Anticipating Futures of Alternative Protein

A briefing report from the AgMIP 2023 expert workshop

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AgMIP 9 Modeling the Future of Food

Introduction

On June 26, experts across climate change, agronomy, economics, and public health convened to identify research priorities regarding the pitfalls and promise of alternative proteins as a climate solution. More broadly, the workshop investigated how alternative proteins will intersect with climate change across a range of environmental and human impacts, and their couplings.

Alternative proteins were defined as analogues to animal-sourced foods, including meats, dairy, eggs, and seafoods, that require no (or far fewer) animals to be reproduced or slaughtered[1]. These can occupy four broad categories of production:

> Plant-based converts crops to mimics of animal-derived proteins
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> Single-cell relies on fermentation and inoculation of organismic biomass, for instance mycoprotein (e.g. Quorn) or bacteria.
>
> Recombinant (i.e. precision fermentation) uses microorganisms like yeast to produce individual ingredients, including complex molecules like insulin, rennet, fats, and heme
>
> Cell-cultured replicates entire animal cells like muscle tissue using culture and tissue engineering. It can produce meats from stem or immortal cell lines in a growth medium.

These technologies all require feedstock crops and energy, which incur climate impacts. Feedstock crops are needed to produce the protein food product itself (plant-based), to power metabolism of microorganisms for fermentation (single cell & recombinant), or to create a nutrient-rich medium for cell proliferation (cell-cultured). Additionally, all processes require energy in the production process, but the amount required can vary by an order of magnitude or more[2], with the least to greatest needs from top to bottom of the above list. Whether these technologies can mitigate climate change depends first upon life-cycle greenhouse gas emissions compared with animal-sourced counterparts, and second upon the extent to which they replace or merely supplement those foods.

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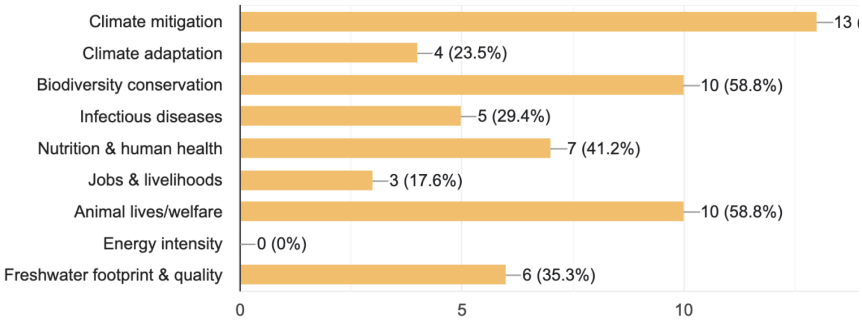
[1] This definition of alternative protein differs from some others, which may include animal-sourced protein foods not often consumed in western or mass markets, including insects, or novel production methods for conventional animals, including e.g. “aquaponics” systems of combining indoor plant and fish production. While research into these systems is an important area of ongoing research, they are subject to some limitations (e.g. animal metabolism) and ethical tradeoffs (e.g. animal slaughter) faced by conventional animal-sourced food production.

[2] A subjective estimation by the authors, but reflects expert knowledge of peer-reviewed and gray literature.

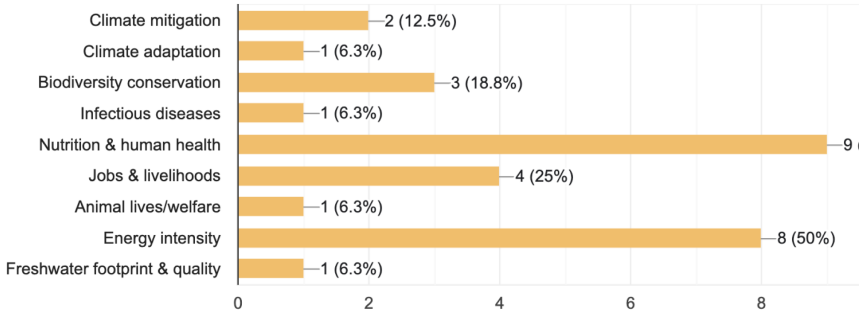
Pre-Workshop Survey

This workshop aimed to thematically organize research around the interaction between alternative with climate change. These interactions are, in turn, connected to myriad other social and environmental impacts We created an informal survey to gauge our expert attendants' impressions of alternative proteins' potential impacts. Seventeen expert participants completed the survey, and were directed to "check all that apply".

