DE-FOA-0003363
Request for Information
Transforming Industry: Strategies for Decarbonization

Interested Party:

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About GFI:

GFI is a 501(c)(3) nonprofit think tank developing the roadmap for a sustainable, secure, and just protein supply. GFI advances open-access research, mobilizes resources and talent, and empowers partners across the food system to make alternative proteins delicious, affordable, and accessible. GFI is funded entirely by private philanthropic support.

June 21, 2024

Hon. Jennifer Granholm
Secretary of Energy
1000 Independence Ave. SW
Washington, DC 20585

Dr. Avi Shultz
Director, Industrial Efficiency and Decarbonization Office
1000 Independence Ave. SW
Washington, DC 20585

Re: DE-FOA-0003363 RFI Response: Alternative Proteins and Biotechnology-Enabled Food Production

Dear Secretary Granholm, Director Shultz, and the IEDO team,

On behalf of the Good Food Institute, we thank you for the opportunity to respond to this Request for Information (RFI) regarding the Department of Energy's (DOE) new vision study, *Pathways for U.S. Industrial Transformations: Unlocking American Innovation*. We are submitting our response to underscore the value of emerging technologies that enable alternative proteins, including plant-based, cultivated, and fermentation-derived foods, in achieving a U.S. industrial sector with net-zero greenhouse gas (GHG) emissions by 2050. Investment in the innovation and production of alternative proteins will help unlock a diverse array of climate, sustainability, economic, and social benefits across the United States.

The Good Food Institute (GFI) is a 501(c)(3) nonprofit think tank and open-access resource hub developing the roadmap for a sustainable, secure, and just protein supply. Alongside scientists, businesses, and policymakers, GFI advances alternative proteins as an essential solution needed to meet the world's climate, global health, food security, and biodiversity goals. GFI is not an alternative protein company or trade association. We analyze the industry and work closely with companies across the entire value chain to accelerate growth and innovation.

Background

This RFI comes at a time of strong interest in and support for the bioeconomy, including biotechnology-enabled food production like alternative proteins. President Biden's Executive Order on Biotechnology and Biomanufacturing (E.O. 14081) coordinates a whole-of-government approach to advance biotechnology and biomanufacturing toward innovative solutions in climate change, agriculture, supply chain resilience, health, and national security. Section 3 of the Executive Order specifically highlights "cultivating alternative food sources" as an area of

interest for food and agricultural innovation.[1] We were heartened to see DOE's subsequent contributions to the "Bold Goals for U.S. Biotechnology and Biomanufacturing" report released last year, which set ambitious goals for the bioeconomy, including developing new food sources—with an emphasis on alternative proteins as a key priority.[2]

We commend the Industrial Efficiency and Decarbonization Office for your extensive work in developing the RFI and pathways analysis summary—and the expressed interest in alternative protein technologies. Repeated mentions of "alternative proteins" and "meat alternatives" in both documents demonstrate DOE's recognition of the opportunity to advance alternative protein technologies as part of U.S. decarbonization strategies. Alternative proteins can contribute to decarbonization with reduced GHG footprints on a product basis while offering opportunities to advance environmental justice within the food/beverage sector. With proper investment and support, DOE can significantly accelerate alternative protein product development and commercialization, helping to usher in a new era of climate-smart food production.

Recommendations to DOE

GFI strongly recommends that DOE identify alternative proteins as high-value and high-priority decarbonization technologies within the food/beverage subsector. As public support is necessary to unlock the alternative protein industry's full decarbonization potential, GFI urges DOE to consider additional agency actions to support the success of the emerging sector.

GFI recommends the following specific DOE actions to advance alternative protein innovation and market adoption:

- Establish, as part of the agency's Energy Earthshots Initiative, a new Earthshot focused on fermentation, food, and alternative proteins. DOE is well positioned to accelerate major innovative breakthroughs at the intersection of climate-smart agriculture and low-carbon food technologies, supporting 2050 net-zero carbon goals while generating jobs in the clean manufacturing economy.
- Expand eligibility for and prioritize alternative protein technologies in existing programs, including those under IEDO, the Bioenergy Technologies Office (BETO), the Office of Clean Energy Demonstrations (OCED), and the Loan Programs Office (LPO).

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[1] Executive Order 14081 of September 12, 2022. "Advancing Biotechnology and Biomanufacturing Innovation for a Sustainable, Safe, and Secure American Bioeconomy." Federal Register 87, 56849-56860. https://bit.ly/3GKyRvN.

[2] White House Office of Science and Technology Policy. 2023. "Bold Goals for U.S. Biotechnology and Biomanufacturing." https://www.whitehouse.gov/wp-content/uploads/2023/03/Bold-Goals-for-U.S.-Biotechnology-and-Biomanufacturing-Harnessing-Research-and-Development-To-Further-Societal-Goals-FINAL.pdf. The *Bold Goals* report highlights "engineering circular food protein production systems" as a goal (p. 9). R&D needs include conducting R&D on plants and microbial communities to produce new, less carbon-intensive feedstocks and scaling up biotechnology-based protein production (p. 10). The report also describes goals of developing new food sources, "including production of novel or enhanced protein and fat sources," enhancing food nutrient density, and reducing foodborne illness, all of which investment in alternative protein technology supports (p. 17). R&D needs include researching the structural design of alternative protein products and food components that increase the palatability and affordability of novel foods (p. 20).

- Partner with USDA to carry out a whole-of-government approach to ensure U.S. leadership on alternative protein research, development, production, and workforce development.[3] DOE and USDA, along with other relevant federal agencies, should collaborate to design and implement efficient government programs that support advances in alternative protein technologies. Given alternative protein technologies' multidisciplinary nature, coordination across the Federal Government is necessary for the success of these technologies and their application to climate mitigation, food security, and economic goals.

Below we share specific responses to many of the questions in DOE's RFI Section 4 focused on Net-Zero Emissions Decarbonization Pathways for Specific Industrial Subsectors. We focus on alternative protein technologies—enabling the production of plant-based, cultivated, and fermentation-derived foods—as a decarbonization pathway for the food and beverage industry. We have provided specific information for each technology platform where relevant.

