Innovations for net-zero energy and materials systems

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Innovation Brief Series

Alternative Proteins

Unlocking land for nature and biomass

Source sustainably and manage end-of-life

Energy Transitions Commission

SYSTEMIQ

This innovation brief was created by Systemiq and the Energy Transitions Commission as part of the *Carbon in an electrified future* series. Each brief highlights a key technological innovation that can drive electrification, circularity, or carbon sourcing.

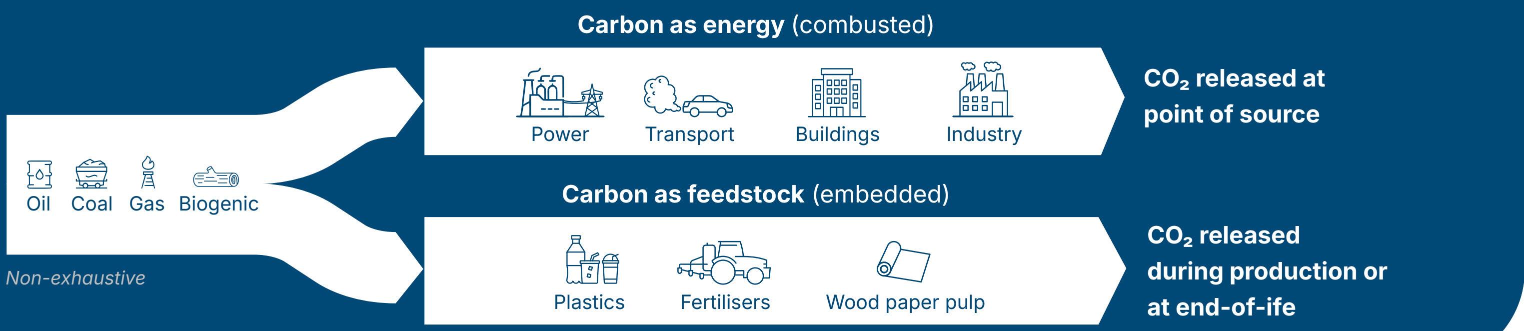
Learn more at www.energy-transitions.org/publications/carbon-in-an-electrified-future
www.systemiq.earth/resource-category/carbon-in-an-electrified-future

INNOVATIONS FOR NET-ZERO ENERGY AND MATERIALS SYSTEMS

Alternative Proteins

Carbon sits at the centre of today's energy and materials systems

Carbon is the core component of the fossil fuels and material feedstocks that underpin today's energy and materials systems. When these carbon-based resources are combusted or transformed to produce energy, heat, mobility, and materials, they release carbon dioxide (CO_2). Achieving net zero requires both reducing the carbon entering the system and actively managing the residual carbon that remains.



Three steps towards net-zero energy and materials systems

1 Reduce the use of carbon

- Increase supply of clean electricity
- Switch to electrification where possible
- Use clean hydrogen when not possible to electrify

2 Recycle and reuse carbon

- Increase durability and reuse of carbon products
- Scale recycling of carbon products
- Capture and reuse carbon emissions

3 Source sustainably and manage end-of-life

- Prioritise non-fossil carbon inputs and capture of unavoidable emissions
- Secure permanent storage for residual carbon

Alternative Proteins

What are Alternative Proteins?

Alternative proteins are protein-rich foods made without conventional livestock farming, including cultivated meat, fermentation-derived proteins, and plant-derived proteins.

Key takeaways

A **Alternative proteins can free up land for sustainable biomass supply,** creating space to expand biomass without intensifying land-use pressures. Three key innovations – **biomass fermentation, precision fermentation and cultivated meat** - offer complementary uses to displace animal protein, ranging from substituting base ingredients to structured meat products.

B **Under the right conditions, alternative protein technologies could become cost-competitive with animal protein** by 2050. Progress is required on: improving biological productivity (increasing production per batch); industrialising production at scale; optimising inputs and streamlining processing.

C **Alternative proteins must overcome consumer acceptance and technology readiness barriers to scale.** Despite faster production and higher resource efficiency, they are not yet mainstream and technology maturity remains significantly below conventional animal protein.