Participants were **optimistic** about alternative proteins' potential impact upon:



Participants were **pessimistic** about alternative proteins' potential impact upon:



There were nearly twice as many optimistic responses (58) as there were pessimistic responses (30), but at least one expert was pessimistic about every potential impact domain. The expert group as a whole agreed that the public and policymakers are lacking independent, trustworthy expertise that could navigate, analyze, and communicate these myriad and intersecting impacts, along with their tradeoffs and cobenefits. Later discussion focused on using tools developed by the Agricultural Modeling Intercomparison and Improvement Project (AgMIP) to investigate these tradeoffs and cobenefits among a regionally constrained set of questions and outcomes. In particular, the regional integrated assessment (RIA) protocols can provide this research with a framework for thinking through the interconnections, while generating policy-relevant and stakeholder-oriented guidance[3].

[3] Rosensweig et al. (2018) "Protocols for AgMIP Regional Integrated Assessments: Version 7.0" Agricultural Modeling Intercomparison and Improvement Project. https://agmip.org/regional-integrated-assessments-2/

Guest Presentations

Sanah Baig – Deputy Undersecretary of Research, Education, and Economics at USDA highlighted Agency and Biden administration priorities for supporting next generation biotechnology, including alternative proteins. The USDA has publicly funded an estimated $33 million into alternative protein research to date. In recent developments, President Biden signed the *Executive Order on Advancing Biotechnology and Biomanufacturing Innovation*, which highlights needs for foundational research and capacity building for a "bio-based" economy, including alternative food sources like novel proteins[4]. Goals of this order include building technological leadership and economic competitiveness, with sustainability, environmental justice, and equity as guiding principles. Following this executive order, the USDA will be aligning future research calls under its grantmaking divisions (e.g. ERS, NIFA). This will include a five-year timeline to foster breakthrough research into producing novel foods from biomass, waste, and CO_2. More foundational research is needed into the effects of such advancements at scale, especially as they pertain to livelihoods and land. Economic opportunities for improved livelihoods may include onshoring manufacturing and growth in feedstock crops, but alternative proteins might also reduce or displace existing agricultural products. The agency can assist in planning for and managing certain impacts: ERS can plan for economic shocks and the NRCS can deploy resources that address environmental benefits or tradeoffs. Additionally, the agency can also secure agreements with producers to supply feedstock crops for novel pilot programs. Pilots may also focus on communities facing historical inequities.

Rosie Wardle – Partner and Co-Founder of Synthesis Capital presented her perspective from the world's largest dedicated fund for alternative proteins. The sector experienced substantial growth over the previous decade, but as a nascent sector still faces technological, commercialization, consumer, and regulatory hurdles. She presented key industry tailwinds driving progress across alternative proteins, including technology breakthroughs such as wastes-as-feedstock, as well as government and regulatory support in the Netherlands, Singapore, and the US[5]. She then presented structural challenges faced by the incumbent industry, and then a summary of persistent headwinds and key industry challenges. Using internal data for market share projections, Synthesis expects alternative proteins to follow the S-Curve adoption theory for novel technologies: growth starts slowly (slower than linear projections of adoption) but then quickly accelerates non-linearly/exponentially as economic and regulatory headwinds are overcome.

