Quest
VENTURES

Venture Capital Opportunities in Food and Agricultural Technology

An approach to solving Hunger

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Contents

1. Overview

With almost 8 billion hungry customers with a constant appetite for consumption, there is no larger market than the market for food[1]. With USD$39.3 billion[2] invested by venture capitalists globally in 2021, food tech startups are quickly gaining traction.

As food security continues to be a problem in many regions of the world and the consequences of our environmentally damaging behaviour catch up with us, entrepreneurs are finding ways to improve the sustainability, accessibility and ethicality of the ways we produce, store and transport food. Given the urgency of world hunger and that most innovative food companies aim specifically to become scalable and replicable, venture capital is well poised to accelerate the development of foodtech.

The problem of hunger is a multifaceted one. In the current period, it is of utmost importance that we feed the 820 million[3] who go hungry every day. In the impending future, the consequences of human activities are catching up to us, with increased extreme weather events, loss of arable land, water scarcity and political instability causing food insecurity in areas once lush with food.

This report seeks to survey promising new fields and technologies that private sector investment can support in order to seek the dual goals of alleviating world hunger and achieving profitable returns.

1. Poinski, M. (2022, February 17). *Food Tech saw $39.3B in VC Investments last year, says Pitchbook*. Food Dive. Retrieved July 6, 2022, from https://www.fooddive.com/news/food-tech-saw-393b-in-vc-investments-last-year-says-pitchbook/618916/#:~:text=For%20products%2C%20ingredients%20and%20R%26D,adding%20up%20to%20%2414.3%20billion
2. World Bank Open Data. (n.d.). Retrieved July 6, 2022, from https://data.worldbank.org/indicator/SP.POP.TOT
3. World Health Organization. (n.d.). *World hunger is still not going down after three years and obesity is still growing – UN report*. World Health Organization. Retrieved July 6, 2022, from https://www.who.int/news/item/15-07-2019-world-hunger-is-still-not-going-down-after-three-years-and-obesity-is-still-growing-un-report#:~:text=More%20than%20820%20million%20people%20are%20hungry%20globally&text=This%20underscores%20the%20immense%20challenge,the%20World%20report%20released%20today.

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Foreword

History has a way of repeating itself. Having avoided (and failed to avoid) famines several times in key junctures in the history of the world, scientists and investors are now at yet another inflection point. With massive amounts of investment capital going into all parts of the value chain for food, there is never a better time for the world to guarantee its food security.

Challenges exist. From taste to nutrition, from supply chain to markets, there are innovators and policy makers looking and testing for new efficiencies.

There will be many failures along the way, but if history is any guide, humanity will finance, create, and consume new sources of food.

James Tan
Managing Partner
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2. Reducing Hunger

2.1 Reducing Hunger Now

Lack of sufficient food causes 25,000 deaths a day[4] and the undernourishment of 690 million people[5], the stunting of growth in 21.3% of children[6] and costs the world at least hundreds of billions of dollars yearly in healthcare costs (USD160B in just the USA alone[7]).

While an obvious solution seems to be improving how we produce food, the fact is that the world has long been able to produce more than sufficient food for everyone, with this 2012 paper from the Journal of Sustainable Agriculture titled "We Already Grow Enough Food for 10 Billion People … and Still Can't End Hunger"[8]. In it, the authors state that "Hunger is caused by poverty and inequality, not scarcity."

Unfortunately, poverty is not an issue solvable by the private sector alone. First because the scale of poverty is immense relative to the possible impact of job creation and lending that can be done. Second because the poor are by necessity not ideal customers, even for goods and services that can help them out of poverty. One cannot expect profit-driven corporations to act without the promise of profitability. Lastly, some of the issues that plague the poor are due to a lack of public goods, known by economists as goods that are non-excludable and nondepletable. Essentially, to ask a firm to provide such goods is to ask it to suffer all the costs and share the benefits, a tough ask for profit-driven organisations.

To illustrate this, let us return to the premise that we already produce sufficient food for everyone indicates two possible solutions. First, the improvement of supply chains and logistics so that food can reach those who need it the most. Second, to increase production of food where people are starving.

4. United Nations. (n.d.). Losing 25,000 to hunger every day. United Nations. Retrieved July 6, 2022, from https://www.un.org/en/chronicle/article/losing-25000-hunger-every-day
5. *World hunger: Key facts and statistics 2022*. Action Against Hunger. (2022, April 14). Retrieved July 6, 2022, from https://www.actionagainsthunger.org/world-hunger-facts-statistics#:~:text=About%20690%20million%20people%20globally%20are%20undernourished
6. *SDG goal 2: Zero hunger*. UNICEF DATA. (2021, February 24). Retrieved July 6, 2022, from https://data.unicef.org/sdgs/goal-2-zero-hunger/#:~:text=Worldwide%2C%20nearly%20half%20of%20all,5.6%20per%20cent%2C%20were%20overweight.
7. $160 billion: The Health Costs of Hunger in America. Hunger Report 2020. Better Nutrition, Better Tomorrow. Bread for the World Institute. (n.d.). Retrieved July 6, 2022, from http://www.hungerreport.org/costofhunger/

When considering the issue of transporting food to poor rural areas, the issue is classically "chicken-and-egg" in nature. There is a lack of transport infrastructure, such as roads and ports, in these areas. The difficulty of transporting food to these areas drives up costs, which are unaffordable for the hungry and the poor. But any company that would stand to gain from building roads there (e.g. food logistics companies) is unlikely to build a road that its competitors can also use. Simultaneously, the lack of accessibility means reduced trade, job opportunities, and access to education and healthcare, all factors which keep individuals mired in poverty. Low incomes lead to low purchasing power, meaning that companies are unlikely to want to invest in these areas anyways.

However, this is not to say that the private sector cannot alleviate the problem of hunger and act in a way that is aligned with its profit motives.

One solution is to help the 500 million small farm households[9] in the world that make up a large portion of both the world's poor and the hungry. By providing them with goods and services that improve their businesses, corporations can play an active role in alleviating both poverty and hunger. These farms are of such small scale that they are mostly subsistence in nature, unable to provide sufficient food for the families let alone enough for sale. Helping these small farmers is crucial because the food they would produce helps not just their families, but also the world. Small farmers operate just 12% of all farmland, but produce 35% of the world's food[10].

By directly increasing food production in the exact areas which experience poverty and hunger, we can bypass the need for expensive infrastructure and supply chains, thereby reducing food wastage in transit and emissions created from feeding our hungry.

8. Holt-Giménez, E., Shattuck, A., Altieri, M. A., Herren, H., & Gliessman, S. (n.d.). *We already grow enough food for 10 billion people … and still can't end …* Retrieved July 6, 2022, from https://www.researchgate.net/publication/241746569_We_Already_Grow_Enough_Food_for_10_Billion_People_and_Still_Can't_End_Hunger
9. worldbank.org/en/news/feature/2016/02/25/a-year-in-the-lives-of-smallholder-farming-families#:~:text=There%20are%20an%20estimated%20500,less%20than%20%242%20a%20day.
10. Marie, A. (2022, May 17). *Addressing the digital divide for Smallholder Farmers*. ALI Social Impact Review. Retrieved July 8, 2022, from https://www.sir.advancedleadership.harvard.edu/articles/addressing-digital-divide-for-smallholder-farmers

2.1 Reducing Hunger in the Future

Since the invention of agriculture, humanity has never stopped improving upon the methods by which we produce, store and transport food; from irrigation and the wheel, to factories and preservatives and more recently, lab-grown meat. Alas, recent phenomena have reminded even the developed world that we are still far from a post-scarcity economy.

Climate change has caused changes in global temperatures[11] and precipitation patterns[12], increased frequency of extreme weather events[13], and even encouraged the spread of once less common crop diseases[14]. To make matters worse, our methods of food production themselves contribute significantly to climate change[15].

Political instability has caused countless price fluctuations and food shortages, with the worst cases resulting in famine, whether they be trade disputes[16] or armed conflict[17,18,19].

We have also long been aware that the Earth contains only finite resources; the precious land, labour and capital with which we produce food. Thomas Robert Malthus' in *An Essay on the Principle of Population*, famously describes what is now known as the Malthusian trap: humanity's exponentially growing population needs far outpacing our linearly increasing capacity for food production[20]. With current production capabilities and population growth data, it is estimated that we will need to increase our amount of farmland by twice the landmass of India, or on the whole, a total land usage of 70% of the Earth's habitable land[21] by 2050.

11. Dahlman, R. L. A. N. D. L. A. (n.d.). *Climate change: Global temperature*. Climate Change: Global Temperature | NOAA Climate.gov. Retrieved July 8, 2022, from https://www.climate.gov/news-features/understanding-climate/climate-change-global-temperature
12. Environmental Protection Agency. (n.d.). EPA. Retrieved July 8, 2022, from https://www.epa.gov/climate-indicators/climate-change-indicators-us-and-global-precipitation
13. Greenough, G., McGeehin, M., Bernard, S. M., Trtanj, J., Riad, J., & Engelberg, D. (2001, May). *The potential impacts of climate variability and change on health impacts of extreme weather events in the United States*. Environmental health perspectives. Retrieved July 8, 2022, from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1240666/
14. Zhou, Y., Shan, Y., Guan, D., Liang, X., Cai, Y., Liu, J., Xie, W., Xue, J., Ma, Z., & Yang, Z. (2020, September 15). *Sharing tableware reduces waste generation, emissions and water consumption in China's takeaway packaging waste dilemma*. Nature News. Retrieved July 8, 2022, from https://www.nature.com/articles/s43016-020-00145-0
15. Ritchie, H., & Roser, M. (2020, January 15). *Environmental impacts of food production*. Our World in Data. Retrieved July 8, 2022, from https://ourworldindata.org/environmental-impacts-of-food
16. *Trade wars are huge threats to food security*. UNCTAD. (2020, January 22). Retrieved July 8, 2022, from https://unctad.org/news/trade-wars-are-huge-threats-food-security
17. Watts, M. J., & Bohle, H.-G. (n.d.). *The space of vulnerability: The causal structure of hunger and famine*. Retrieved July 8, 2022, from https://www.researchgate.net/publication/248018431_The_Space_of_Vulnerability_The_Causal_Structure_of_Hunger_and_Famine
18. Messer, E., Cohen, M. J., & Marchione, T. (n.d.). *Power-sharing and peacebuilding in Burundi*. Retrieved July 8, 2022, from https://medialibrary.uantwerpen.be/oldcontent/container2143/files/DPP%20Burundi/Ethnicit%C3%A9/Partage%20du%20pouvoir/Falch%20and%20Becker%20(2008)%20Power-sharing%20and%20Peacebuilding%20in%20Burundi%20(CSCW%20Paper).pdf
19. Cohen, M. J., & Pinstrup-Andersen , P. (n.d.). *Food security and conflict - JSTOR*. Retrieved July 8, 2022, from https://www.jstor.org/stable/40971318
20. Malthus, T. R. (n.d.). *An essay on the principle of population*. Retrieved July 8, 2022, from http://www.esp.org/books/malthus/population/malthus.pdf
21. Cohen, M. J., & Pinstrup-Andersen , P. (n.d.). *Food security and conflict - JSTOR*. Retrieved July 8, 2022, from https://www.jstor.org/stable/40971318

On the other end of the wealth spectrum, there is also rising demand for environmentally friendly or ethically produced food from the increasingly affluent population. The current size of the global ethical food market is USD542B and is expected to reach USD742B by 2025[22]. Examples of such lifestyle practices, widely known as environmentally sustainable food consumption (ESFC), include increasing consumption of plant-based[23], insect-based foods[24], seasonal products[25] and in some cases, buying locally produced[26] and/or organically produced food[27], as well as a conscious decision to reduce meat consumption[28].

The cumulative effect of the supply shocks, a rising demand backed by a steadily growing population, as well as to a smaller but non-negligible extent: the rising appetite for high-carbon footprint meat due to rising incomes in developing nations[29], places humanity between a rock and a hard place.

And yet, humanity has managed to overcome these issues before. Malthus' prediction did not account for the invention of pesticides, machines, refrigeration, and other technical advances that have improved how we produce, store and transport food. Crucially, he overlooked a factor of production which modern economists have recognised: Entrepreneurship.