A Alternative proteins can free up land for biomass supply; three key innovations offer complementary uses to displace animal protein

Biomass is a sustainable source of carbon, but sustainable supply is limited

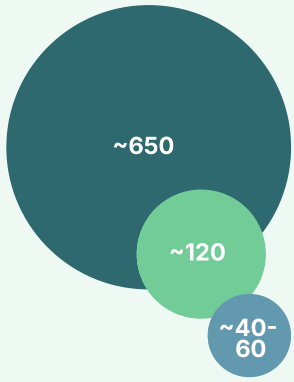
Biomass captures carbon via photosynthesis, therefore providing a sustainable source of carbon over its lifecycle. Biomass is currently used in bioenergy (e.g. power and heat generation, aviation fuel), bioplastics, biochar, and other products.

Biomass can only be considered sustainable if certain conditions are met

- No competition with other critical uses of land
- Respect growth periods which will delay supply
- No deforestation or peatland conversion
- Close-to-zero emission collection, transportation and processing
- Target degraded land, with little plant growth
- No environmental or social harm

Truly sustainable biomass is finite and cannot meet the demand for the energy and materials sector

Potential biomass 2050, EJ/y



Demand if all energy and material sectors convert current demand to biomass[1]

Supply under ETC's Ambitious Scenario[2,3]

Supply under ETC's Prudent Scenario[2]

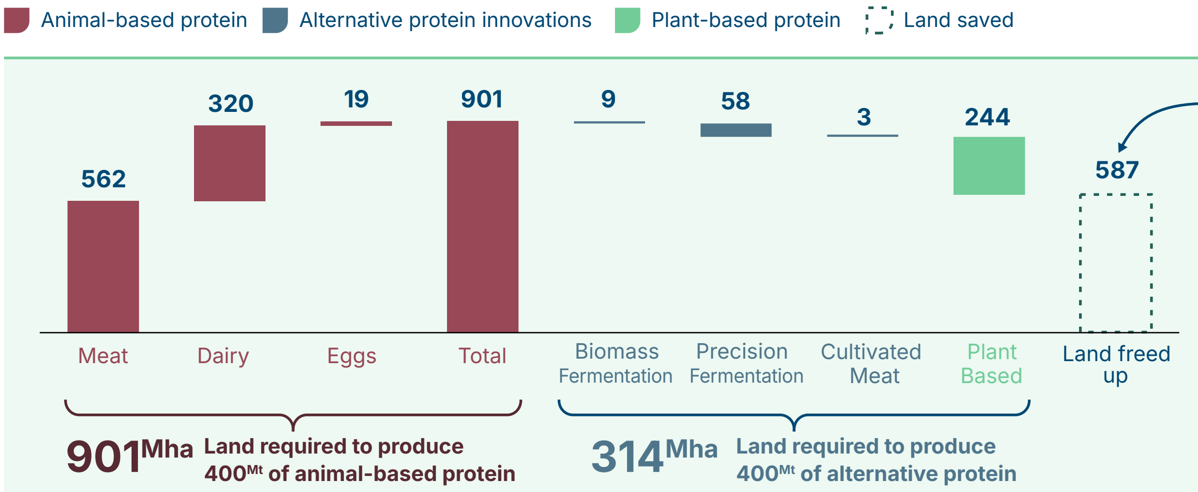
Alternative proteins can ease constraints on sustainable biomass supply by freeing up land used for animal protein

Three key innovations in alternative proteins have potential to save 90% of land vs animal protein alternative[4,5]

	Biomass Fermentation[6,7]	Precision Fermentation[8,9,10]	Cultivated Meat[11,12]
Definition	Using fast-growing microorganisms to generate whole protein-rich biomass	Engineering microbes to produce specific functional molecules	Culturing animal cells in controlled bioreactors into meat-like products
Use cases	Base ingredients for meat-like products(e.g., mycoprotein, fungal burgers)	Ingredients such as egg white, casein, whey, rennet	Whole cuts and structured meat products
Example companies	Quorn, SOLAR FOODS	GELTOR, PERFECT DAY	BELIEVER, MOSA MEAT

In a high adoption scenario, a shift to alternative protein innovations and plant-based proteins could free up ~590 Mha[13] of land by 2050, roughly the size of the Amazon rainforest