Ross Miranti – Senior Manager of Business Development at One Acre Fund provided his perspective from a social impact enterprise in Rwanda. One Acre Fund, together

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[4] Exec. Order No. 14,081, 87 FR 56849 (September 15, 2022).
[5] USDA Food Safety and Inspection Service. Directive 7800.1 https://www.fsis.usda.gov/policy/fsis-directives/7800.1

with the Rwandan government and local university partners, is co-developing shelf-stable meat replacements (e.g. textured vegetable protein or 'TVP') from locally grown agri-biodiverse crops. Their theory of change is based on leapfrogging Africa's growing demand for meat as a source of protein, taste, and as a 'luxury good', by providing enjoyable and accessible alternatives. One Acre Fund's work involves developing markets for these products in Rwanda across both supply and demand. Household surveys of prospective products have performed well. By driving adoption across a complete domestic value chain, One Acre Fund aims to achieve a "triple win" of economic development, climate resilience, and improved nutrition outcomes. Their fund aims to achieve this through a rapid & lean strategy of "learning by doing".

Expert Workshop

The expert attendants were split into two groups, each choosing to provide guiding questions for the research community into one of the above impact areas, with the option of adding more specificity.

Group 1 Chose to focus on climate mitigation through land use and greenhouse gas emissions. Other core themes of this group were consumer behaviors, substitution effects, animal-sourced fats, and incorporating these various aspects into appropriate future trajectories for use in scenario modeling.

Land use is globally dominated by global food systems, predominantly for pasture (for ruminants like cows and sheep) and cropland (for animal feed, food, fiber, and biofuels). Agricultural expansion and land clearing cause CO_2 emissions. Conversely, reducing agricultural land use can allow for reforestation and other habitat restoration, causing CO_2 sequestration. Animal sourced foods represent the largest opportunity cost for this CO_2 removal on land.[6]

At scale, alternative proteins could create leverage to reduce pasture land, which occupy nearly a third of the earth's habitable surface. In many areas, pastures have displaced forests (e.g. Northeastern US, the UK, or the Brazilian Amazon), incurring a high carbon opportunity cost. For cropland, plant-based meat's requirements are very low, but the literature contains widely varying estimates for cell-cultured meat. Two questions arise about land requirements (1) how efficient are production processes at converting crops to protein-rich foods? And (2) how can low- to no-value waste streams be utilized as feedstocks for alternative protein?

Changes in land use create new concerns. The group agreed that a useful conceptual tool for understanding these concerns was the option space, i.e. the diverse matrix of alternative economic uses, management decisions, and user groups potentially using that land. Freed up land can be used for nature restoration, alternative

[6] Hayek MN, Harwatt H, Ripple WJ, Mueller ND (2021) The carbon opportunity cost of animal-sourced food production on land. Nat Sustain 4:21–24. https://doi.org/10.1038/s41893-020-00603-4

agricultural techniques (e.g. organic), recreation, biofuels, energy production, indigenous repatriation and management, and more. Alternative land uses create mitigation as well as adaptation concerns: if food and other economic activities are using less land, or if land uses homogenize (or diversify), what are the consequences for resilience to climate-related shocks and changes?

Life-cycle analysis (LCA) will be a useful tool to investigating upstream impacts of future alternative proteins, but has critical limitations in a prospective or predictive capacity. Namely, many of the assumptions made by LCA depend upon present environmental and economic conditions. Because so many assumptions are limited or undefined in future scenarios, scenario analysis will be essential for investigating environmental impacts and tradeoffs across the option space.

Concerns were also raised over energy requirements and replacement effects. Greenhouse gas emissions depend upon the efficiency of production techniques, and also upon the mix of clean and renewable energy sources. Both are challenging to predict.

Additionally, major questions remain about whether alternative proteins will displace or supplement large quantities of meat consumption in developed countries. If displacement effects do occur, will they replace high emissions and worst nutrient meat, or lower emissions meat with higher nutritional value? Scenarios must include all prospective technologies and replacement effects.

Group 2 Chose to focus on economic impacts on jobs and livelihoods in developed countries and developing contexts. Additional themes were consumer attitudes, nutrition, and cultures.

