given the diversity of the food and beverage manufacturing, varying CO_2 sources, geographical differences, and different emissions control designs at plants. Availability of CO_2 transport infrastructure varies by different potentials for capture efficiency at new food and beverage plants. Plant location also varies. Processing food-grade CO_2 for reuse is another potential challenge.

The opportunities for utilization of captured CO_2 in the food and beverage manufacturing include using CO_2 as a feedstock to improve the resiliency of the global food system. Captured CO_2 can be reused for meat packing, carbonated beverage production, sugar refining, and in the manufacturing of dry ice that is used to preserve food. CO_2 is also integral to the production, packaging, preservation, refrigeration, and marketing of products such as canned goods, alcoholic and carbonated beverages, cheese, and processed meats. Other opportunities include pumping captured CO_2 into greenhouses, though there are concerns in some cases about nutritional content reductions and food quality. Finally, there is significant potential for reductions from fuel combustion and fermentation processes in food and beverage manufacturing. As with other technological innovations, the applications of CCUS need to be demonstrated and vetted to the food and beverage manufacturing industry for both product regulatory compliance and public perceptions of food quality.

Final author's comment: As with the prior sectors, I am not including the next section that includes implementation planning.