Question 4C.1: How do you expect the U.S. demand and production of the subsectors studied or other food and beverage products to change by 2050 and why?

Demand for alternative protein products is expected to increase in line with the rising food demands of a growing population. Relative to crop calories produced in 2010, the world will have to close a 56 percent food production gap by 2050 due to population growth.[4] Innovative food technologies like fermentation, cell cultivation, and plant-based food manufacturing can be employed to ensure food security in coming decades in the United States and globally.[5] Additional research and development (R&D), commercial, and regulatory support for alternative protein products will be key to achieving the higher-level market shares outlined in the analyses referenced below.

Beyond food security, protein diversification is key to addressing the climate crisis. Alternative proteins have significantly smaller GHG footprints than conventional animal-based product counterparts, and can thus enable decarbonization of the food system—which accounts for over a

[3] U.S. House of Representatives (117th Congress). 2022. "Commerce, Justice, Science, and Related Agencies Appropriations Bill, 2023: Committee on Appropriation Report." p. 116-117. https://www.congress.gov/117/crpt/hrpt395/CRPT-117hrpt395.pdf.
[4] Searchinger, Tim, Richard Waite, Craig Hanson, and Janet Ranganathan. 2018. "Creating A Sustainable Food Future: A Menu of Solutions to Feed Nearly 10 Billion People by 2050." World Resources Institute, p. 7. https://research.wri.org/sites/default/files/2019-07/creating-sustainable-food-future_2_2.pdf. Note: Includes all crops intended for direct human consumption, animal feed, industrial uses, seeds, and biofuels.
[5] Swanson, Zane, Caitlin Welsh, and Joseph Majkut. 2023. "Mitigating Risk and Capturing Opportunity: The Future of Alternative Proteins." Center for Strategic and International Studies (CSIS), Washington, DC. https://csis-website-prod.s3.amazonaws.com/s3fs-public/2023-05/230511_Swanson_Alternative_Proteins.pdf?VersionId=Za76gtRSXe0eahjwFvr5hw54uHzCXuT5.

third of global GHG emissions.[6] Plant-based and fermentation-derived meat products result in up to 98 percent and 96 percent fewer GHG emissions, respectively, as compared to conventional meat products, according to available LCA data.[7] According to the Boston Consulting Group, by capturing 11 percent of the global protein market by 2035, alternative proteins can slash GHGs on a scale roughly equal to decarbonizing the entire aviation industry.[8]

Additionally, a transition toward alternative protein production can help improve community health as these products result in significantly less pollution than conventional protein products. For example, plant-based and fermentation-derived meat products result in up to 99 percent and 91 percent fewer particulate matter emissions, respectively, as compared to conventional meat products.[9] In the United States, a shift to alternative proteins could prevent approximately 12,000 deaths per year from a reduction in air pollution alone.[10] As air pollution and associated public health detriments—including those associated with food and agriculture production—disproportionately impact minority and low-income communities across the United States, a transition toward alternative proteins can promote environmental justice within the food system. Concentrated animal feeding operations (CAFOs), for instance, are disproportionately located in minority and low-income communities and generate ammonia, particulate matter, hydrogen sulfide, volatile organic compounds, and other forms of air pollution—along with water and soil pollution. Alternative protein production facilities, in contrast, generally produce fewer emissions and are expected to minimize impact on surrounding populations.[11] Expansion of the alternative protein sector can therefore support efforts to achieve environmental justice and social objectives.

Currently, plant-based proteins, including meat and milk, lead the alternative protein sector for market penetration. In 2023, plant-based meat and seafood's market share represented 1.8 percent of total retail packaged meat dollar sales or 0.9 percent of the total meat category in the

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[6] Xu, Xiaoming, Prateek Sharma, Shijie Shu, Tzu-Shun Lin, Philippe Ciais, Francesco N. Tubiello, Pete Smith, Nelson Campbell, and Atul K. Jain. 2021. "Global Greenhouse Gas Emissions from Animal-based Foods are Twice Those of Plant-based Foods." *Nature Food* 2 (September): 724–732. https://doi.org/10.1038/s43016-021-00358-x.

[7] Good Food Institute. 2023. "Environmental Impacts of Alternative Proteins." https://gfi.org/resource/environmental-impacts-of-alternative-proteins.

[8] Morach, Benjamin, Malte Clausen, Jürgen Rogg, Michael Brigl, Ulrik Schulze, Nico Dehnert, Markus Hepp, Veronique Yang, Torsten Kurth, Elfrun von Koeller, Jens Burchardt, Björn Witte, Przemek Obloj, Sedef Koktenturk, Friederike Grosse-Holz, and Olivia Stolt. 2022. "The Untapped Climate Opportunity in Alternative Proteins." Boston Consulting Group, MA. https://www.bcg.com/publications/2022/combating-climate-crisis-with-alternative-protein.

[9] Good Food Institute (see note 7).

[10] Domingo, Nina G. G., Srinidhi Balasubramanian, Sumil K. Thakrar, Michael A. Clark, Peter J. Adams, Julian D. Marshall, Nicholas Z. Muller et al. 2021. "Air Quality–related Health Damages of Food." *Proceedings of the National Academy of Sciences* 118, no. 20: e2013637118. https://doi.org/10.1073/pnas.2013637118.