Alternative proteins could represent both a threat and opportunity to livelihoods and economic well-being across both developed and developing countries. These effects will likely be complex, nonlinear, and unpredictable even with sophisticated modeling. However, initially constraining questions to few test cases and pilot programs could reveal illuminating tradeoffs.

The group decided that we could test hypotheses and evaluate outcomes using an adapted version of AgMIP's Regionally Integrated Assessment (RIA) protocols, which link site-specific data with modeling, for forecasting climate change and food systems interactions. The group noted that Rwanda could be one example test site, where the One Acre Fund is developing markets for novel plant-based protein foods based off of regionally-suitable, climate-resilient, locally grown crops. As the pilot programs and the markets they aim to generate scale, we could collect publicly-available demographic information and survey producing households to predict, model, and validate the effects of diversifying production for these feedstock crops. In California, plant-based dairy substitute companies like Oatly and Miyoko's Creamery are aiming to transition dairy and fodder crop producers to production of oats and potatoes for use in their products. Additionally, across the state of Montana and the wider North American Dry Plains/Prairie region, farmers are introducing more frequent rotations and hardier heat and frost-resistant varietals of legumes for plant-based meat

markets. RIA tools can also help inform a unified experimental framework across these regions, using information from networks of farms for case-control studies.

Many questions remain about the tradeoffs incurred by shifts to alternative proteins. These include whether crop production will become more agri-biodiverse or less so, which is also related to scale and substitution effects in alternative protein production. Additionally, questions about whether consumers will benefit in terms of nutrition remain uncertain. Lastly, will consumers accept alternative proteins, and if these answers are uncertain, what does it take to drive adoption? The group proposed a range of potential answers to the latter including advertising with climate information, as previous research has shown that climate labeling can indeed drive adoption of alternatives to emissions-intensive meat and dairy.

Next Steps

The workshop illuminated an expansive set of questions related to alternative proteins and climate. However, we identified two urgent but feasible areas for the research over the following two years. To select these research areas, we used enumerated criteria to select where tangible research progress can be accomplished using a combination of already established tools, data, and modeling protocols, combined with primary data collection described herein:

1. **Land use at scale**
    a. Domain: existing cell-cultured and precision fermentation companies in multiple geographic regions, at stages between prototype and commercial scales
    b. Data needs: key parameters from alternative protein and feedstock companies that will inform land use and energy use. These parameters include feedstock refinement into principal ingredients, the use and generation of by/co-products in manufacturing feedstocks, and the effective "feed conversion ratios" for cell-culturing processes.
    c. Modeling needs:
        i. Link downstream manufacture processes with upstream agricultural commodities and their land use requirements.
        ii. Create a framework for GHGs and carbon opportunity costs on croplands.
        iii. Design viable scenarios (cooperatively with stakeholders) that can test tradeoffs across the full land use option space.
2. **Agricultural Livelihoods**
    a. Domain: Plant-based protein agricultural production in two geographic regions with existing markets or pilot programs. One in a developed region (e.g. California or Montana) and one a developing region (e.g. Rwanda).

b. Data needs: demographics, incomes, agricultural statistics, and climate, from household to country level. Data collection to occur before and after interventions.
c. Modeling needs: crop, climate, and economic modeling using RIA as a framework. Cooperative design with governments and industries. Use a tradeoff model (e.g. TAO-MD) in conjunction with agricultural adoption models to understand the impacts on farmers' economic wellbeing and livelihoods following shifts to producing alternative protein feedstocks.

The two teams will reconvene in an online workshop this fall, with additional researchers. The following workshop will add specificity to these projects, discuss specific model designs, settle on relevant project domains and stakeholders, and identify funding opportunities to materialize the projects. This and subsequent workshops will have the added benefit of creating more connective and collaborative research with colleagues' ongoing projects, and discussing rapidly evolving developments and concerns of stakeholders likely to be affected by this sector.