22. *Global $727.86 billion ethical food markets, 2015-2020, 2020-2025F, 2030F*. Global $727.86 Billion Ethical Food Markets, 2015-2020, 2020-2025F, 2030F. (2021, May 12). Retrieved July 8, 2022, from https://www.prnewswire.com/news-releases/global-727-86-billion-ethical-food-markets-2015-2020--2020-2025f-2030f-301289793.html
23. Lea, E. J., Crawford, D., & Worsley, A. (2006, February 1). *Public views of the benefits and barriers to the consumption of a plant-based diet*. Nature News. Retrieved July 8, 2022, from https://www.nature.com/articles/1602387
24. Megido, R. C., Gierts, C., Blecker, C., Brostaux, Y., Haubruge, É., Alabi, T., & Francis, F. (2016, May 6). *Consumer acceptance of insect-based alternative meat products in western countries*. Food Quality and Preference. Retrieved July 8, 2022, from https://www.sciencedirect.com/science/article/abs/pii/S095032931630091X
25. Macdiarmid, J. (n.d.). *Seasonality and dietary requirements: Will eating seasonal food ...* Retrieved July 8, 2022, from https://www.researchgate.net/publication/263970775_Seasonality_and_dietary_requirements_Will_eating_seasonal_food_contribute_to_health_and_environmental_sustainability
26. James MacGregor, B. V. (n.d.). *"fair miles"? the concept of "food miles" through a sustainable development lens*. Publications Library. Retrieved July 8, 2022, from https://pubs.iied.org/11064iied
27. Hughner, R. S., McDonagh, P., Prothero, A., Shultz, C. J., & Stanton, J. (2007). Who are organic food consumers? A compilation and review of why People Purchase Organic Food. *Journal of Consumer Behaviour*, *6*(2-3), 94–110. https://doi.org/10.1002/cb.210
28. Hoek, A. C., Luning, P. A., Stafleu, A., & de Graaf, C. (2004). Food-related lifestyle and health attitudes of Dutch vegetarians, non-vegetarian consumers of meat substitutes, and meat consumers. *Appetite*, *42*(3), 265–272. https://doi.org/10.1016/j.appet.2003.12.003
29. Delgado, C. L. (2003). Rising consumption of meat and milk in developing countries has created a new Food Revolution. *The Journal of Nutrition*, *133*(11). https://doi.org/10.1093/jn/133.11.3907s

3. Survey of Existing Frameworks

Frameworks to solve the world hunger crisis and other sustainability issues with our current food production, storage and transportation systems offer a hint of the gaps which startups can turn into market opportunities, and in turn such information can be used as an evaluation tool for VCs. If a new technology or business model aligns itself well to promising solutions to long-standing global problems, its potential to scale, reach untapped markets or underserved communities will be immense.

3.1 Investing in Nutrition - World Bank

This investment framework was created by the World Bank[30] in collaboration with Results for Development Institute, and 1,000 Days, with support from the Bill & Melinda Gates Foundation. It aims to be a guide for investment needed to help the world reach the global 2030 nutrition targets, of which we are not on track to achieve any of the six.

The six nutrition targets are:

1. Reduce Stunting
2. Reduce Anaemia
3. Reduce Low Birth Weight
4. Reduce Overweight
5. Increase Exclusive Breastfeeding
6. Reduce Wasting

30. *Investing in nutrition - 1,000 days*. (n.d.). Retrieved July 11, 2022, from https://thousanddays.org/wp-content/uploads/Investing-in-Nutrition-The-Foundation-for-Development.pdf

"

This paper lays out an investment framework to reach these global nutrition targets:

1. Global action is urgently needed to tackle the pervasive problem of malnutrition.
2. Reaching the targets to reduce stunting among children and anaemia in women, increase exclusive breastfeeding rates, and mitigate the impact of wasting will require an average annual investment of $7 billion over the next 10 years. This is in addition to the $3.9 billion the world currently spends on nutrition annually.
3. To catalyse progress toward the global nutrition targets, priority should be given to a set of the most cost-effective actions which can be scaled up immediately. Financing this more limited set of actions will require an additional annual investment of just over $2 billion for the next 10 years. The majority of this annual investment would come from country governments and donors, $1.4 billion and $650 million, respectively, while innovative financing mechanisms and households fund the remaining gap.
4. When combined with other health and poverty reduction efforts, this priority investment can yield significant returns: an estimated 2.2 million lives can be saved and there will be 50 million fewer cases of stunting in 2025 compared to in 2015.
5. Achieving the targets is within reach if all partners work together to immediately step up in investments in nutrition.

"

Investing in Nutrition[30]

3.1.1 Investing in Nutrition - Evaluation

Though this report is targeted to public investment, and aimed at saving lives and improving health outcomes rather than financial return or potential exit of a company, there are overlapping important criteria to consider.

1. Cost-effectiveness: considering poverty is a large cause of lack of access to food, solutions cannot be inaccessible to low income households. Additionally, the food manufacturing industry tends to be a price-competitive arena where keeping cost low is vital.
2. Scalability: solutions that cannot be implemented in the magnitude of millions should be considered dead on arrival, as they have both low impact on solving malnutrition and hunger, as well as lack financial viability in the food industry.

The framework also recommends that "financing is front-loaded in… low-income and lower middle-income countries to help catalyse greater domestic investment and scale … quickly".

This recommendation is applicable to startups and VCs looking for opportunities in the foodtech or agritech sector as well. A focus on affordable food solutions in low-income regions are attractive for public sector investment, contracts as well as grants.

For example, Nigerian agritech startup Releaf raised 4.2m in its seed round last year, of which 1.5m was in grants from The Challenge Fund for Youth Employment (CFYE) and the United States Agency for International Development[31]. Demand for such solutions in lower income nations is great, to the extent that Tolaram, a conglomerate with majority of its operations in Africa, invested in Singapore-based Shandi, an alt-protein startup, last year[32].

However, as Tolaram's own New Business Development Manager, Avinash Aswandi, said, operating in such regions requires "overcoming challenges with setting up robust supply chain, manufacturing and distribution models for scale, and navigating political and economic risks" and that "more work is needed to ensure the cost-effectiveness of existing spending on nutrition, address implementation bottlenecks and knowledge gaps"[33], indicating some common issues with operating in low-income countries. Many lack infrastructure for supply chains, such as ports and roads, causing bottlenecks in distribution. Many are embroiled in domestic or regional political instability, causing significant risk to both the possible operations and the customer base. Thus, the benefits and costs of the location of market entry must be carefully considered for foodtech and agritech startups.

31. Kene-Okafor, T. (2021, September 16). Nigerian agritech startup Releaf secures $4.2M to scale its food processing technology – TechCrunch. TechCrunch. Retrieved from techcrunch.com/2021/09/15/nigerian-agritech-startup-releaf-secures-4-2m-to-scale-its-food-processing-technology/
32. *Tolaram-led funding raises over US$700,000 for food-tech startup Shandi*. Businesstimes.com.sg. (n.d.). Retrieved July 11, 2022, from https://www.businesstimes.com.sg/companies-markets/tolaram-led-funding-raises-over-us700000-for-food-tech-startup-shandi
33. Neo, P. (2021, September 7). *From noodles to alt protein: Tolaram signals new asia approach after decades of African domination*. foodnavigator. Retrieved July 11, 2022, from https://www.foodnavigator-asia.com/Article/2021/09/07/From-noodles-to-alt-protein-Tolaram-signals-new-Asia-approach-after-decades-of-African-domination

3.2 FAST - JP Morgan

FAST or the Food and Agriculture Sustainability Transition[34] is a framework for a global strategy that advises corporations on the opportunities available in the ESG space, and specifically the food and agriculture sector. Section 2 however, directly addresses the role VCs can play.

1. The Private Sector Has a Critical Role In Establishing a FAST Standard

This section of the FAST framework underlines the growing importance of sustainability to the private sector. It focuses on the fact that stakeholders, like institutional shareholders, investor activists, and consumers are beginning to prioritise ESG factors in their decision making. As a result, companies are committing to net-zero promises, ESG reporting is becoming standardised, and those that can demonstrate sustainable growth are receiving a premium in their valuation. The latter is due to such companies being "viewed as inherently having attractive long-term fundamentals supporting the business, comparable to how the market used to view value investing" (Pg 11).

It also suggests "Venture Investments in Emerging Technologies", saying that transition-focused businesses provide diversification and a "robust pipeline of M&A opportunities and learning synergies". They can also help the corporation achieve its own ESG goals, such as reducing emissions or repurposing by-products.

34. *Establishing a framework for Food and agriculture sustainability ...* (n.d.). Retrieved July 11, 2022, from https://www.jpmorgan.com/content/dam/jpm/cib/complex/content/investment-banking/center-for-carbon-transition/Establishing_a_Framework_for_Food_and_Agriculture_Sustainability_Transition.pdf

2. Driving a Realignment of Capital Flows and Stakeholder Priorities

Here JP Morgan outlines the current lack of private investment into food and agriculture. In 2021, almost 50% of all VC investment into "Climate tech" categories went to electric vehicle (EVs) startups. For the food sector specifically, 2020 was the first year that upstream technologies raised more VC money than downstream technologies. Upstream technologies are more critical in addressing food demand and sustainability issues, but remain underfunded, with their estimate of the food and agriculture space being 5-7 years behind the EV market in both total transaction value and average deal size.

They highlight the importance of sovereign wealth funds as well as public policy to support food and agriculture startups, and their assistance and investment tends to be "consistent with underlying food security concerns in their home markets".

Finally, it emphasises the importance of realising "all climate solutions are interconnected as a system and, combined together, have the greatest impact" (Pg 16). More substantially, combining sustainable energy production with sustainable food production will greatly reduce the quantum of emissions.

3. Promising Strategies and Solutions

JP Morgan highlights the solutions that it finds promising. These strategies can be classified into 4 categories:

1. Alternative proteins
    i. Plant-based
    ii. Cultivated
    iii. Precision fermentation
    iv. Biomass fermentation
2. Enhanced Farming Practices
    i. Controlled environment
    ii. Agricultural biotech
    iii. Precision agriculture technologies (PAT)
    iv. Boosting pasture productivity (fertilisation of pasture, rotational grazing, feed quality and veterinary care)
    v. Reduce Enteric fermentation (reduce gaseous emissions from ruminant livestock)
    vi. Improve crop breeding
    vii. Improve rice cultivation
3. Decreasing Food Waste
    i. Packing innovation and coatings
    ii. Upcycled food
4. Accelerated Development of Carbon Markets
    i. Carbon offsets
    ii. Can encourage carbon sequestration through regenerative agriculture practices

4. Making Food and Agriculture Environmental Sustainability a Foreign and Domestic Policy Priority

This section pertains entirely to their recommendations to the US government, and are thus not suited to either a private sector or a global approach.

3.2.1 FAST by JP Morgan - Evaluation

This report reaffirms that the importance of sustainability is beginning to achieve mainstream status amongst various stakeholders in industry and finance. As we align to new standards of measuring sustainability and emissions, there will also be a clearer premium paid for companies and services that excel in those standards. Additionally, by recommending that corporations engage the services of or acquire 'transition-based' companies, there is an implied opportunity for startups to exit via strategic acquisitions that bestow upon the new parent company a competitive advantage, particularly as carbon credits become more common.

Its mention of vested interest by sovereign wealth funds and governments means that VCs and startups can possibly base market entry decisions on the public policy environment. Notably, "Europe is already ahead of the global curve on transitioning businesses to sustainable practices and Asia has a significant incentive to reduce reliance on the rest of the world for food supply". Countries that face food security issues are inherently more likely to support companies that solve those issues for them, providing not just a welcoming customer base, but also possibilities for government cooperation in the form of grants, investment and even favourable tax policy.

3.3 World Resources Institute

This framework aims to feed 10 billion people by 2050 sustainably. This means closing three gaps:

“

1. A 56 percent food gap between crop calories produced in 2010 and those needed in 2050 under “business as usual” growth;
2. A 593 million-hectare land gap (an area nearly twice the size of India) between global agricultural land area in 2010 and expected agricultural expansion by 2050; and
3. An 11-gigaton GHG mitigation gap between expected agricultural emissions in 2050 and the target level needed to hold global warming below 2oC (3.6°F), the level necessary for preventing the worst climate impacts.

“

World Resources Institute[35]

It utilises 3 pathways, in which there are 22 solutions

1. Reduce Growth In Demand for Food and Other Agricultural Products (Demand-side solutions)
    - 1.1. Reduce food loss and waste
    - 1.2. Shift to healthier, more sustainable diets
    - 1.3. Avoid competition from bioenergy for food crops and land
    - 1.4. Achieve replacement-level fertility rates

2. Increase Food Production Without Expanding Agricultural Land (Supply-side solutions)
    - 2.1. Increase livestock and pasture productivity
    - 2.2. Improve crop breeding
    - 2.3. Improve soil and water management
    - 2.4. Plant existing cropland more frequently
    - 2.5. Adapt to climate change (breeding crops to cope, establishing water conservation systems, changing production systems)

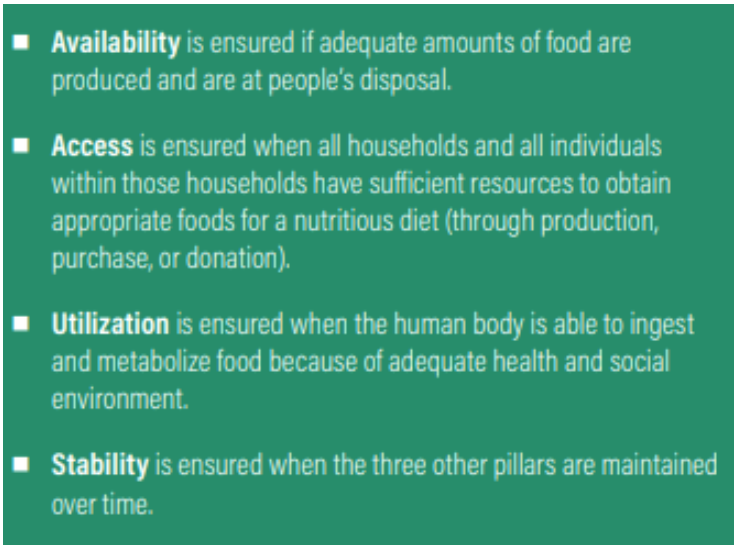
35. Waite , R., Hanson, C., Ranganathan, J., & Dumas, P. (n.d.). *Creating a Sustainable Food Future*. Retrieved July 11, 2022, from https://files.wri.org/d8/s3fs-public/wrr-food-full-report.pdf

3. Protect and Restore Natural Ecosystems and Limit Agricultural Land-Shifting
   - 3.1. Link productivity gains with protection of natural ecosystems (as a measure of /KPI for financial incentives like low interest rate credit)
   - 3.2. Limit inevitable cropland expansion to lands with low environmental opportunity costs
   - 3.3. Reforest agricultural lands with little intensification potential
   - 3.4. Conserve and restore peatlands