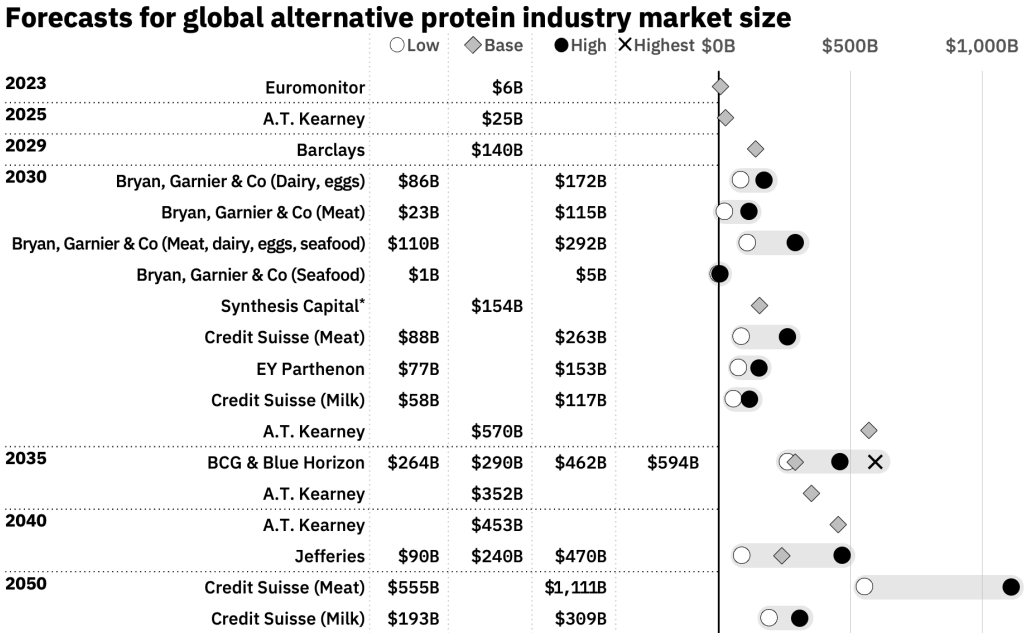
[11] Son, Ji-Young, Rebecca L. Muenich, Danica Schaffer-Smith, Marie Lynn Miranda, and Michelle L. Bell. 2021. "Distribution of Environmental Justice Metrics for Exposure to CAFOs in North Carolina, USA." *Environmental Research* 195 (February): 110862. https://doi.org/10.1016/j.envres.2021.110862; Son, Ji-Young and Michelle L. Bell. 2023. "Concentrated Animal Feeding Operations (CAFOs) in Relation to Environmental Justice Related Variables in Wisconsin, United States." *Journal of Exposure Science & Environmental Epidemiology* (September). Advance online publication. https://doi.org/10.1038/s41370-023-00598-y.

United States. Plant-based milk had nearly a 15 percent share of total milk dollar sales.[12] As Figure 1 (on the next page) demonstrates, alternative protein market forecasts from consulting firms, think tanks, and research organizations vary widely in their estimates of the potential future market size, but all project robust growth from today's market size. Most third-party projections conclude that alternative proteins will significantly grow in global market share of protein consumption in the coming decades, typically in the 10–60 percent range by 2040.

- According to Credit Suisse, the global alternative meat market share will grow to 25–50 percent by 2050, while the alternative milk market share will increase to 50–80 percent by 2050.[13]
- A 2021 Global Innovation Needs Assessment conducted by Vivid Economics on behalf of the Climateworks Foundation and United Kingdom Foreign, Commonwealth & Development Office predicts that, with a high level of innovation, "novel plant-based, precision fermented, and cellular agriculture could account for more than half of the total protein market" by 2040–50.[14]
- According to AT Kearny, approximately 60 percent of meat consumption will come from alternative proteins by 2040.[15]
- The Jefferies Group calculated the 2040 global market share for alternative meat at 9–17 percent.[16]
- In 2021, Boston Consulting Group predicted that consumption of alternative meat, eggs, dairy, and seafood products would reach 11–22 percent by 2035.[17]

[12] Good Food Institute. 2023. "Plant-based Category Dollar Share of Total Respective Category." https://gfi.org/marketresearch/#market-share.
[13] Klerk, Eugene. 2021. "The Global Food System: Identifying Sustainable Solutions." Credit Suisse Research Institute, p. 60. https://www.credit-suisse.com/media/assets/corporate/docs/about-us/research/publications/the-global-food-system-identifying-sustainable-solutions.pdf.
[14] UK Foreign, Commonwealth and Development Office, ClimateWorks Foundation, and Vivid Economics. 2021. "Global Innovation Needs Assessment: Protein Diversity." bit.ly/3KOd74C.
[15] Gerhardt, Dr. Carson, Fabio ZiemBen, Dr. Mirko Warschun, Dave Donnan, and Dr. Hans-Jochen Kühnle. 2019. "How Will Cultured Meat and Meat Alternatives Disrupt the Agricultural and Food Industry?" AT Kearney, p. 17. https://www.kearney.com/documents/291362523/291366549/How+Will+Cultured+Meat+and+Meat+Alternatives+Disrupt+the+Agricultural+and+Food+Industry.pdf?t=1559860712714.
[16] Powell, Simon, Don Lau, Kevin Grundy, Laurence Alexander, and Martin Deboo. 2019. "The Great Protein Shakeup." Jefferies, p. 1. https://www.jefferies.com/wp-content/uploads/files/Insights/The_Great_Protein_Shakeup.pdf.
[17] Boston Consulting Group (BCG). 2021. "Alternative Protein Market to Reach at Least $290 Billion by 2035." Press Release, March 23, 2021. https://www.bcg.com/press/23march2021-alternative-protein-market-reach-290-billion-by-2035.

Figure 1



*Some forecasts projected a share of the total meat market rather than the industry in dollars. For those forecasts, we estimated the dollar size of the alternative protein sector using EY's forecast for the total 2030 meat market.
Sources: A.T. Kearney, Barclays, BCG & Blue Horizon, Bryan, Garnier & Co, Credit Suisse, Euromonitor International Limited 2023 © All rights reserved., EY Parthenon, Jefferies, Synthesis Capital.

It is important to note that long-term food subsector projections are inherently uncertain given the diversity of factors that impact food production and sales. Realizing such growth will require ambitious investment and innovation.

Question 4C.2: What do you think of the net-zero subsector emissions by 2050 pathway described above and detailed in the pathways analysis summary document (if reviewed)?

GFI was encouraged to see alternative proteins (also referenced as "meat alternatives") mentioned as a measure to reach net-zero emissions in the 2050 pathways described above and the pathways analysis summary document. However, these technologies were not included in DOE's roadmap modeling. Based on available LCAs and TEAs, alternative protein technologies have widespread decarbonization benefits (see Table 1 below for an overview of comparative LCA data). GFI strongly encourages DOE to elevate alternative proteins more centrally in the upcoming vision study and to prioritize and support these technologies within the agency's decarbonization efforts.