Land required to produce 400 Mt of protein by source[14] Mha

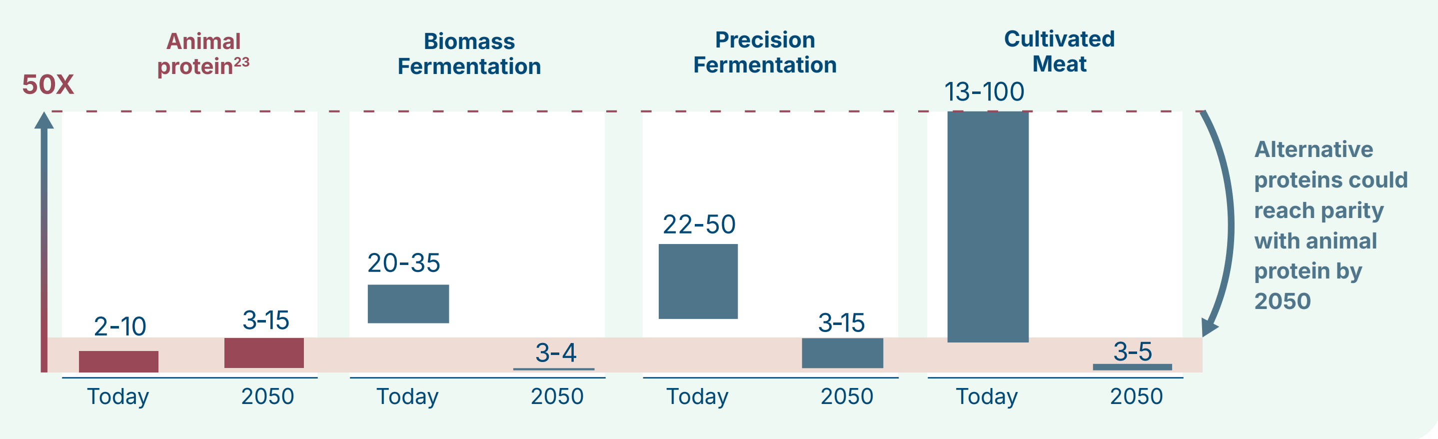


Alternative protein innovations could account for **~20% of the ~590 Mha land freed up[15]**. Land freed up can be used to return to nature, managed forestry, or energy crops

B Under the right conditions, all alternative protein technologies could reach cost parity with animal protein

Alternative proteins remain up to 50× more expensive today, but technological advances and scale could enable them to reach cost parity by 2050[21]

Comparison of the cost of 1kg of alternative proteins vs. animal proteins[22] $/kg



Three levers can enable alternative protein cost parity

Improve biological productivity	Increase cell or microbe density and improve yields so more product is produced per batch, reducing unit costs and downtime
Industrialise production at scale	Move from pilot to large-scale facilities, including larger (and more efficient) bioreactors and more standardised production, to unlock economies of scale
Optimise inputs and processing	Lower the cost and improve the efficiency of key inputs (feedstocks/media and energy) and streamline downstream processing to reduce losses

C Alternative proteins must overcome consumer acceptance and technology readiness barriers to scale

Alternative proteins can be produced faster and use fewer resources, and can unlock revenue from freed land, but scaling is constrained by consumer adoption and technology maturity.[19]

Most favourable / Least favourable

	Animal protein	Alternative proteins
Production speed	Months-years	Days-weeks
Resource efficiency	High land, water and energy demand; biological losses	Lower land, water and energy demand; higher conversion efficiency
Consumer adoption	Dominant protein source	Not yet mainstream, improving
Technology readiness level[20]	Meat, dairy, eggs.......................... **9**	Biomass fermentation.................**6–9** Precision fermentation.................. **~7** Cultivated meat.......................... **3–5**
Opportunity for additional revenue stream	Limited	Freed up land can support forestry, energy crops and, biodiversity restoration

Alternative proteins: shifting protein production to free up land and expand sustainable biomass supply

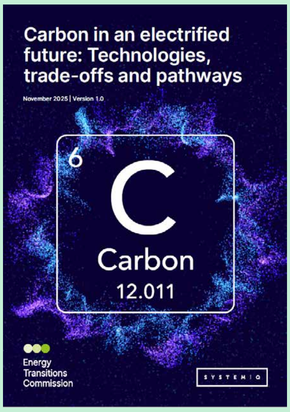
Alternative proteins can:

Provide a more efficient route to protein production with fewer raw inputs, higher conversion efficiencies and faster production time.

Expand potential sustainable carbon supply by easing land use constraints on sustainable biomass production.