4. Increase Fish Supply
   - 4.1. Improve wild fisheries management
   - 4.2. Improve productivity and environmental performance of aquaculture

5. Reduce Greenhouse Gas Emissions from Agricultural Production
   - 5.1. Reduce enteric fermentation through new technologies
   - 5.2. Reduce emissions through improved manure management
   - 5.3. Reduce emissions from manure left on pasture
   - 5.4. Reduce emissions from fertilisers by increasing nitrogen use efficiency
   - 5.5. Adopt emissions-reducing rice management and varieties
   - 5.6. Increase agricultural energy efficiency and shift to non-fossil energy sources
   - 5.7. Implement realistic options to sequester carbon in soils

The report also references the FAO or Food and Agriculture Organisation of the United Nations, stating the 4 main pillars of food security:



4 Pillars of Food Security
Source: World Resources Report[35]

And that in addition to these four, experts have long argued for a fifth: sustainability, "which is ensured only if food production and consumption patterns do not deplete natural resources or the ability of the agricultural system to provide sufficient food for future generations"

3.3.1 World Resources Institute - Evaluation

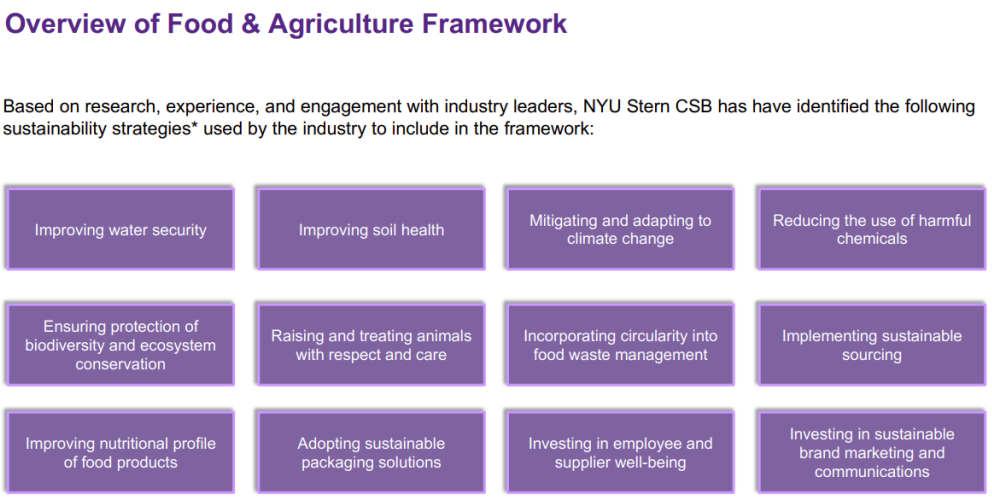
This report extensively covers solutions from multiple aspects, and is focussed on utilising existing proven solutions due to its practical and comprehensive call to action. It outlines the bare minimum that must be done for humanity to survive past 2050.

But from a venture capital perspective, one must believe in the possibility of technological advancement, and the ability of entrepreneurs to do more. For example, the report does not mention alternative proteins, though that would resolve issues 2.1 (Livestock productivity) and 5.1 (enteric fermentation), remove the need for animal feed in 5.6 (agricultural energy efficiency), and can be achieved in tandem with 1.2 (Shift to healthier, more sustainable diets).

This framework can thus be used to evaluate companies by categorising the impacts of their proposed solutions, thereby giving us a metric of the possible breadth of their impact. The five pillars approach can become a tool for VCs or other investors to target specific pillars.

3.4. Food and Agriculture ROSI Framework - NYU Stern

Food and Agriculture ROSI (Return on Sustainable Investment) is NYU's framework to identify "sustainability strategies and their related agricultural practices" and "develops monetization frameworks to demonstrate the financial benefits of those sustainability investments in the industry". It focuses on possible practices that incumbent players can incorporate in order to become more sustainable, and outlines the sustainability strategies below.

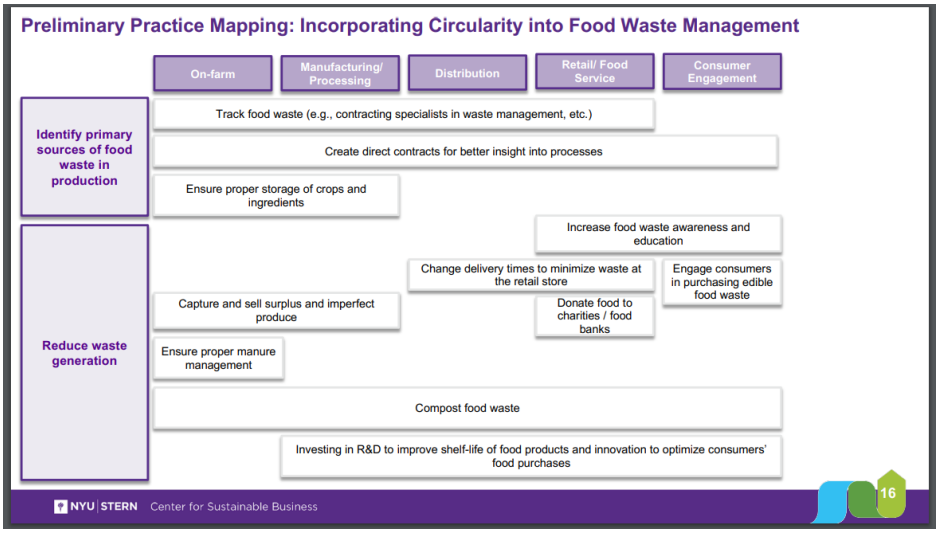


Food and Agriculture ROSI Framework - NYU Stern[36]

Its principle framework is Mapping, or the categorising of strategies on two axes:

1. Stage of supply chain it can be implemented in
2. Aspect of strategy it targets

e.g. Food Waste Management and Circularity



36. *Food and Agriculture Sustainability Strategies Framework*. NYU Stern. (n.d.). Retrieved July 11, 2022, from https://www.stern.nyu.edu/experience-stern/about/departments-centers-initiatives/centers-of-research/center-sustainable-business/research/return-sustainability-investment-rosi/food-and-agriculture-sustainability-strategies

3.4.1 NYU ROSI Framework - Evaluation

Such a categorisation method is useful in identifying both corporations' possible usage of a solution provided by a startup and how comprehensively a startup targets a specific problem.

By exploring where a startup's solution could be utilised in an existing supply chain, we gain a better understanding of its product-market fit, possible serviceable addressable market, customer acquisition routes, LTV, and potential exit strategies.

While the scope of a startup is not an indicator of its success, that information combined with knowledge of the entire supply chain could indicate potential expansion opportunities and augment competition analysis, since if other existing companies provide solutions that are in a different space, they can be complementary rather than substitutional.

4. Categorisation of Foodtech/Agritech

The foodtech and agritech sectors are not a homogeneous space. Companies exist across different verticals and at different stages of the food supply chain. For the purposes of VC investments, the categorisation used by the World Resources Institute is not appropriate as its goal is not profitability, and a majority of scalable monetizable solutions are supply-side where a solution can be sold, as opposed to the demand-side solutions such as reduction of consumption. Instead, the JP Morgan FAST framework's categorisation of Food Production, Decreasing Food Waste, and Accelerated Development of Carbon Markets (or carbon offsets) is more applicable to a private investment context.

The categorisation used must also inform the analysis of a company's product or service. NYU's ROSI framework is then also unsuitable, as foodtech and agritech companies frequently provide goods and services that cover multiple strategies to solve food sustainability issues. But its use of categorising by stage of food production is informative, as Foodtech companies tend to vary by stage of food production they target, with some focusing on just production or retail and others providing end-to-end services. As mentioned in the evaluation of the ROSI framework, this would provide information on possible competition and expansion of product offerings in adjacent spaces.

Startups should be categorised by
- Stage of supply chain
- Vertical

4.1 Stages of Food Supply Chain

Utilising the ROSI framework from NYU Stern, we begin with 5 stages: On-farm, manufacturing/processing, distribution and retail/food service

However, given the rise in scientific advancement in improving the inputs to agriculture, such as GMO crops, bioengineered pesticides, and feed that reduces enteric fermentation, we feel the need to add a pre-farm or "pre-production" stage[37]. This category would also include any firms providing inputs to farms or manufacturing plants, to distinguish it from firms that use their technological or business model advantages to operate their own farms.

1. Pre-Production
2. On-farm
3. Manufacturing/Processing
4. Distribution
5. Retail/Food Service

37. Section 3 - Supply Chain. (2020, February 20). Farming First. https://farmingfirst.org/sustainable-food-system/section-3-supply-chain/#home

4.2 Foodtech/ Agritech Vertical

Adopting the categorisation used in the FAST framework by JP Morgan, we decide to combine the alternative proteins and enhanced farming practices verticals into one: Food Production. This is because many analyses apply to technologies under both the alternative protein/farming practices groups due to the fact that they intend to create a more sustainable, scalable way to feed humanity, and both are clearly different from methods which focus on the reduction of food waste. The accelerated development of carbon markets which the FAST framework mentions is a key global strategy to create a more sustainable world, but they are not of interest in this report.

	Industry Verticals		
Solutions	**Assisting Small Farmers**	Increasing Food Production	Decreasing Food Waste
	○ **Marketplaces** ○ **Finance** ○ **Insurance**	○ Alternative proteins i.Plant-based **ii.Insect-based** iii.Cultivated iv.Precision fermentation v.Biomass fermentation ○ Enhanced Farming Practices i.Controlled environment ii.Agricultural biotech iii.Precision agriculture technologies (PAT) iv.Boosting pasture productivity (fertilisation of pasture, rotational grazing, feed quality and veterinary care) v.Reduce Enteric fermentation (reduce gaseous emissions from ruminant livestock) ~~vi.Improve crop breeding~~ ~~vii.Improve rice cultivation~~	○ Packing innovation and coatings ○ **Food Logistics** ○ Upcycled and Recycled Food ○ **Marketplaces**

The items in bold are Quest added categories.

First, the field of agricultural finance and marketplaces has been rife with activity in the past few years, with Indonesia's Tanihub, a B2C produce marketplace securing their $65.5 million Series B, and Kenyan Agri-finance startup, Apollo Agriculture raising $40 million for their series B. These companies enable small independent farmers to lower customer acquisition costs and obtain cheaper financing or insurance respectively. These will be added under a new category titled "Helping small farmers".

As for alternative proteins, insect-based protein has been overlooked in favour of plant-based or cultivated protein, but present a possible alternative as they require simpler processes to obtain and can offer a more protein (most legumes and cereals are sources of incomplete proteins).

In the Enhanced Farming practices category, we have also removed improved crop breeding and rice cultivation as these are not monetizable endeavours or at least ones easily adopted as a business model by startups.

Under the category of reduction of food waste, we have also added the goal of increasing awareness of food waste as a vertical, where companies such as Goodr, a B2B that helps businesses get tax deductions for donation of surplus food[38]. Additionally, food logistics has many areas of improvement with regards to wastage, which many startups are attempting to solve.

38. G. (2021, December 7). Surplus Food Recovery. Goodr - Feed More, Waste Less. https://goodr.co/food-waste-solutions/surplus-food-recovery/

5. Food Supply Chain Considerations

5.1 Farm

Firms in the food pre-production stage are B2B, selling products and services that augment the farming process to farms or manufacturers. These can be farm inputs such as feed and fertiliser, as well as bioengineered seeds or livestock. They can also be selling hardware such as IoT harvesting or livestock health monitoring, or providing physical spaces for farming live hydroponic or vertical farming lots, or marketplaces for farming inputs.

Some firms in this stage can also be farmers themselves utilising the technologically advanced methods or innovative business models they develop.

With full-scale in-lab protein production still a ways to go and plant crops still being necessary, farms are here to stay. Firms that offer innovative farming solutions are B2B, while firms that do the farming themselves can also be DTC if they choose to provide an end-to-end service, though many farmers choose to work with wholesalers

In this stage, it is important to consider the applicability and replicability of solutions to a wide variety of crops. Research into the unit economics of their customers (i.e.food producers) is also crucial to consider what businesses can afford their solutions. Both these factors provide a better understanding of the firms' TAM, SAM and SOM.

Confirming a realistic SOM is important, as farmers or food manufacturers have different priorities in their business and different levels of profitability and scales of production. For example, until sustainability goals are fully aligned with profit incentives via carbon taxes and credits, most farmers would be unlikely to spend more to reduce enteric fermentation, meaning the true addressable market is perhaps limited to farmers who market their meat as environmentally friendly, or live in jurisdictions where carbon taxes are enforced, such that their unit economics is improved by the introduction of the presumably more expensive feed. Similarly, farming equipment startups can represent high CAPEX which might only be accessible to large farms[39], which limits their potential customers as five of every six farms in the world are smaller than two hectares and they collectively produce a third of the world's food[40].

11. Kata R, Wosiek M. Inequality of Income in Agricultural Holdings in Poland in the Context of Sustainable Agricultural Development. Sustainability. 2020; 12(12):4963. https://doi.org/10.3390/su12124963
12. Ritchie, H. (2021, July 8). Farm Size. Our World in Data. https://ourworldindata.org/farm-size

Interviewing prospective as well as existing customers is one way of confirming these assertions, though it is likely that many early stage startups are pre-revenue and lack LOIs from potential customers.