GFI recommends DOE recognize alternative proteins as significant "Material Efficiency" measures—the more efficient use of materials and resources, as described in both documents. As underscored in the roadmap document, scenario modeling for additional aspects of decarbonization not included in the roadmap is necessary to develop a comprehensive and holistic strategy for the entire industrial sector. Overall, the extraction of natural resources and subsequent processing into manufactured goods account for nearly 50 percent of total GHG emissions globally, as noted by the agency.[18] An increased focus on Material Efficiency would address a major decarbonization need and support the transition to a more circular economy. While further research is required for various measures within the category, the effectiveness and decarbonization potential of some material efficiency solutions has been established.

Alternative protein production can be employed to support the food and beverage subsector's transition toward "[r]edesign, reuse, repurposing, and recycling of all, especially energy and carbon-intensive, industrial products and commodities, as well as their substitution with functionally identical (or better) alternatives with lower embodied carbon" (pathways analysis summary document, p. 10). Introducing alternative processes, feedstocks, and innovative products that reduce embodied carbon and other environmental impacts is particularly important for the food/beverage subsector, especially the animal-based product industries. The production of animal-based products accounts for up to 20 percent of all GHG emissions globally, while livestock alone account for nearly 40 percent of U.S. methane emissions.[19] The Paris Agreement's 1.5°C warming limitation goal cannot be met unless conventional meat consumption declines.[20] GFI thus encourages DOE to elevate alternative protein technologies within the 2050 pathway as key tools to enable more efficient protein production systems. GFI further recommends that DOE reorder the draft Industrial Decarbonization Decision Tree (as presented in Figure 4 of the RFI) to move up "alternative approaches" earlier in the decision-making process, ensuring a more holistic evaluation. "Apply alternate approaches," which encompasses alternative proteins in the food/beverage subsector, should not necessarily be the final step in the sequence of decarbonization strategies listed. A sequence where promising "alternative approaches," such as alternative proteins, are considered at the onset of DOE's decarbonization planning ensures due consideration of cutting-edge, emerging technologies that enable and support innovative food production.

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[18] Ellen MacArthur Foundation. 2021 (reprint). "Completing the Picture: How the Circular Economy Tackles Climate Change." https://www.ellenmacarthurfoundation.org/publications/completing-the-picture-climate-change; International Resources Panel (IRP). 2019. "Global Resources Outlook 2019: Natural Resources for the Future We Want." https://www.resourcepanel.org/reports/global-resources-outlook-2019.

[19] Xu et al. (see note 6); U.S. Environmental Protection Agency (EPA). 2020. "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2018." EPA 430-R-20-002. Washington, DC: p. ES-22. https://www.epa.gov/sites/default/files/2020-04/documents/us-ghg-inventory-2020-main-text.pdf. Note: Methane emissions from enteric fermentation and manure management represented 28.0 percent and 9.7 percent of total CH4 emissions from anthropogenic activities, respectively, in 2018.

[20] Clark, Michael A., Nina G. G. Domingo, Kimberly Colgan, Sumil K. Thakrar, David Tilman, John Lynch, Inês L. Azevedo, and Jason D. Hill. 2020. "Global Food System Emissions Could Preclude Achieving the 1.5° and 2°C Climate Change Targets." *Science* 370, #6517 (April): 705-8. https://pubmed.ncbi.nlm.nih.gov/33154139.

Table 1: Comparative Life Cycle Assessments

Producing this alternative protein	instead of this conventional meat	reduces this environmental impact category by this much		
		GHG EMISSIONS	LAND USE	AIR POLLUTION (PM)
Impossible Burger[I]	Beef burger patty	89%	96%	–
Beyond Burger[II]	Beef burger patty	90%	97%	–
Quorn Fillet[III]	Chicken breast	75%	78%	–
Morningstar Original Chik Patties[IV]	Chicken sausage patty	46%	84%	69%
Plant-based burger (soy protein)[V]	Beef burger patty	98%	87%	99%
	Chicken burger patty	90%	82%	90%
	Pork burger patty	90%	85%	90%
Plant-based burger (soy)[VI]	Beef burger patties	82%	84%	95%
Plant-based burger (pea)[VI]		84%	64%	91%
Fermentation-based burger (mycoprotein)[VI]		82%	69%	91%
Cultivated beef[VII]	Conventional beef	92%	90%	94%
Cultivated chicken[VII]	Conventional chicken	+3%	64%	20%
Cultivated pork[VII]	Conventional pork	44%	67%	42%

This table presents the results of publicly available, externally commissioned industry Life Cycle Assessment (LCA) studies published to date, as well as relevant peer-reviewed academic LCAs published January 2021–August 2023, that compare alternative protein products with conventional meat products. Impact reductions are calculated as follows: (impact of conventional meat product - impact of alternative protein product) ÷ (impact of conventional meat product).

Sources: I. Khan, et al. "Comparative environmental LCA of the Impossible Burger with conventional ground beef burger." (2019); II. Heller, et al. "Beyond Burger 3.0 Life Cycle Assessment." (2023).; III. Kazer, et al. "Quorn Footprint Comparison Report." (2021); IV. Dettling, et al. "A comparative life cycle assessment of plant-based foods and meat foods." (2016); V. Saerens, et al. "Life cycle assessment of burger patties produced with extruded meat substitutes." (2021); VI. Smetana, et al. "Meat substitution in burgers: nutritional scoring, sensorial testing, and Life Cycle Assessment." (2021); VII. Sinke, et al. "Ex-ante Life Cycle Assessment of Commercial-scale Cultivated Meat Production in 2030." (2023). Full citations and further information, including additional LCA analyses data, available at https://gfi.org/resource/environmental-impacts-of-alternative-proteins.