Three priorities to scale alternative proteins

Key priorities	Key players	Key actions
Improve consumer attractiveness	• Alternative protein producers • Food companies • Retailers • Governments	Innovation in product performance (taste, texture, nutrition), plus targeted consumer engagement to manage perceived health risks can reduce initial resistance and cultural barriers. Early adoption via public procurement and food service can normalise products via repeated exposure, while stable volume contracts can help scale production.
Build manufacturing capacity and resilient supply chains	• Alternative protein producers • Biomanufacturing and equipment suppliers • Food companies • Governments	Investment in manufacturing capacity, supply chains and distribution networks is needed to move beyond pilot volumes and support large-scale adoption.
Drive price parity with animal protein	• Alternative protein producers • Investors • Governments	Sustained cost reductions toward price parity with animal-based protein (≤ US $15/kg by 2050). Key enablers include breakthroughs in cell and culture density, improved process efficiency, and large-scale biomanufacturing to unlock economies of scale and reduce capital costs.



Further reading: Also in this Innovation Brief Series

Electrification will drive the global transition to net zero, powering cleaner industries, homes and transport. But even in a world where electricity dominates, carbon molecules will play a remaining role in producing essential fuels and materials.

This innovation brief is part of the ***Carbon in an electrified future*** series. Each brief highlights a key technological innovation that can drive electrification, circularity, or sustainable carbon sourcing across three steps towards net-zero emissions energy and materials systems.

Explore more in the other briefings:

Reduce carbon use → **Recycle and reuse carbon** → **Source sustainably and manage end-of-life**

Sodium-ion batteries
Diversifying beyond lithium-ion with a scalable alternative

Molten Oxide Electrolysis and Electrowinning
Electrifying ore-based steel production

Carbon Capture and Utilisation
Enabling targeted carbon utilisation for high-value industrial application

Alternative Proteins
Unlocking land for nature and biomass

Sources and notes

1. FAO (2022) Food balance sheets 2010 – 2022; UN (2022) World Population Prospects 2022: Summary of Results
2. ETC (2021) Bioresources within a Net-Zero Emissions Economy: Making a Sustainable Approach Possible
3. Potential supply estimated without major system changes
4. McKinsey & Company (2025) Ingredients for the future: Bringing the biotech revolution to food
5. Green Circle Capital Partners (2023) Protein Pricing Comparison Summary
6. McKinsey & Company (2025) Ingredients for the future: Bringing the biotech revolution to food
7. Genetic Engineering & Biotechnology News (2023) Fermentation Margins and Cost of Goods
8. Good Food Initiative (2024) Precision Fermentation: Communication Guide
9. Risner, D. et al. (2023) A techno-economic model of mycoprotein production: achieving price parity with beef protein
10. Knychala et al. (2024). Precision Fermentation as an Alternative to Animal Protein, a Review
11. Negulescu (2022) Techno-economic modelling and assessment of cultivated meat: Impact of production bioreactor scale
12. Pasitka et al. (2024) Continuous Manufacturing of Cultivated Meat: Empirical Economic Analysis
13. ETC (2021) Bioresources within a Net-Zero Emissions Economy: Making a Sustainable Approach Possible
14. Systemiq analysis of: GFI (2023) Environmental benefits of alternative proteins; Blue Horizon (2020) Environmental impacts of animal and plant-based food; Sinke et al. (2023) Ex-ante life cycle assessment of commercial-scale cultivated meat production; Poore et al. (2018) Reducing food's environmental impacts through producers and consumers; expert interviews
15. Additional to 40-60 EJ/year sustainable supply baseline in ETC scenario
16. ETC and Systemiq (2025) Carbon in an electrified future: Technologies, trade-offs and pathways
17. Ranges reflect cost variations by protein type, geography, and production method, representing global averages
18. Given projections for the cost of animal-based proteins by 2050 are very limited, cost increases of 20-60% are assumed to reflect increased demand from global population growth, resource constraints, and inflation
19. Systemiq analysis for the ETC (2025), and Systemiq (2025), A Taste of Tomorrow: How Protein Diversification Can Strengthen Germany's Economy
20. Technology readiness level (TRL) is a standard scale used to assess the maturity of a technology, from 1 (basic principles observed and documented) to 9 (technology proven in operation and in industrial production)