When considering firms that sell equipment to farms, low LTV is still a concern due to these products mostly being capital for production rather than a direct input and could have low purchase frequency. Many technology hardware companies get around this by implementing Hardware as a Service models adapted from software companies' SaaS models, by providing long-term payment plans in exchange for frequent maintenance and software upgrades.

However, this may prove untenable. Deere & Company, the world's largest agriculture machinery manufacturer and the creator of the first commercially successful mechanised steel plough in 1837, has been embroiled in lawsuits regarding farmers' right to repair[41] . Companies that seek to increase customer LTV via high margins basic ancillary services like maintenance and repairs might see pushback from farmers who are accustomed to fixing their own machinery[42], though more software-based technology might be more immune to this.

In the case that the firm operates the farm, a large concern is the low value density of products produced and low LTV of individual customers. DTC models might circumvent this by giving the firm the ability to sell produce in season, in varieties of their choosing, at a scale they prefer, and with greater control over pricing and production practices[43] , thus improving unit economics by allowing farmers to capture a larger proportion of the final consumer dollars, thereby increasing revenues. However, the firm then takes on the associated risks and costs of marketing and sales.

In guiding the growth of the firm, funds have to monitor competing firms and their metrics, such as retention rate of customers in comparison to that of their competitors as the firm matures. While B2B customers tend to have a higher long-term retention rate (especially if product is a key input such as fertiliser or feed), foodtech and agritech are fast moving fields where competitors can gain a technical advantage quickly. As such, the firm must be focussed on both customer acquisition and R&D. If the firm is still pre-revenue and R&D focussed, it should begin talks with potential customers, seeking LOIs or even trials to secure a pipeline of business.

11. Bloomberg - Are you a robot? (2022, January 21). Bloomberg. Retrieved July 25, 2022, from https://www.bloomberg.com/tosv2.html?vid=&uuid=c1052050-0c11-11ed-ae3b-4c6a4c6f5672&url=L25ld3MvYXJ0aWNsZXMvMjAyMi0wMS0yMC9qb2huLWRlZXJlLWlzLWZhY2luZy1hLWZhcm1lci1yZXZvbHQtb3Zlci10aGUtcmlnaHQtdG8tcmVwYWly#xj4y7vzkg
12. Moran, G. (2022, April 28). In the Battle Over the Right to Repair, Open-Source Tractors Offer an Alternative. Civil Eats. Retrieved July 25, 2022, from https://civileats.com/2022/04/27/right-to-repair-open-source-tractors-john-deere-oggun-farms-profitability-technology/
13. Sitaker, M., McGuirt, J., Wang, W., Kolodinsky, J., & Seguin, R. (2019). Spatial Considerations for Implementing Two Direct-to-Consumer Food Models in Two States. Sustainability, 11(7), 2081. MDPI AG. Retrieved from http://dx.doi.org/10.3390/su11072081

5.2 Manufacturing/Processing

In this stage, companies either utilise raw ingredients to create finished products, whether they be plant or meat produce from farms or biochemical serums and cells from labs. Foodtech companies that are in this stage are namely alternative protein manufacturers, using plants, fungi, cells or bacteria and yeast for their products. There are also firms trying to reduce the waste at this stage, from reducing the amount of non-biodegradable packaging to utilising or repurposing food waste. Companies can be both B2B and B2C, as they decide between being able to capture a larger revenue share with a D2C model, or the cost-savings and stability associated with selling ingredients to other manufacturers, or both.

Funds should take a close look at the cost basis (COGS) of products by firms in this stage of the food production supply chain. While plant-based alternative proteins utilise relatively low-cost raw ingredients, the production processes required to make plant matter taste and look like meat are by no means cheap. Beyond Meat, the world's largest meat-like plant based burger reportedly managed to reduce their cost basis of a pound of alternative meat from USD4.50 in 2019 to USD3.50 in 2020[44] using both intense cost-cutting measures and economies of scale, giving them a price of USD7.79 in 2022. Meanwhile, the price of a pound of beef in the average US grocery store is USD4.916[45]. The costs associated with other meat alternative production methods will be discussed in greater detail in section 6.2.1.2.

Firms that utilise waste from other food manufacturers should logically have a low cost of raw materials, and while some could have complex processes to turn inedible food waste (such as seeds or husks) into edible products such as Regrained which turns beer byproducts into pasta, snacks and baking mixes, others have simpler methods, such as Wtrmln Wtr turning aesthetically undesirable watermelons from farms into juice. While simpler production methods are less costly, they also do not provide the defensible revenue and barriers to entry that a patented, technically advanced process would. A more complex process is also typically necessary for the conversion of inedible (not just unattractive, and thus cheaper) "waste" into edible food.

Additionally, while such waste products might be widely available and cheap at the moment, the upcycled food space is becoming increasingly crowded. Increased demand for such waste products might steadily erode the cost advantage, crowding out smaller startups in the long run. Firms must have access to a sustainable and secure supply of their inputs.

11. Piper, K. (2021, February 2). Impossible Foods cuts prices for its plant-based meat offerings. Vox. Retrieved July 25, 2022, from https://www.vox.com/future-perfect/2021/2/2/22260454/impossible-foods-burger-plant-based-meat
12. Average Retail Food and Energy Prices, U.S. and Midwest Region : MidÃ¢Â Â“Atlantic Information Office : U.S. Bureau of Labor Statistics. (2022, June 10). U.S. Bureau of Labor Statistics. https://www.bls.gov/regions/mid-atlantic/data/averageretailfoodandenergyprices_usandmidwest_table.htm

In direct food manufacturing and processing, the crucial metric to observe is scale and unit economics. Most companies using novel technologies have incurred significant costs in R&D that have to be recouped. But using high prices to do so, as is done in the pharmaceutical industry, is untenable in a price sensitive market like food. Regardless of the supposed health or environmental benefits, consumers will not be willing to pay significant premiums on a commonly consumed product, barring a marketing shift, such as what Starbucks did to coffee.

If the majority of cost is fixed, their proof of concept must incorporate future expected maintenance or capital replacement costs, unless cost of capital machinery is low. If the majority of cost is variable, they must have plans to reduce cost of inputs, whether via R&D or bulk purchasing and renegotiating purchasing contracts.

There are also companies who intend to focus solely on the research of food manufacturing technologies, and then to licence their technology to existing food manufacturing companies. This strategy takes advantage of larger firm's existing scale and possibly overlapping machinery. Nevertheless, they must have an idea of the costs involved in order to pitch their production methods or products to possible licensees.

A company must have an understanding of how many returning customers they must retain to support a scale of production that would be profitable in the long run. Are their customers wholesalers, distributors or direct consumers? Wholesalers and distributors have minimum order requirements, and upcharge their bulk purchases to retailers. Selling products to them allows you to gain access to multiple retail revenue streams, from supermarkets to restaurants. Direct to consumer models require significantly more marketing and knowledge of the industry, but allow for higher selling prices. Considering that the latter will be covered in the retail segment, we will discuss the former here.

Wholesalers and distributors generally use two pricing strategies[46]. The first is absorption pricing, where all costs, including their own profit margins are included into the final price. This means that manufacturers should discuss the final prices that end consumers will see, and not just the price at which the product is sold to the middle man. The second is differentiated pricing, which is calculated in response to demand. This is preferable as the wholesaler will do their own research, and possibly provide feedback on demand and willingness to pay to the manufacturer, allowing the company to get a better understanding of what scale and thus cost level they must achieve.

46. Bland, A. (2021, December 14). The Wholesale Food Distribution Industry: A Guide for 2022. Unleashed Software.
https://www.unleashedsoftware.com/blog/the-wholesale-food-distribution-industry-a-guide-for-2022

5.3 Distribution

In the distribution stage, startups are generally not attempting to get into the distribution or wholesale businesses themselves. However, they need to have an understanding of the business in order to offer themselves as service providers to these companies. They have to comprehend what factors drive the distributor's bottom line and top line. For VCs, it is crucial that such startups are at least in talks to sign PoC agreements with distributors or wholesalers to prove their product-market fit.

For example, in countries where supply chains are unsophisticated and for example, have warehouses that lack cold chain facilities, it would seem hasty to incorporate IoT trackers and sensors to ensure produce is being kept at a suitable temperature. Meanwhile, startups creating warehouse robots could target food distributors in areas seeing rising labour costs threaten their bottom line.

Most startups involved in this stage of the food supply chain are logistics innovators: involved in packing, processing, storage, tracking or delivery of food from producers to retailers or consumers. Many are attempting to reduce waste and spoilage in the supply chain, thus improving food safety, efficiency and profitability of distribution. Therefore, the issues plaguing distributors and wholesalers will be discussed in further detail in section 6.3.1 and especially 6.3.2.

5.4 Retail/Food Service

In this stage we have startups that are involved only with retail, such as innovative marketplace solutions, as well as those that are DTC farmers, manufacturers or distributors. The former is discussed in further detail in sections 6.1.1 for small farmers in rural areas, and 6.3.4 for marketplaces that attempt to sell food "rescued" from waste.

Retail is a business heavily dependent on public image and marketing, especially in a price sensitive market. With the rise of different technologies in foodtech, food is becoming less of a commodity and more of a brand. If a customer is interested in a specific product, such as alternative proteins, the question is not just of location of production, as it is with traditional food items, or that of technology, whether it be plant or cell based, but that of which brand. Impossible Foods or Beyond Meat?

To a certain extent, the choice is based on the variety of offerings. After all, product proliferation has been a successful market strategy for consumer goods, and especially food, for a long time. Think of Coca Cola and beverages, or Kellogg's and cereal. If someone is seeking a specific product, say alternative pork, then they would have to go to Impossible Foods rather than Beyond Meat. And if the product is satisfactory, then when the consumer is about to purchase a more widely available product offered by multiple companies, they would be more likely to go to Impossible again. Formally, this means that a firm with larger variety saturates the product space and minimises unmet demand[47]. Additionally, having a wide variety of offerings makes it difficult for new startups to compete[48].

However, the key thing to note here is that the "brandification" of the consumer packaged foods vertical is a double-edged sword. If a farmer produced a bad batch of produce, no consumer would be able to identify and avoid their produce again because supermarkets or restaurants do not display their sources. But a brand with the same issue can find it difficult to shed their bad reputation. Nevertheless, to manufacturers, a brand offers an opportunity to capture loyalty and a price premium, and to customers, it represents a level of quality that saves them a great deal of search time[49]. A strong brand can become the key to obtaining customer retention that will support the scaling of a company.

47. Piazzai, M., & Wijnberg, N. M. (2019). Product proliferation, complexity, and deterrence to imitation in differentiated-product oligopolies. Strategic Management Journal, 40(6), 945–958. https://doi.org/10.1002/smj.3002
48. Piazzai, M., & Wijnberg, N. M. (2019). Product proliferation, complexity, and deterrence to imitation in differentiated-product oligopolies. Strategic Management Journal, 40(6), 945–958. https://doi.org/10.1002/smj.3002

49. Parameswaran, A. P. (2016, June 5). Give us this day our daily bread. Business Standard. https://www.business-standard.com/article/management/give-us-this-day-our-daily-bread-116060500684_1.html

Another benefit of being directly consumer facing is the possible collection of data. This is particularly viable as many direct to consumer food manufacturers and distributors have online platforms. Providing the option to create an account with them allows companies to profile customers and personalise their experiences. Data collected can then be used to forecast future demand, resulting in more accurate ordering of inventory, reduction of waste and spoilage, and a more appropriate scale of production that can be varied according to the forecasts.

When working with consumers directly, companies have to be certain that their products will be a hit. Even with the commercial success of Impossible Foods and Beyond Meat, there are already staunch critics who took their opinions online, casting further doubt and distaste towards alternative proteins. Their collaborations with food giants such as Burger King and KFC mean little if consumers do not have favourable views of them. The difficulty of selling direct to consumer means that there are no PoC or prototype agreements. Startups must work with those in industry, such as chefs and commercial food providers, to ensure that their products are satisfactory before launch.

6. Solutions by Industry Vertical

As elaborated in Section 2, there are two main food issues the world has to contend with. The first is hunger now, and the second is hunger in the future. Hunger today can only be reduced if we assist small farmers, many of whom are exactly those that suffer from lack of food security due to their small scale of farming providing only subsistence-levels of food production. Preventing humanity from going hungry in the future can only be done if we stop producing food now at the expense of our environment, and the future generations.

6.1 Assisting Small Farmers

Conventionally, larger corporations are viewed as more productive and efficient, able to reap the benefits of economies of scale to reduce or eliminate redundancies. However, the opposite seems to be true in farming. "Smallholdings" or farms mostly of size smaller than 2 hectares, represent 84% of all farms worldwide and only operate about 12% of all agricultural land. Yet, these small farms are accountable for 35% of the world's food supply[50] , and still have considerable catch-up growth to capture in terms of farming knowledge and technology usage.

While it is untenable for private sector investment to directly tackle poverty, it is possible for companies to find mutually beneficial, sustainable opportunities in developing areas by providing ways to break out of the poverty cycle to underserved communities. Many farmers are stuck in poverty due to living hand to mouth relying on subsistence farming. Without any surplus production, their lives and livelihoods are entirely vulnerable to climate variability and the appearance of pests, and they are unable to utilise profit gained from sale of surplus goods to improve their production processes or to tide over bad harvests. The FAO states that in 2015, over 2 billion people live on subsistence farming[51] on farms known as "smallholdings", farms mostly of size smaller than 2 hectares.

What companies have to understand is that these millions to billions of smallholder farms are essentially small businesses, and as the FAO states "smallholders operate their farms as entrepreneurs operate their firms, or at least they try"[52]. They raise capital and try to invest in equipment like a bicycle or a spade, decide what to plant and what inputs to use and how. However, these small businesses face a multitude of issues.