The significant decarbonization opportunity presented by alternative proteins has been recognized by a wide range of entities and organizations, including the United Nations Environmental Programme (UNEP), the World Bank, the World Resources Institute, and the Center for Strategic & International Studies.[21] In an analysis of 26 of the agrifood sector's most

[21] United Nations Environment Programme (UNEP). 2023. "Frontiers 2023: What's Cooking? An assessment of the potential impacts of selected novel alternatives to conventional animal products." Nairobi: p. x. https://doi.org/10.59117/20.500.11822/44236; Sutton, William R., Alexander Lotsch, and Ashesh Prasann. 2024. "Recipe for a Livable Planet: Achieving Net Zero Emissions in the Agrifood System." Conference Edition. World Bank, Washington, DC: p. 70. http://hdl.handle.net/10986/41468; Waite, Richard, Jessica Zionts, and Clara Cho. 2024. "Toward 'Better' Meat? Aligning

promising emissions climate mitigation interventions, the World Bank ranked alternative proteins second for climate mitigation potential, at 6.1 GtCO2 eq per year. The mitigation potential of alternative proteins is approximately nine times more than the next most promising intervention to improve conventional meat production (improved ruminant feed digestibility, at 680 MtCO2 eq/year).[22] The World Bank noted that government investment is critical to realize the full potential of alternative proteins outlined in the analysis.[23] According to UNEP: "Animal products—including animal emissions, feed, changes in land use and energy-intensive global supply chains—account for almost 60 percent of food-related emissions, for a total of 14.5–20 percent of global emissions. … Novel ASF [animal source foods] alternatives already show strong potential for reduced environmental impacts compared to many conventional animal products."[24]

In the 2023 report "Bold Goals for U.S. Biotechnology and Biomanufacturing," DOE announced a major goal to "Engineer Circular Food Protein Production Systems" (Goal 3.3) as part of an increased focus on "Climate-Focused Agricultural Systems and Plants" (Theme 3).[25] DOE stated that R&D investments are required to support circular food protein production and that the goal is related to ongoing efforts at DOE and USDA to address both food security and climate mitigation needs.[26] GFI strongly recommends that DOE continue work in this critical area of the food/beverage subsector and formally incorporate objectives focused on alternative protein innovation into the 2050 pathways outlined above. Greater support for and uptake of alternative proteins as pivotal material efficiency measures is necessary to achieve net-zero emissions by 2050, while addressing food security and environmental justice issues.

Question 4C.3.1: For which specific subsector (by name/4-digit NAICS code) and/or product does this response apply?

Alternative proteins are defined as foods with the characteristics of animal-based meat and seafood produced with plants, cell cultivation, or fermentation. The term also encompasses egg and dairy products made from plants or via fermentation. As such, our response applies to the following subsectors:

- Dairy product (3115)
- Animal slaughtering and processing (3116)
- Seafood products (3117)

Meat Sourcing Strategies with Corporate Climate and Sustainability Goals." World Resources Institute. https://doi.org/10.46830/wrirpt.22.00006; Swanson, et al., p. 3-4 (see note 5).

[22] Sutton et al., p. 70 (see note 21).

[23] Sutton et al., p. 37 (see note 21).

[24] UNEP, p. x (see note 21).

[25] White House Office of Science and Technology Policy, p. 5 (see note 2).

[26] White House Office of Science and Technology Policy, p. 9 (see note 2).

Question 4C.3.2: What are the primary solutions/technologies necessary for that pathway? What is the likely utilization of each solution/technology by this subsector in the near-term (now-2030), mid-term (2030-2040), and long-term (2040-2050) (such as the percent of subsector production)?

"Alternative protein" is a term that can encompass a number of food production and processing technologies, including extrusion, 3D printing, shear cell technology, precision fermentation, biomass fermentation, and animal cell cultivation. Extrusion for plant-based meat production is currently the most widely used alternative protein production method, but we expect utilization of other technologies to continue to increase. Many alternative protein end-products will likely be made using a combination of technologies: for example, by combining small levels of ingredients made using precision fermentation or animal cell culture with textured vegetable protein made via extrusion.

For alternative proteins to capture a meaningful share of the global protein market, it is essential to scale up manufacturing capacity across each of these technologies. Even modest growth in demand will outpace alternative protein supply in the near future. Lead times for retrofitting or building new alternative protein facilities can vary from six months to three years, and capital expenditures can range from $15 million to $250 million per facility, according to conversations with industry participants. Funding and building manufacturing capacity is a primary barrier to the near-, medium-, and long-term growth of alternative proteins.

Alternative proteins currently occupy a very small share of the global protein market. GFI estimates that the current global plant-based meat manufacturing capacity is about 2.2 MMT per year,[27] fermentation manufacturing capacity is about 0.4-2.8 MMT per year,[28] and cultivated meat production currently occurs on a small scale, with most production operations at the kilogram level.[29] Euromonitor estimates that global plant-based meat and seafood sales were $6.4 billion in 2023, or 656,000 tons of finished product.[30] By comparison, FAO estimates that 2021 global meat production was 350.13 million tons and 2021 global seafood production was 174.92 million tons.[31] These estimates imply that alternative proteins currently constitute less than one percent of the global protein market.[32]

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[27] Good Food Institute. 2023. "Plant-based Meat Manufacturing Capacity and Pathways for Expansion." https://gfi.org/resource/plant-based-meat-manufacturing-capacity-and-pathways-for-expansion.
[28] Good Food Institute. 2023. "Fermentation Manufacturing Capacity Analysis." https://gfi.org/resource/fermentation-manufacturing-capacity-analysis.
[29] Harsini, Faraz and Elliot Swartz. 2023. "Trends in Cultivated Meat Scale-up and Bioprocessing." Good Food Institute. https://gfi.org/resource/trends-in-cultivated-meat-scale-up-and-bioprocessing.
[30] Good Food Institute. 2024. "2023 State of the Industry Report: Plant-based: Meat, seafood, eggs, and dairy." https://gfi.org/resource/plant-based-meat-eggs-and-dairy-state-of-the-industry-report.
[31] Our World in Data. n.d. "Seafood and Fish Production: World." Accessed May 30, 2024. https://ourworldindata.org/grapher/seafood-and-fish-production-thousand-tonnes?time=latest.
[32] Ritchie, Hannah, Pablo Rosado, and Max Roser. 2023. "Meat and Dairy Production." Our World in Data. https://ourworldindata.org/meat-production.

Achieving near-term growth in the alternative protein market will require significant capital expenditures. GFI's *plant-based meat manufacturing capacity analysis* modeled pathways to increasing production capacity to 10 MMT per year—which would capture 2.5 percent of the global meat market—and found that between $10.4 billion and $17.5 billion in capital expenditures would be required to build or retrofit extrusion and processing facilities to meet this production volume.[33] Our *plant-based meat production volume modeling analysis* estimated that the industry would require $27 billion in investment to build more than 800 extrusion facilities to capture even six percent of the global meat market—in addition to significant growth in ingredient supply chains.[34]

GFI's *fermentation manufacturing capacity analysis* found that capital expenditures required to build or retrofit commercial-scale fermentation manufacturing facilities vary widely depending on the type of fermentation. Our research and conversations with industry participants indicated that capital expenditures can be anywhere from $15 million to $150 million per facility.[35]

GFI's *cultivated meat scale-up and bioprocessing survey* of 30 active cultivated meat companies found that the median anticipated total capital investment for future cultivated meat facilities was $90 million. Two companies have publicly announced the anticipated capital expenditures of their commercial production facilities: UPSIDE Foods ($141 million)[36] and Believer Meats ($123 million),[37] providing real-world evidence that commercial cultivated meat production facilities may require approximately $100 million in initial capital expenditure.

Scaling alternative proteins as a decarbonization solution—while creating good manufacturing jobs in America and securing the U.S. food supply—requires ambitious investment in manufacturing capacity. **DOE can support alternative protein manufacturing through existing programs and incentivize the use of renewable energy and energy-efficient equipment to achieve deep decarbonization of alternative protein manufacturing.**

4C.3.3 What are the main factors that influence the choice of this pathway at the facility level?

The main factors that influence the choice of alternative protein pathways at the facility level include capital expenditures, lead time, equipment availability and cost, co-location with

[33] Good Food Institute (see note 27).
[34] Good Food Institute. n.d. "Plant-based Meat: Anticipating 2030 Production Requirements." Accessed May 30, 2024. https://gfi.org/resource/anticipating-plant-based-meat-production-requirements-2030.
[35] Good Food Institute (see note 28).
[36] Illinois.gov (Governor JB Pritzker). 2023. "Gov. Pritzker Announces UPSIDE Foods Will Open Its First Commercial-Scale Cultivated Meat Production Plant in Glenview." https://www.illinois.gov/news/press-release.27020.html.
[37] Poinski, Megan. 2022. "Believer Meats Breaks Ground on World's Largest Cultivated Meat Plant." Food Dive. https://www.fooddive.com/news/believer-meats-commercial-scale-cultivated-meat-groundbreaking-future-meat-technologies/638263.

feedstocks, and availability of renewable energy sources. Expanding manufacturing capacity for alternative proteins will involve a combination of retrofitting suitable facilities from other industries, constructing new greenfield facilities, and increasing contract manufacturing availability (i.e. facilities that multiple companies can use). By incentivizing the construction of these facilities in America, the federal government can ensure the creation of good manufacturing jobs in the United States, improve national food security, and take critical action toward decarbonization goals. There are many factors to consider when planning and funding alternative protein facilities:

Plant-based meat*:* GFI's *Plant-based meat manufacturing capacity analysis*[38] modeled pathways to expanding global plant-based meat manufacturing capacity to 10 MMT per year based on available industry reports, data, and expert interviews. Our analysis found significant potential benefits to retrofitting existing suitable facilities, requiring a third of the lead time and a fifth of the capital expenditure, on average, compared to greenfield. Facilities suitable for retrofitting for extrusion include those that currently produce pet food, pasta, breakfast cereals, and dry snacks, while animal meat processing facilities are well-suited for retrofitting to plant-based meat post-processing. Our full analysis whitepaper lays out specific facility-level considerations for retrofitting or building greenfield plant-based meat manufacturing and processing facilities, including size, equipment type, and utility considerations.

Fermentation: GFI's *Fermentation manufacturing capacity analysis*[39] examined decision factors and capital expenditure requirements for building or retrofitting facilities to produce biomass and precision fermentation-produced proteins. Our analysis again found significant potential benefits to retrofitting: brownfield development and retrofitting equipment have the potential to reduce upfront capital expenditure by 70–85 percent compared to greenfield development and buying new equipment. Industries well-suited to brownfield site development or retrofitting equipment for alternative protein fermentation include breweries, ethanol plants, and wineries. However, fermentation production processes and corresponding equipment needs vary widely. Our full analysis whitepaper lays out specific facility-level considerations for building or retrofitting facilities and equipment for fermentation, including cost, skills and expertise, lead time, financing, process and product ownership, and geography.

Cultivated: GFI's *Cultivated meat techno-economic assessment and life cycle analysis* used interviews and data provided by 15 cultivated meat manufacturers to model a hypothetical commercial-scale cultivated meat facility capable of producing 10 kilotons of minced cultivated meat per year.[40] The facility modeled in the TEA had expected capital expenditure costs of approximately $450 million, although more recent estimates from our 2023 *Trends in cultivated*

[38] Good Food Institute (see note 27).
[39] Good Food Institute (see note 28).
[40] Good Food Institute. 2021. "The Costs and Environmental Impacts of Cultivated Meat." https://gfi.org/resource/cultivated-meat-lca-tea-report-analysis.

meat scale-up and bioprocessing survey indicated that companies expect initial facility capital expenditure to be closer to $100 million.[41] Cultivated meat manufacturers should strategically co-locate future facilities to reduce their environmental impacts, costs, or both. Locating facilities in areas where renewable energy is abundant or generating electricity on-site (e.g. through solar panels) will allow manufacturers to realize lower carbon footprints. The LCA shows that with conservatively high energy use emissions, about 75 percent of cultivated meat's carbon footprint is driven by active cooling. Manufacturers could offset this cooling demand by constructing facilities with passive cooling systems in colder climates or using absorption cooling technologies that rely on sustainable heat sources such as residual heat (sourced internally or from co-locating near an industrial site), solar heat, or geothermal.