50. Marie, A. (2022, May 17). Addressing the Digital Divide for Smallholder Farmers. ALI Social Impact Review. https://www.sir.advancedleadership.harvard.edu/articles/addressing-digital-divide-for-smallholder-farmers
51. Food and Agriculture Organization of the United Nations. (2015). The economic lives of smallholder farmers.
52. Food and Agriculture Organization of the United Nations. (2015). The economic lives of smallholder farmers.

First, they mostly operate in economic environments with dysfunctional informal markets. Second, there are considerable physical limitations with the average smallholder family taking more than 11 mins to reach a paved road, and those in countries like Nicaragua having an average distance of 48km away from a paved road. Third, their lack of starting capital means their farms are not as productive as they can be; the typical European farm uses 130kg of fertiliser per hectare, while the average Ethiopian farmer uses just 20kg[53] . This can be very harmful to smallholders, especially in Sub-Saharan Africa where soil fertility is declining due to the cultivation of cereals without the addition of fertilisers, leading to a collapse of their basis for food production.

Startups have begun to realise the myriad of opportunities this presents. Many have begun microfinance operations, allowing farmers to have the capital to purchase transportation, fertiliser and other equipment, or to tide over bad seasons. Others have started marketplaces, increasing access for farmers to both purchase inputs and sell outputs, formalising markets and streamlining their decision-making processes.

53. Food and Agriculture Organization of the United Nations. (2015). The economic lives of smallholder farmers.

6.1.1 Marketplaces

According to BlueWeave Consulting, the total value of the global digital farming market is expected to reach $10.2 billion by 2025[54]. These platforms, known as agribusiness marketplaces or agriculture trading platforms. They typically provide not just a marketplace but also other software tools.

Marketplaces allow for several benefits.

On the supply side, farmers can more easily source inputs and equipment that make their land more productive. A formal online marketplace increases visibility, meaning suppliers of such inputs now have to compete on price, possibly reducing cost of inputs for the farmer. They gain access to a wider range of possible inputs, from fertilisers to pesticides, and with contractual agreements, can be more certain of future costs and be protected from temporary market fluctuations.

On the demand side, farmers can use online marketplaces to study demand and make better production decisions, connect with buyers, arrange deliveries and finalise transactions. A centralised marketplace can reap economies of scale to utilise more secure payment systems and engage lawyers to create legally binding contracts, thereby reducing legal and transactional risks, increasing certainty of revenue for farmers. Marketplaces can go even further, adding logistics and fulfilment services, creating one stop shops for farmers, reducing barriers to market entry and complication, as well as increasing supply chain transparency for end consumers.

Examples of such startups are Africa's Maano - Virtual Farmers Market that connects farmers to buyers while providing real-time commodity prices, France's Agriconomie that sells farming supplies from tractor parts to seed varieties, and India's Agrostar that has fulfilment centres and last-mile delivery networks, as well as recently raised USD70M in its Series D round[55].

However, such solutions face 2 critical barriers.

54. Global Digital Farming Market Size, Share and Forecast 2025 | BlueWeave. (2021, April). BlueWeave Consulting. https://www.blueweaveconsulting.com/report/global-digital-farming-market-bwc19388#ReportSample/
55. AgroStar - Crunchbase Company Profile & Funding. (n.d.). Crunchbase. https://www.crunchbase.com/organization/agrostar

Firstly, the countries where farmers suffer from a lack of a formal, well-functioning marketplace tend to also be countries with low levels of digital penetration and literacy, let alone digital literacy. In 2022, around 4 out of 10 people in Africa had internet access with only 3 countries having over 70% internet penetration[56], while Southeast Asian countries generally had over 70% internet penetration rate, except for Myanmar, Laos and Timor-Leste[57]. In regions where computers and internet connection are scarce, it is difficult to implement platform based solutions like marketplaces which rely on both buyers and sellers having access to the internet. The lack of digital penetration unfortunately suffers the same problems as poor physical infrastructure: local governments do not have the resources to improve the situation and individuals in the area lack the purchasing power for the private sector to justify investment.

Second, farming is a traditional industry with long hours and lots of work, meaning adding technology that they have to learn how to use is unsurprisingly viewed as a hassle or a risky endeavour. A study interviewing 100 farmers in Vietnam, Indonesia and Myanmar found that it consistently took at least 3 years for a farmer who is already using online chat groups to begin “active discovery”, to venture outside their existing social group to find new transaction partners, new technologies, production methods, etc[58]. We can thus foresee that the time to develop such digital competencies would require an even longer runway in regions that still lack internet access.

Nevertheless, as internet access widens and mobile phone usage increases, online marketplaces offer farmers a democratised platform for sales and sourcing of goods, increasing the stability of their businesses and helping to move the food from where it is produced to where people need it the most. In the meantime, agribusiness marketplaces can sink their roots into areas where farmers are already comfortable using such social technology in their daily lives, building the necessary logistical expertise to scale once the opportunity presents itself.

56. Statista. (2022, July 21). Internet penetration in Africa January 2022, by country. https://www.statista.com/statistics/1124283/internet-penetration-in-africa-by-country/
57. Ganbold, S. (2022, March 14). Internet usage in Southeast Asia - statistics & facts. Statista. https://www.statista.com/topics/9093/internet-usage-in-southeast-asia/
58. International Fund for Agricultural Development. (n.d.). Driving AgriTech Adoption: Insights from Southeast Asia’s Farmers. Grow Asia Partnership Ltd. http://exchange.growasia.org/system/files/Driving%20AgriTech%20Adoption%20-%20Insights%20from%20Southeast%20Asia%27s%20Farmers.pdf

6.1.2 Loans and Financing

As the International Fund for Agricultural Development (IFAD) states "What characterises the poorest is not only their very small income but also the irregularity of this income." Smallholders are the most vulnerable to sudden supply shocks (weather and pestilence), and would only see income during harvests or not at all (in cases of absolute subsistence farming). Microfinance for less wealthy individuals in developing countries have shown concrete evidence that having access to credit substantially increases their quality of life, smoothing over difficult times, helping them build assets to afford school fees, improve homes and afford medical care. The same can be done and has been done for agriculture.

While such microloans were initially unpopular due to the preconceived notion that the poor would not be creditworthy, most studies have shown they display higher rates of repayment than conventional borrowers, with repayment rates as high as 98% in some institutions[59]. This makes such business models win-win solutions, allowing lenders to invest in a reliable debt product that is highly diversified away from financial markets and borrowers to have access to funds that let them plan for the long term.

The microfinance sphere has been around for decades since Muhammed Yunus from Grameen Bank founded the industry, and it has matured considerably, expanding into savings deposits, remittances, money transfers and microloans outside working capital loans, such as housing finance and education loans[60]. While initially, many loans had to be supported by donations, a few MFIs (Micro-Finance Institutions) began charging low fees and interest rates that could be afforded by borrowers, allowing such loans to be self-sufficient. By the mid-1990s, MFIs were commercialised and profitable[61].

59. Microfinance: macro benefits. (n.d.). IFAD. https://www.ifad.org/es/web/latest/-/news/microfinance-macro-benefits#:%7E:text=Microfinance%20is%20one%20way%20of,the%20reach%20of%20poor%20people
60. LIEBERMAN, I. W., DILEO, P., WATKINS, T. A., & KANZE, A. (Eds.). (2020). *The Future of Microfinance*. Brookings Institution Press. http://www.jstor.org/stable/10.7864/j.ctvbnm3hx
61. LIEBERMAN, I. W., DILEO, P., WATKINS, T. A., & KANZE, A. (Eds.). (2020). *The Future of Microfinance*. Brookings Institution Press. http://www.jstor.org/stable/10.7864/j.ctvbnm3hx

Now, with the growth of fintech, technology enabled microfinance has become even more capable of being self-sufficient. On a simpler level, digital banking and the proliferation of mobile phones have allowed MFIs to access a much larger group of people, without requiring physical banks or agents on the ground, reduced application and processing times, and increased visibility for the borrowers[62]. On a more complex level, developments such as credit scoring algorithms are circumventing the lack of formal borrowing history that most unbanked adults have in order to provide them with credit[63].

Companies that utilise such AI-powered algorithms rely on alternative sources of data. Mumbai-based CASHe uses social behaviour and data points like smartphone metadata, social media footprint and career. Bengaluru's SmartCoin Financials uses AI to digitalise processes such as delinquency prediction, fraud detection, and KYC, as well as using smartphone data and digital footprint for customer onboarding and verification[64]. In Latin America, Quipu Market is a marketplace that allows entrepreneurs to publish product catalogues and record transactions, then using that data to assess credit worthiness.

However, similar to online marketplace solutions, such companies are heavily reliant on digital penetration to grow, meaning that no method of short of buying phones and internet plans for rural farmers will allow startups to inorganically acquire new customers in rural areas (which will likely exceed any VCs' allowable CAC - customer acquisition cost). Fintech startups can perhaps develop capabilities in traditional methods of financing where potential customers are more averse to utilising technology, or conduct trials with select farmers and then use their feedback to convince other farmers.

62. K. (2020, February 10). What Impact do Fintechs have on Microfinance? FintechLab. https://www.thefintechlab.com/blog/what-impact-do-fintechs-have-on-microfinance/
63. Krishna, S. (2022, June 24). How microfinance startups leverage AI to democratise credit access. Analytics India Magazine. https://analyticsindiamag.com/microfinance-startups-leverage-ai-to-democratise-credit-access/
64. Krishna, S. (2022, June 24). How microfinance startups leverage AI to democratise credit access. Analytics India Magazine. https://analyticsindiamag.com/microfinance-startups-leverage-ai-to-democratise-credit-access/

6.1.3 Insurance

According to the Asian Development Bank, "Agricultural incomes are subject to substantial covariate shocks", relating to how most risks faced by farms are also correlated with the weather, and are thus undiversifiable. This means that farmers are likely to "rationally underinvest in inputs and thus slow down the Agricultural Transformation"[65]. In order to encourage smallholders to invest more into the long-term productivity of their farms, risk ownership in this field must be restructured. However, if the risk moves to agricultural banks, " it will lead to an under-provision of credit due to the difficulty of hedging this large covariate shock for any but the largest and best diversified banks".

Consider an agricultural insurance policy for a certain region that pays out in the event of crop destruction. As a singular disastrous weather event would mean paying out every insured party in the region, this policy is not diversified and thus untenable, and undermines the basis of insurance, which is that idiosyncratic, non-covariate risks can be diversified over a large population.

As improvements in measuring global environmental conditions improved, index insurance emerged as an innovative way to provide insurance policies. It is a policy that pays out for loss of typically working capital on the basis of a predetermined index hitting certain levels (e.g. rainfall levels). The index measures deviations from the normal level of parameters such as rainfall, temperature, earthquake magnitude, wind speed, crop yield, or livestock mortality rates[66]. The cost of administering such policies are low, typically not requiring insurance claims assessors as the basis of the payout is entirely objective and based on data[67], making it worthwhile for insurance companies to cover such a large number of farms with low margins. The insurance company also would not suffer from moral hazard or adverse selection, as "the object against which insurance is written is beyond the control of the insured party"[68].

65. Asian Development Bank Institute, McIntosh, C. M., & Mansini, C. S. M. (2018, September). The Use of Financial Technology in the Agriculture Sector. Asian Development Bank Institute. https://www.adb.org/sites/default/files/publication/455116/adbi-wp872.pdf
66. Index Insurance - Frequently Asked Questions. (n.d.). International Finance Corporation. https://www.ifc.org/wps/wcm/connect/industry_ext_content/ifc_external_corporate_site/financial+institutions/priorities/access_essential+financial+services/giif+frequently-asked-questions#:%7E:text=What%20is%20index%20insurance%3F,from%20weather%20and%20catastrophic%20events
67. Reuters. (n.d.). Reuters. https://www.reuters.com/article/us-food-africa-india-idUSKBN0L21WH201501290
68. Asian Development Bank Institute, McIntosh, C. M., & Mansini, C. S. M. (2018, September). The Use of Financial Technology in the Agriculture Sector. Asian Development Bank Institute. https://www.adb.org/sites/default/files/publication/455116/adbi-wp872.pdf

The largest issue faced by insurtech companies in the microinsurance space is lack of demand. A report from the Society of Actuaries states " It is not uncommon to hear of microinsurance programs spending over a year building a back-end technological platform, only to realise in the first month of sales that there is no customer demand". In Vietnam, both the government and private insurers have offered agricultural insurance for the past 30 years, and yet very few of their 8.6 million farmers are insured[70]. Their National Agriculture Insurance Pilot Program (NAIPP) found that lack of farmer awareness and trust were the main reasons for the low take-up of insurance options, despite the substantial government subsidies.

Insurtech companies thus suffer the double whammy of being pushed away due to lack of familiarity with technology as well as general distrust towards insurance. One possible strategy to combat this is for insurtech companies to partner with existing MFIs that already have an existing customer base, thus leveraging the existing goodwill and customer relationships to acquire customers.

For example, one company in this space is Kenya's Pula, which has more than 5m farmers insured in over 16 countries and raised $6m in 2021. It works with states and multilateral organisations such as the World Food Programme, the Central Bank of Nigeria and the Zambian and Kenyan governments, as well as development agencies, financial providers, commodity buyers, aggregators and mobile network operators, showing that partnerships with existing, trusted service providers allows for wider customer outreach. US' Stable, which raised $46.5m in 2021, utilises AI to reference agricultural price indices across 70 countries to accurately price insurance premiums, and works with the Agricultural Commodity Exchange for Africa, as well as food businesses in the US[71]. Luxembourg based IBISA, which raised about $1.7m in their 2021 seed round, provides weather-index based insurance to smallholder farmers in the Philippines and India[72].

69. Society of Actuaries, Chow, Q. C., Ng, J. M. N., Biese, K. B., & McCord, M. J. M. (2019, May). Technology in Microinsurance - How New Developments Affect the Work of Actuaries. Society of Actuaries. https://www.soa.org/globalassets/assets/files/resources/research-report/2019/2019-technology-microinsurance.pdf
70. Bringing the benefits of agricultural insurance to smallholders in Viet Nam: Building awareness and understanding. (n.d.). Stockholm+50. https://www.stockholm50.global/news-and-stories/bringing-benefits-agricultural-insurance-smallholders-viet-nam-building-awareness
71. Terazono, E. (2021, November 23). Agricultural insurtech offers lifeline for smallholders. Financial Times. https://www.ft.com/content/3bc0a0c2-635e-48d4-8535-6a93fab7b0fc
72. IBISA Network – Enabling the Next Generation of Insurance for Agriculture. (n.d.). IBISA. https://ibisa.network/
73. Ceballos, F., Kramer, B., & Robles, M. (2019). The feasibility of picture-based insurance (PBI): Smartphone pictures for affordable crop insurance. Development Engineering, 4, 100042. https://doi.org/10.1016/j.deveng.2019.100042

Insurtech companies are continuing to develop innovative methods to price premiums at scale, making products that would otherwise be unprofitable viable for sale to smallholder farmers at affordable prices, whether it be index based insurance policies, picture-based insurance (PBI)[73] , or inserting RFID microchips into livestock[74]. Agricultural insurance is a field that offers tremendous opportunities due to having a large unserved market - less than 20% of smallholder farmers have insurance[75], and technological improvements allowing greater scale and lower premiums and screening costs.

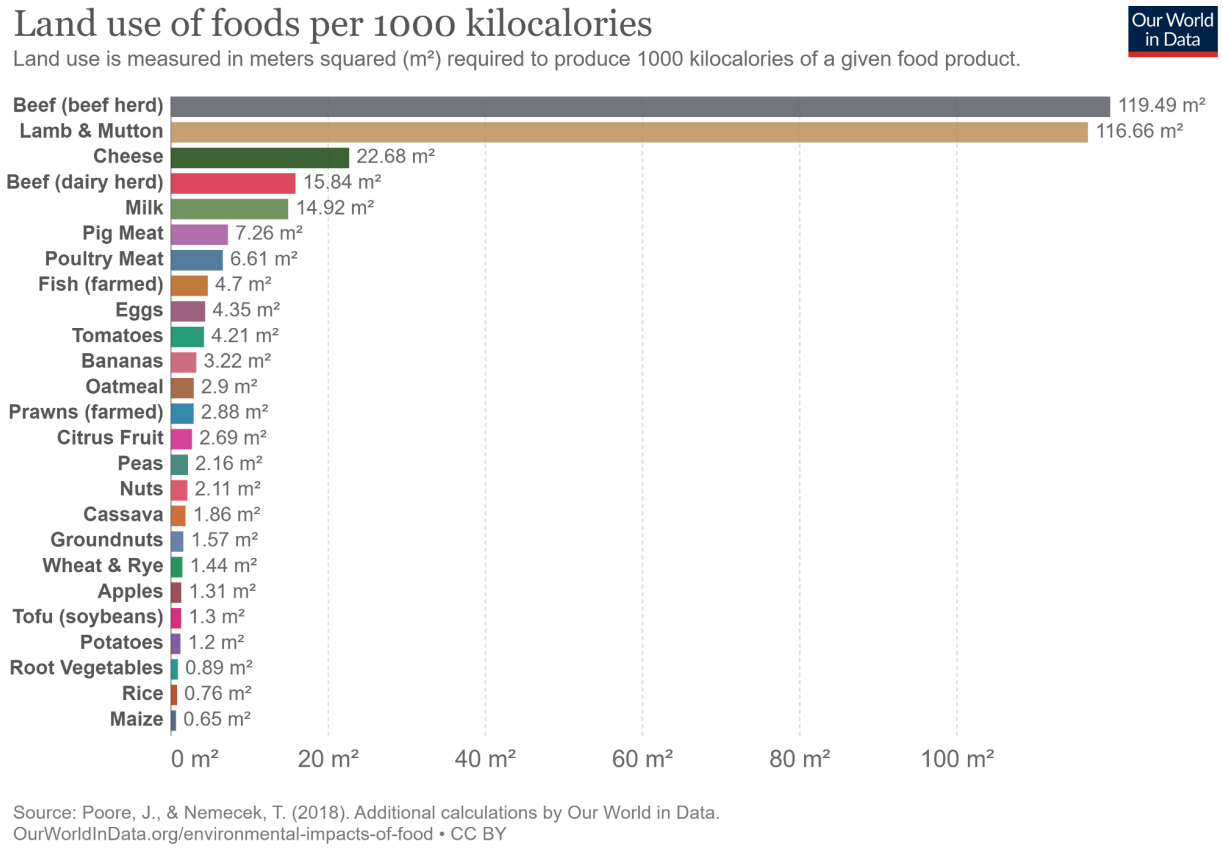
74. United States Agency for International Development, & Tranh, N. T. (2018, January). Guide to Using Digital Tools to Expand Access to Agricultural Insurance. United States Agency for International Development. https://www.usaid.gov/sites/default/files/documents/15396/Guide_to_Using_Digital_Tools_to_Expand_Agricultural_Insurance.pdf
75. GSMA. (2020, May). Agricultural insurance for smallholder farmers - Digital innovations for scale. https://www.gsma.com/mobilefordevelopment/wp-content/uploads/2020/05/Agricultural_Insurance_for_Smallholder_Farmers_Digital_Innovations_for_Scale.pdf

6.2 Sustainable Food Production

At its core, food production startups seek to solve one issue: inefficient production of calories. The FCR or Feed Conversion Ratio measures the ratio of the calories an animal eats to the calories it provides when eaten.

- Chickens – 2x-5x
- Pigs – 4x-9x
- Cows – 6x-25x[76]

This calculation also does not account for the large quantities of land usage that is required for livestock, let alone humane livestock conditions (free-range/cage-free).



Land Use of Foods per 1000 kilocalories
Source : Reducing food's environmental impacts through producers and consumers[77]

76. A Well-Fed World. (2022, July 20). Feed-to-Meat - Conversion Inefficiency Ratios. https://awellfedworld.org/feed-ratios/

77. Land use of foods per 1000 kilocalories. (2018). Our World in Data. https://ourworldindata.org/grapher/land-use-kcal-poore

2Nor does it account for water usage.

	Litre per kilogram	Litre per kilocalorie	Litre per gram of protein	Litre per gram of fat
Sugar crops	197	0.69	0.0	0.0
Vegetables	322	1.34	26	154
Starchy roots	387	0.47	31	226
Fruits	962	2.09	180	348
Cereals	1644	0.51	21	112
Oil crops	2364	0.81	16	11
Pulses	4055	1.19	19	180
Nuts	9063	3.63	139	47
Milk	1020	1.82	31	33
Eggs	3265	2.29	29	33
Chicken meat	4325	3.00	34	43
Butter	5553	0.72	0.0	6.4
Pig meat	5988	2.15	57	23
Sheep/goat meat	8763	4.25	63	54
Bovine meat	15415	10.19	112	153

Water Footprint for Select Food Products
Source: Water Footprint Network[78]

Many startups are involved in the creation or application of novel methods that increase the productivity of these inputs, whether they be feed, land or water, or circumvent the issue of livestock all together. These methods are without a doubt more efficient than traditional farming methods, but they still face many issues in implementation.

78. Water footprint of crop and animal products: a comparison. (n.d.). Water Footprint. https://waterfootprint.org/en/water-footprint/product-water-footprint/water-footprint-crop-and-animal-products/

6.2.1 Alternative Proteins

Several barriers stand in the way of alternative protein being the default option.

1. Nutrition
2. Cost
3. Taste

6.2.1.1 Barriers

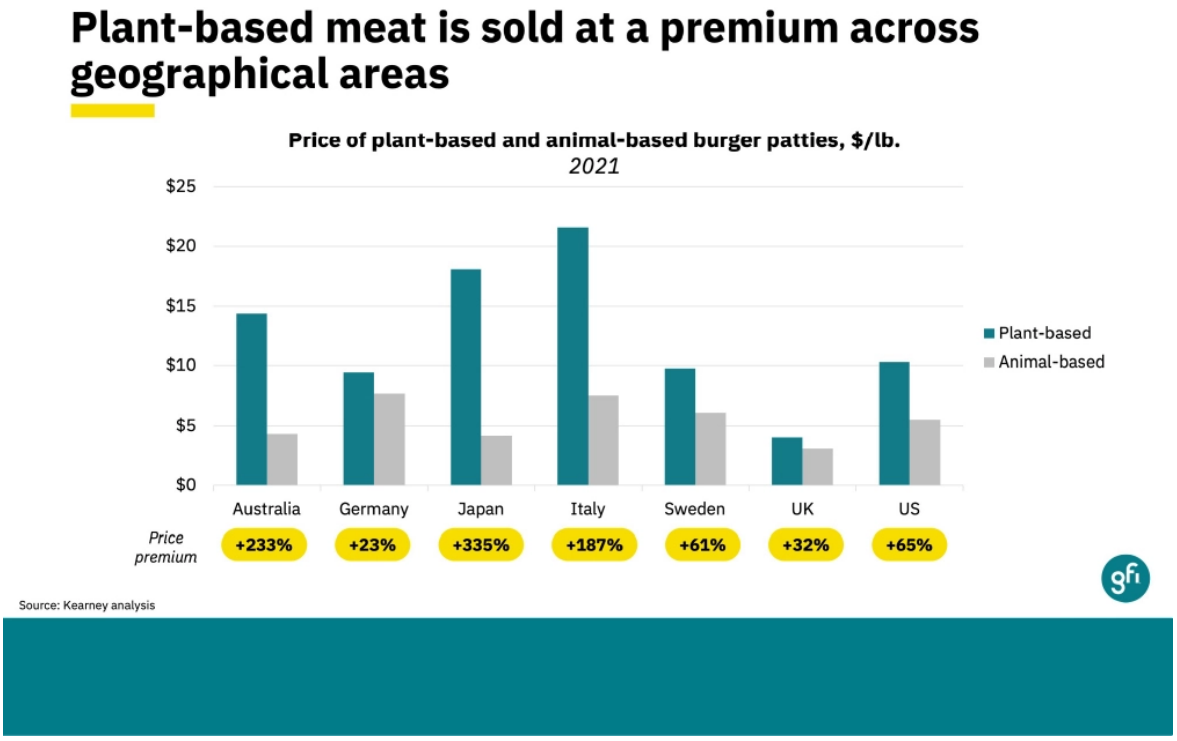
6.2.1.1.1 Nutrition

Protein alternatives are not a new concept, and was first implemented by the Chinese Han Dynasty (206 BC–220 AD) with soybeans, giving us tofu. Its use as a meat substitute was recorded in the 10th century, when the spread of Buddhism gave rise to vegetarianism in China. But as more people began to move away from meat for health reasons and into plant-based proteins, many products lacked the necessary amino acids to be considered "complete" proteins such as the seed proteins of common commodity crops like rice, wheat and corn (though soy is considered "almost" complete). Additionally, to make such products more palatable, many meat alternatives have unhealthy levels of salt[79] and higher levels of carbohydrates and sugars than meat[80]. Fortunately, as will be elaborated in the later section, most cutting-edge alternative protein solutions have managed to create realistic meat alternatives with complete proteins, at the cost of having to use additives to improve its taste.

79. Alessandrini, R., Brown, M. K., Pombo-Rodrigues, S., Bhageerutty, S., He, F. J., & MacGregor, G. A. (2021). Nutritional Quality of Plant-Based Meat Products Available in the UK: A Cross-Sectional Survey. Nutrients, 13(12), 4225. https://doi.org/10.3390/nu13124225
80. Curtain, F., & Grafenauer, S. (2019). Plant-Based Meat Substitutes in the Flexitarian Age: An Audit of Products on Supermarket Shelves. Nutrients, 11(11), 2603. https://doi.org/10.3390/nu11112603

6.2.1.1.2 Cost

Studies have shown that consumers tend to be price sensitive when purchasing meat[81] and with meat alternatives commanding a hefty price premium over meat in most areas, the barrier to customer acquisition is very much related to price.