Because most emissions associated with cultivated meat are anticipated to be scope 1 and scope 2, cultivated meat manufacturers will have a significant degree of control over the carbon footprint of their processes—and DOE has a significant opportunity to influence deep decarbonization of the cultivated meat sector. GFI's 2023 survey[42] of 13 cultivated meat companies showed that companies are taking various approaches to energy sourcing at production facilities. Two companies reported planning to install their own renewable energy source and use it as the facility's primary energy source; another company stated they are aiming toward carbon and water neutrality using solar energy, water recycling and reuse, and advanced cooling technologies; five companies anticipate relying on the standard energy mix available at the facility's location; and six other companies plan to set up their own renewable energy production capacity at the facility to supplement their energy needs.

A key facility-level consideration across all three alternative protein production pillars is co-location with ingredients and feedstocks. One of the benefits of alternative proteins is their potential for circularity: sidestreams from other industries and recycling opportunities within alternative protein production processes make this industry a compelling opportunity to realize Bold Goal 3.3: Engineer Circular Food Protein Production Systems. GFI's *Cultivating alternative proteins from commodity crop sidestreams* analysis identifies high-value crop sidestreams that could be upcycled for protein concentrates for plant-based food ingredients, protein hydrolysates for fermentation or cultivated meat media, and lignocellulosic sugars for fermentation media. We found that soy meal, canola meal, wheat bran, wheat gluten, tomato pomace, corn distillers dried grain with solubles (DDGS), corn gluten meal, and brewer's spent grain were high-potential sidestream candidates for protein concentrates; soy meal, corn DDGS, canola meal, brewer's spent grain, and corn gluten meal were high-potential for protein hydrolysates; and corn stover, soy straw, sugarcane trash/bagasse, and barley straw/husks were

[41] Good Food Institute. 2024. "Trends in cultivated meat scale-up and bioprocessing." https://gfi.org/resource/trends-in-cultivated-meat-scale-up-and-bioprocessing.
[42] Harsini & Swartz (see note 29).

high-potential sources of lignocellulosic sugars.[43] **More research is needed to understand and improve sidestream functionality and conversion into alternative protein inputs.** Companies can further improve the sustainability of their production processes by co-locating facilities with abundant sources of sidestream inputs for upcycling.

Another key facility-level decision for alternative protein manufacturers is whether to pursue contract manufacturing or a company-owned facility. A GFI industry survey[44] conducted in January 2024 found that about 24 percent of alternative protein manufacturer respondents anticipated primarily producing products at commercial scale via contract manufacturing, 40 percent using their own facility, and 34 percent using a combination of both. Contract manufacturing is an important option for companies to consider given the significant lead time and capital expenditure associated with building or retrofitting facilities. Contract development and manufacturing organizations (CDMOs) facilities, particularly at the demo and lab scales, have an important role in the alternative protein scale-up pathway given that such facilities can allow multiple companies to develop and scale their bioprocesses. Our *Fermentation manufacturing capacity analysis*[45] details further considerations for contract manufacturing and recommends an increased governmental focus on incentivizing the development of these contract manufacturing facilities.

4C.3.4 What are the primary barriers/challenges faced by this pathway and how can they be overcome?

Availability of growth financing is among the top barriers facing alternative proteins as a decarbonization pathway. Funding capital expenditures to expand manufacturing is critical for the industry to meet even modest demand growth. Yet alternative protein manufacturers face systemic challenges in accessing this type of funding.

Many novel technologies face bankability challenges when financing manufacturing facilities. Typical public and private funding pools that support novel technology R&D, including research grants and venture capital, are generally not well-suited to financing commercial manufacturing facilities given the typical size, risk tolerance, and return expectations of these funding sources. The technological and market risks associated with building manufacturing facilities for novel technologies are often too great for traditional commercial lenders. For this reason, the jump from pilot production to demonstration and commercial scale is known as the "valley of death" in biotechnology.

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[43] Eastham, Lucas, Priera Panescu, Simone Costa, Amanda Bess, Bryan Quoc Le, Vesna Radovanović, and Veljko Mijušković. 2023. "Cultivating Alternative Proteins from Commodity Crop Sidestreams." Good Food Institute: p. 3. https://gfi.org/resource/cultivating-alternative-proteins-from-commodity-crop-sidestreams.
[44] Good Food Institute, 2024. "Industry Survey" gfi.org/industry-survey.
[45] Good Food Institute (see note 28).

Overcoming these challenges will require ambitious and creative public investment. Governments can de-risk private investment by providing tax incentives, manufacturing grants, loans, and loan guarantees. Existing DOE programs are well-suited to continue and expand support for alternative proteins, including:

- ARPA-E
- The Bioenergy Technologies Office
- The Industrial Efficiency and Decarbonization Office
- The Office of Clean Energy Demonstrations
- The Loan Programs Office

Ecosystem-enabling efforts such as developing open-access facility blueprints and techno-economic analyses (TEAs) could also reduce risk and lower transaction costs for conducting diligence on and funding new facilities.

Government-supported contract development and manufacturing organizations (CDMOs) can lower the cost, effort, and time required for alternative protein manufacturers to scale up bioprocesses. Other governments, including the European Union[46] and Singapore[47], have funded CDMOs that enable companies and researchers to develop fermentation processes from bench to commercial scale. DOE could spearhead a similar effort in the United States, which would support alternative proteins alongside a host of biomanufacturing technologies.

4C.3.5 What potential factors would hinder or maximize the success of this pathway?

Factors that would hinder the success of alternative proteins include a lack of funding, low consumer adoption, and regulatory burden. To maximize the success of this pathway, public and private sectors alike must make ambitious and complementary investments to further R&D and expand manufacturing capacity. Products must meet consumer expectations for taste and price and can offer additional benefits such as improved health, convenience, and food safety. Regulators must ensure that the path to market is transparent, fair, and designed to improve consumer confidence without placing undue burdens on producers.

A Global Innovation Needs Assessment conducted by Vivid Economics on behalf of the Climateworks Foundation and United Kingdom Foreign, Commonwealth & Development Office found that alternative proteins have an annual unmet global funding need of $10.1 billion.[48] Private sector investment in alternative proteins from 2014–2023 totaled $15.7 billion while

[46] Bio Base Europe Pilot Plant. 2022. “Speeding Up Your Biobased Innovation.” https://www.bbeu.org.
[47] Nurasa. n.d. Accessed May 30, 2024. “Food Tech Innovation Centre.” https://nurasa.com/wp-content/uploads/2022/10/Nurasa-FTIC-Brochure.pdf.
[48] UK Foreign, Commonwealth and Development Office, ClimateWorks Foundation, and Vivid Economics (see note 14).

all-time public sector investment totals $1.67 billion. Newly announced global public funding amounted to $523 million in 2023, meeting less than 4 percent of the $10.1 billion annual funding need identified for alternative proteins.[49] For alternative proteins to realize their full potential, public funding levels must increase significantly.