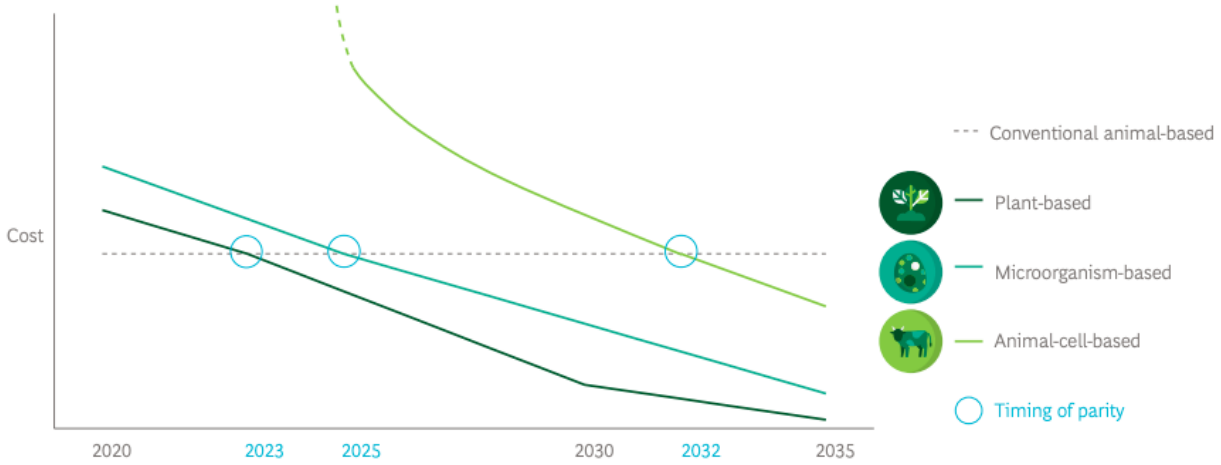


Plant-based Premium
Source: Good Food Institute[82]

81. Andreyeva, T., Long, M. W., & Brownell, K. D. (2010). The Impact of Food Prices on Consumption: A Systematic Review of Research on the Price Elasticity of Demand for Food. American Journal of Public Health, 100(2), 216–222. https://doi.org/10.2105/ajph.2008.151415
82. de Oca, C. M. (2022, January 19). When will the price be right? The Good Food Institute. https://gfi.org/blog/when-will-the-price-be-right/

Alternative protein companies know this, and in 2021, Impossible Foods announced its second price reduction within a year to $9.32/lb, a 20% drop[83], while Beyond Meat is aiming to achieve price parity in at least one category by 2024.

On an industry level, Blue Horizon and BCG released a report estimating the time of price parity for different alternative protein types in 2021.



Time to Cost Parity
Source: Blue Horizon and BCG[84]

As of 2022, global food prices have risen, causing the price gap to narrow. Whether this is a boon or bane for meat alternatives is yet to be determined, as higher prices for everything else could also tighten overall expenditure on food, as well as make consumers more price sensitive. Regardless, companies must have a clear avenue to price parity with conventional meat products in order to truly have any sustainable impact, since its value is in replacing existing products rather than having any environmental benefit in and of itself. Additionally, it would be difficult to envision a solution to world hunger supported by alternative protein with costs that consumers in the developed world cannot stomach.

83. IMPOSSIBLE FOODS CUTS SUGGESTED GROCERY STORE PRICES 20%. (2021, February 2). Impossible Foods. https://impossiblefoods.com/media/news-releases/impossible-foods-cuts-suggested-grocery-store-prices-20
84. Morach, B., Witte, B., Walker, D., von Koeller, E., Grosse-Holz, F., Rogg, J., Brigl, M., Dehnert, N., Obloj, P., Koktenturk, S., & Schulze, U. (2021, May 26). Food for Thought: The Protein Transformation. BCG Global. https://www.bcg.com/publications/2021/the-benefits-of-plant-based-meats

6.2.1.1.3 Taste

According to a study conducted by the Good Food Institute with Mindlab, they found that taste was the main primary motivator among consumers for purchasing decisions, beating out price[85]. Achieving taste parity is the ultimate goal of meat alternative companies. Getting a consumer to try their product is comparatively easy due to the low initial price barrier, but achieving retention is harder. This is further exacerbated by the brandification of the vertical, in stark contrast to the commodity-based traditional meat industry which typically uses private labels or unbranded products[86]. As a result, brand image and reputation is crucial. A customer becomes much less likely to make a repeat purchase if their first taste is unappetising.

However, there is more to consumer tastes than just flavour and texture. Many of the innovative products in this space are creating foods that simply have never existed, meaning they do not satisfy a current consumer need (aside from those who care about sustainability or ethics). While it is true that the world has a large-scale hunger crisis that requires a less environmentally-taxing method of food production, the initial cost of these experimental foods are too high to bear by the individuals who need it the most. This means that successful companies must be attractive to the developed world first in order to develop an acceptable level of economies of scale. With that in mind, products that are attempting to take the place of existing ingredients in existing food products, such as burgers or flour, are easier sells than convincing the world to embrace new and strange food products.

85. Good Food Institution, Parry, J. P., & Szejda, K. S. (2019, October). How to drive plant-based food purchasing. https://gfi.org/images/uploads/2019/10/GFI-Mindlab-Report-Implicit-Study_Strategic_Recommendations.pdf
86. Evans, J. (2022, January 27). Has the appetite for plant-based meat already peaked? Financial Times. https://www.ft.com/content/996330d5-5ffc-4f35-b5f8-a18848433966

6.2.1.2 Vertical-specific Developments

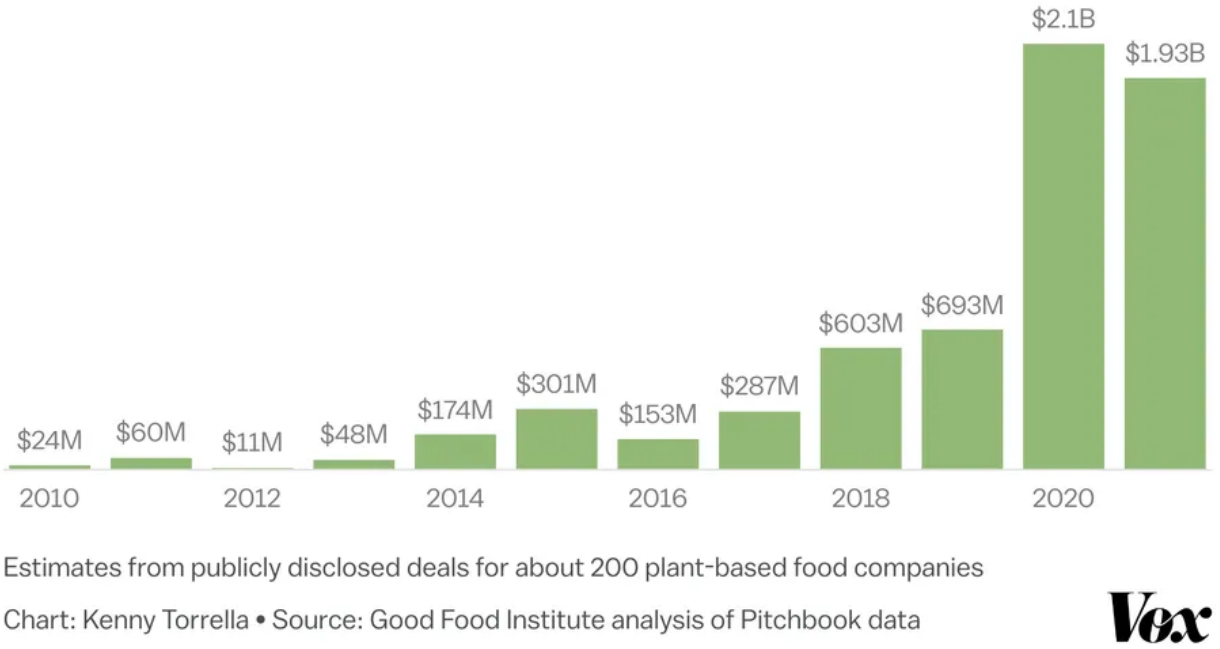
6.2.1.2.1 Plant-based Protein

Plant-based protein is currently the most popular alternative protein on the market, with options like the aforementioned tofu or tempeh having existed for centuries. However, such products have traditionally failed to convert consumers away from meat, and instead achieved popularity as complementary ingredients in many regions. Entrepreneurs began to realise that a true alternative protein would have to take the place of meat in existing dishes, and thus replicate the taste and texture of meat, rather than simply being a nutritional substitute.

In order to achieve taste parity, companies have experimented with various methods, the most popular of which being extrusion, where a mixture of plant protein pulses (e.g. lentils, soy, chickpea) are fed into a metal barrel where it is sheared and mixed by two rotating screws while being heated by steam surrounding the cylinder. This is what allows newer products like that of Beyond Meat and Impossible Foods to achieve the desired muscle fibre-like texture[87]. Each company alters the multiple process variables to produce their own proprietary product, requiring considerable R&D, not to mention the high capital cost of purchasing or even building extruders.

In 2020, the Good Foods Institute estimated the size of the plant-based protein market to be USD1.4B. With USD466M and USD230M in revenue for Beyond Meat[88] and Impossible Foods[89] respectively, these 2 companies occupy 49.7% of the market. However, this does not mean that there is no room for competition, as the current plant-based protein market is only 1.4% of the total retail meat market, meaning that startups have the opportunity to expand the overall market by capturing new customers.

87. Merrill, D. (2022, May 26). Plant-based protein manufacturing: Scaling-up extrusion. CRB. https://www.crbgroup.com/insights/food-beverage/plant-based-protein-manufacturing
88. Beyond Meat® Reports Fourth Quarter and Full Year 2020 Financial Results. (2021, February 25). Beyond Meat, Inc. https://investors.beyondmeat.com/news-releases/news-release-details/beyond-meatr-reports-fourth-quarter-and-full-year-2020-financial
89. G. (n.d.). Impossible Foods: Revenue, Competitors, Alternatives. Growjo. https://growjo.com/company/Impossible_Foods



Investment into plant-based food companies
Source: Vox's visualisation of data from the Good Food Institute[90]

Investment into plant-based food companies skyrocketed after 2019, when Beyond Meat IPO'ed at a 1.5 billion dollar valuation. The slight drop from 2020 to 2021 cannot be attributed to global headwinds, as funding for both cultivated and fermented meat alternatives rose significantly from 2020 to 2021, indicating possible crowding of the alternative protein sector.

Plant-based protein has been deemed by many to have overcome both barriers in nutrition as well as taste. However, as many studies have pointed out, most products have high levels of sodium, which can cause health implications such as heart disease[91]. The addition of salt is unfortunately necessary to mimic the taste of meat. While flavour and texture are subjective, many products have become the subject of media scrutiny due to their realistic qualities. Notably, in 2019, Burger King Sweden created a menu item where customers would have a 50-50 chance of getting a meat burger or a plant-based one, and 44% of customers could not correctly identify if they were consuming real meat. Its largest barrier is therefore cost. Unless governments begin to halt traditional meat farming subsidies - which could mean a true price of USD30 per pound of beef[92] - or force producers to internalise the environmental costs of agriculture via taxes, companies have to conduct further R&D or reap the benefits of economies of scale to continue pushing prices down to that of conventional meat.

90. Torrella, K. (2022, May 25). The plant-based future of meat and food doesn't always taste good. Vox. https://www.vox.com/future-perfect/23065941/vegan-vegetarian-plant-based-food-tech-bad-products
91. Gelsomin, E. M. (2022, January 24). Impossible and Beyond: How healthy are these meatless burgers? Harvard Health. https://www.health.harvard.edu/blog/impossible-and-beyond-how-healthy-are-these-meatless-burgers-201908151744 8
92. Gillette, D. (2022, April 21). The True Cost of a Hamburger. AIER. https://www.aier.org/article/the-true-cost-of-a-hamburger/

6.2.1.2.2 Insect-based Protein

Insects have been part of many human diets for a while, most notably that of the Thais, whose country has more than 20,000 large-scale and small backyard insect farms operating across the country[93]. The main issue is that individuals find eating whole insects difficult to stomach, as food consumer researcher Giovanni Sagari says "We associate insects with everything but food. I mean with dirt, danger, with something disgusting, with something that makes us feel sick". According to the European Consumer Association, only 10% of Europeans would be willing to replace meat with insects[94]. As a solution, most insect-based protein startups are grinding insects into powder to be used as ingredients.

The reason why insects are an attractive source of protein is that they are more efficient at converting their food into protein. According to the Food and Agriculture Organisation of the United Nations, crickets need six times less feed than cattle, four times less than sheep and two times less than pigs[95]. They also require an eighth of the land[94], and 95% less water[96]. This is due to the fact they reach maturity quicker, and are cold-blooded, not requiring energy to maintain body temperatures.

Nutritionally, crickets, the most popular edible insect, are almost 70% protein by dry volume[97]. Additionally, farming them does not require antibiotics, and because insects are so genetically dissimilar from humans, there is no risk of viral outbreak - in contrast to consuming mammals[98].

The insect-based protein market is small, with estimates of USD153M[99] to USD303M[100] in 2021. The key players are mainly selling insects as animal feed (fish) rather than consumer products. Aspire Food Group is one company expanding towards the market for human food, building a $90m production facility that will produce 10,000 tons of crickets a year, utilising IoT from Telus for precise farming conditions.