4C.3.6 Are there any unique barriers/challenges for this pathway? Please answer questions 4C.3.1 through 4C.3.6 above for each subsector you are replying for.

Challenges with building and financing commercial-scale manufacturing capacity are not unique to alternative proteins. Other industries, including many decarbonization technologies, face similar barriers. However, the financing challenges alternative proteins face are exacerbated by unique features of the food industry. Offtake contracts, which are a common way for manufacturers to demonstrate predictable long-term, future cash flows to de-risk infrastructure investment, are highly uncommon in the food industry. Rather, in the food industry, a buyer signals an intent to purchase or, at best, makes a short-term purchase commitment (typically for one year, but in rare cases for two to three years). By comparison, 20-year power purchase agreements are common in the renewable energy industry.

Financing pathways for the alternative protein industry are also impacted by the notoriously thin margins of food production. Some alternative protein production processes, namely precision fermentation and animal cell cultivation, can use similar equipment and inputs as pharmaceutical production processes. But while pharma produces low quantities of high-margin products, food producers are focused on producing high volumes of products that will be inexpensive to end consumers. To the extent that alternative protein companies must compete with other industries for manufacturing capacity and funding, the difference in potential returns between alternative proteins and other industries is an impediment.

In addition to financing challenges, alternative proteins face regulatory and market adoption uncertainty. Alternative protein products need to compete with conventional meat, egg, and dairy products on taste and price to achieve widespread consumer adoption, but they can only do so if they are operating on a level playing field in the market.

4C.4 How do Scope 3 GHG emissions affect the food and beverage manufacturing subsector?

Scope 3 emissions represent the majority of emissions in the food/beverage subsector. Alternative proteins offer a way to address and minimize the subsector's Scope 3 emissions.

[49] Good Food Institute. 2024. "2023 State of Global Policy Report." https://gfi.org/resource/alternative-proteins-state-of-global-policy.

Animal-based products account for two-thirds of overall food-system GHG emissions.[50] Emissions from conventional animal-based products are primarily Scope 3, including emissions from animal feed production, animal digestion, and waste.[51]

Alternative proteins have significantly smaller overall GHG footprints as they do not require growing crops for feed and raising methane-emitting livestock. Conventional protein production inefficiently cycles crops through animals—for example, the most efficient of land animals, chickens, require 8 calories of input for 1 calorie of output.[52] In contrast, alternative protein production directly converts crops and resources into food products, requiring fewer agricultural inputs. Plant-based and fermentation-derived meat products result in up to 98 percent and 96 percent fewer GHG emissions, respectively, as compared to conventional meat products, according to available LCA data.[53]

Addressing Scope 3 emissions is crucial to achieving meaningful GHG emissions reduction targets and accelerating the food/beverage subsector's journey towards net-zero. Alternative protein technologies provide a significant tool to address Scope 3 emissions of animal-based products, which represent a majority of the food/beverage subsector's overall emissions.

4C.6 What technical and/or technology solutions does the subsector need that are not currently available?

The term "alternative proteins" encompasses an ever-growing toolkit of more sustainable processes to produce food. Policymakers, scientists, and industry stakeholders should make ambitious and coordinated efforts to expand alternative protein R&D while de-risking and incentivizing scale-up. GFI has identified the following high-priority technical whitespaces in alternative protein R&D based on scientific literature analyses and conversations with academic and industry stakeholders:

- Improving the efficiency of protein production systems through the development of alternative protein manufacturing technologies and downstream processing methodologies that require minimal energy and natural resource (e.g., water) utilization.
- Engineering better plants, animal cell lines, and microbial strains tailored for alternative protein production systems.
- Characterizing and optimizing current feedstocks for use in alternative protein production systems to minimize or recycle waste and derive greater economic value from a variety of food and agricultural sidestreams.

[50] Xu et al. (see note 6).
[51] Xu et al. p. 726-727. (see note 6).
[52] Shepon, A., G. Eshel, and R. Milo. 2016. "Energy and Protein Feed-to-Food Conversion Efficiencies in the US and Potential Food Security Gains from Dietary Changes." *Environmental Research Letters* 11, No. 10 (October). https://iopscience.iop.org/article/10.1088/1748-9326/11/10/105002.
[53] Good Food Institute (see note 7).

- Developing standardized measurement tools to accurately assess carbon and nutrient fluxes in various alternative protein production systems.

In addition to accelerating the development of alternative proteins, addressing the above R&D needs will support the expansion of the U.S. bioeconomy through the creation of a climate-focused food and agricultural system founded on a diverse and resilient biomass supply.

Conclusion

GFI commends DOE for your continued dedication to addressing the global climate crisis and unlocking American innovation while supporting the nation's progress on environmental justice, public health, national security, and other cross-cutting issues. We are grateful for the opportunity to make comments on this RFI and inform the agency's vision study, *Pathways for U.S. Industrial Transformations: Unlocking American Innovation.*

GFI strongly recommends that DOE identify alternative proteins as high-value and high-priority decarbonization technologies within the food/beverage subsector. We further urge DOE to consider agency-wide actions in support of the development and expansion of the alternative protein industry to unlock the sector's full decarbonization potential. As outlined above, recommended actions include establishing an Energy Earthshots Initiative focused on alternative proteins and food innovation, expanding eligibility for and prioritization of alternative protein technologies in existing DOE programs, and partnering with USDA to carry out a whole-of-government approach on alternative protein R&D and production.

As previously stated, GFI is a nonprofit think tank working to improve the global food system. We work closely with alternative protein academic and industry stakeholders and are glad to serve as a resource in answering further questions or connecting you with stakeholders best equipped to provide relevant information.

Sincerely,

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