93. G. (2021, May 27). Altimate Nutrition bets on Singapore's innovative market via new insect-protein bar. Verdict Media Limited. https://www.foodprocessing-technology.com/comment/altimate-nutrition-singapore-insect-protein/
94. The Protein-rich Superfood. (n.d.). BBC. https://www.bbc.com/future/article/20210420-the-protein-rich-superfood-most-europeans-wont-eat
95. Food and Agriculture Organization of the United Nations. (n.d.). The Contribution of Insects to Food Security, Livelihoods and the Environment. https://www.fao.org/docrep/018/i3264e/i3264e00.pdf
96. Cricket Farming: Creating The World's Food Source. (2021, February 12). Pinduoduo. https://stories.pinduoduo-global.com/agritech-hub/cricket-farming-for-human-consumption#:%7E:text=Farming%20crickets%20uses%2095%25%20less,more%20resource%20efficient%20than%20cows
97. Cricket Farming: Creating The World's Food Source. (2021, February 12). Pinduoduo. https://stories.pinduoduo-global.com/agritech-hub/cricket-farming-for-human-consumption#:%7E:text=Farming%20crickets%20uses%2095%25%20less,more%20resource%20efficient%20than%20cows
98. Startup About. (2021, November 10). Altimate Nutrition. https://altimatenutrition.com/startup-about/
99. Insect Protein Market Size, Share & COVID-19 Impact Analysis, By Product Type (Coleoptera, Lepidoptera, Hymenoptera, Orthopetra, and Others), Application (Food & Beverages, Animal Feed, and Pharmaceuticals & Cosmetics), and Regional Forecast, 2022–2029. (n.d.). Fortune Business Insights. https://www.fortunebusinessinsights.com/industry-reports/insect-based-protein-market-100780
100. Global Insect Protein Market Size Report, 2021–2028. (n.d.). Grand View Research. https://www.grandviewresearch.com/industry-analysis/insect-protein-market#:%7E:text=The%20global%20insect%20protein%20market%20size%20was%20estimated%20at%20USD,USD%20303.2%20billion%20in%202028

Because insects can be eaten whole with minimal processing, or in powdered form, they do not require complex machinery or processes, greatly saving on capital expenditure. Costs are thus mostly concentrated at the farming stage rather than at food manufacturing or retail. While it seems financially expensive to set up cricket farms, this is mainly due to the need for R&D. There are very few cricket feed suppliers, and little is publicly known about their ideal conditions for growth. There is lack of scale as it is a nascent industry, indicating available gains in economies of scale. Larger companies like Aspire are using IoT, but startups like Sens[101] also have full-time R&D teams and are attempting to innovate using new farming methods like vertical farming.

The largest barrier to scale is taste. Even with insect powder that lacks discernible taste, it is difficult to imagine consumers would purchase powder just to sprinkle into existing foods, and that such a use case would create sufficient demand for insect-based protein. Companies are trying to create replacement products such as flour, protein bars and protein shakes, but it remains to be seen whether this will catch on.

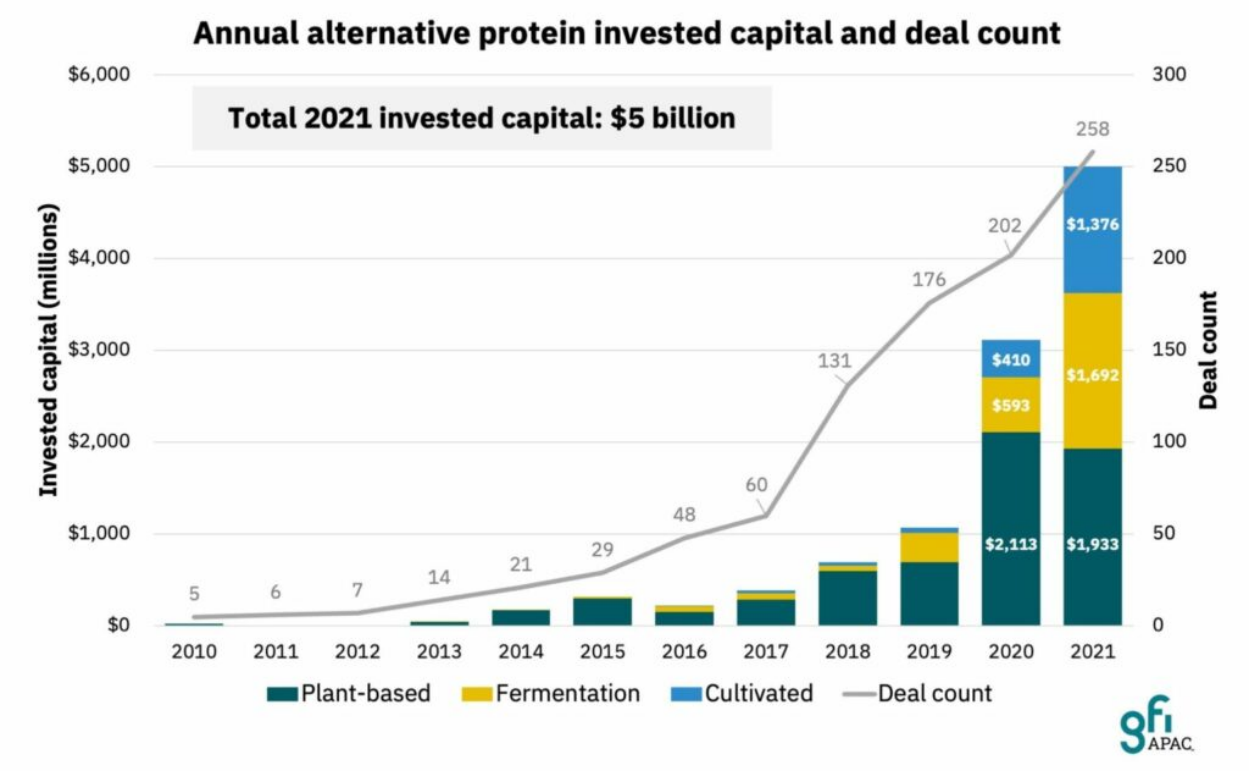
101. Sustainable Cricket Protein, Cricket Flour & Edible Crickets | sens. (n.d.). Sens Foods. https://eatsens.com/

6.2.1.2.3 Cultivated Protein

Cultivated protein, also known as animal cell based proteins, are the result of growing animal cells in a nutrient-rich media in bioreactors[102]. Until recently, the media utilised foetal bovine serum (FBS), a byproduct of harvesting cattle for the meatpacking industry. Until the recent boom in the search for alternative proteins, its use has been limited to academic research due to its prohibitive cost. However, the harvesting of FBS is deemed by many to be incredibly unethical, typically by way of cardiac puncture of foetuses without anaesthetic harvested from slaughtered pregnant cows. As a result, many are deeply invested in the search for a media without the use of animal products.

In 2019, Mosa Meats succeeded in producing cultivated meat without the use of FBS, and published this paper[103] in 2022 in Nature Food, creating a patented cell feed formulation. Given the exorbitant cost of FBS (USD400-900 a litre and a single burger patty took 50 L of serum), this new process managed to reduce the cost of media by 80x (cost of a single patty dropped from 330k for their first burger in 2013 to a projected USD10 in 2021)[104,105].

The cultured meat vertical has exploded in recent years, with over USD1.4B secured in 2021[106] according to GFI, showing significant growth from past years as can be seen in the chart below.



Alternative Meat Funding
Source: Good Food Institute[107]

102. Morach, B., Witte, B., Walker, D., von Koeller, E., Grosse-Holz, F., Rogg, J., Brigl, M., Dehnert, N., Obloj, P., Koktenturk, S., & Schulze, U. (2021, May 26). Food for Thought: The Protein Transformation. BCG Global. https://www.bcg.com/publications/2021/the-benefits-of-plant-based-meats

The fast rise in funding for alternative protein is reflective of the advantages that it provides if it is viable. A product with cultivated meat and fat is likely to be the most faithful reproduction of its unsustainable alternative in both taste and texture. If the final product can be done without FBS, it is also entirely ethical. In terms of nutrition, it would have the exact benefits of meat, without the risk of viruses, antibiotics or microplastic accumulation. It would also have no environmental requirements or be dependent on specific vegetable crops, and thus could be produced anywhere as long as the media and cells were available.

In order to become a possible solution to world hunger, or a commercially viable product, 99 companies in 2022[108] are racing to lower costs of production via further R&D and scale-up efforts. In addition to companies trying to directly produce meat, there are also those which are focussed solely on producing cheaper and more ethical media, such as biftek[109].

103. Messmer, T., Klevernic, I., Furquim, C., Ovchinnikova, E., Dogan, A., Cruz, H., Post, M. J., & Flack, J. E. (2022). A serum-free media formulation for cultured meat production supports bovine satellite cell differentiation in the absence of serum starvation. Nature Food, 3(1), 74–85. https://doi.org/10.1038/s43016-021-00419-1
104. What's been going on with the 'hamburger professor.' (n.d.). News - Maastricht University. https://www.maastrichtuniversity.nl/news/what%E2%80%99s-been-going-%E2%80%98hamburger-professor%E2%80%99
105. Lab-grown Meat at US10 a Patty. (n.d.). Business Times. https://www.businesstimes.com.sg/consumer/lab-grown-meat-at-us10-a-patty-give-it-2-years
106. Record US$5 billion invested in alt proteins in 2021, but GFI warns it's not enough. (2022, March 3). ..Foodingredientsfirst.Com/. https://www.foodingredientsfirst.com/news/record-us5-billion-invested-in-alt-proteins-in-2021-but-gfi-warns-its-not-enough.html
107. Huling, R. (2022, June 2). The State of APAC's Alt Protein Industry in Four Graphs. GFI APAC. https://gfi-apac.org/the-state-of-apacs-alt-protein-industry-in-four-graphs/
108. Markets, R. A. (2022, February 2). 2022 Worldwide Market for Cultured Meat Report - Featuring 3D Bio-Tissues, Agulos Biotech and Aleph Farms Among Others. GlobeNewswire News Room. https://www.globenewswire.com/news-release/2022/02/02/2377373/28124/en/2022-Worldwide-Market-for-Cultured-Meat-Report-Featuring-3D-Bio-Tissues-Agulos-Biotech-and-Aleph-Farms-Among-Others.html#:%7E:text=There%20are%20now%20an%20impressive,to%20only%20four%20in%202016
109. Biftek INC. (n.d.). Biftek. https://biftek.co/

6.2.1.2.4 Fermentation

Fermentation refers to a specific metabolic pathway used to generate energy in the absence of oxygen. In the alternative protein industry, fermentation is largely utilised in 3 ways[110].

1. Traditional fermentation utilises intact live microorganisms, creating products such as yoghurt, cheese and tempeh.

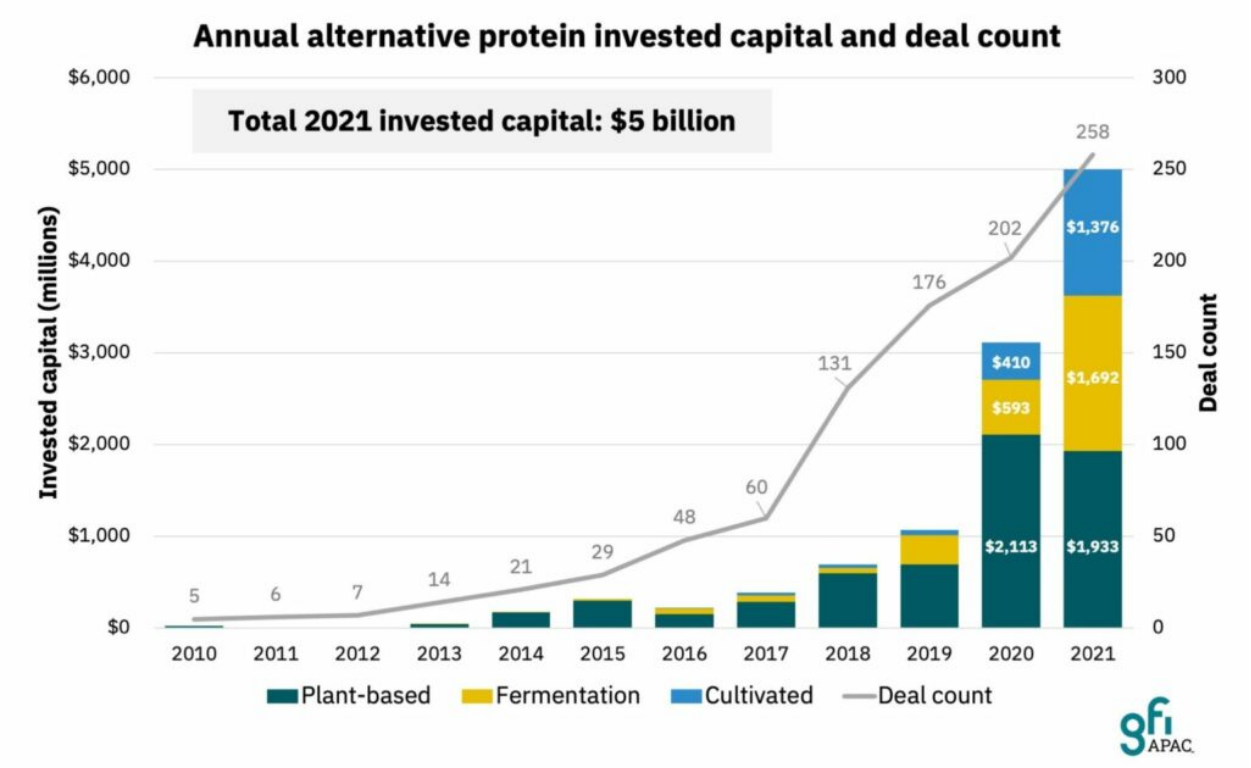
2. Biomass fermentation uses the microbes to efficiently produce large quantities of protein, with the biomass itself becoming the consumable product. Examples of this are Quorn's and Meati's use of filamentous fungi.

3. Lastly, precision fermentation uses microbial hosts as "cell factories" for producing specific ingredients, and are thus used at much lower levels than biomass fermentation. The microbes help improve the taste, texture and/or nutritional qualities of plant-based or cultivated meat. Examples include Perfect Day's dairy proteins, Clara Foods' egg proteins, and Impossible Foods' heme protein.

The reason for using microbes is the same as insects in that they are more efficient at converting calories into protein than mammals or birds. Microbial proteins also benefit from being far-removed from humans genetically, and thus there is less risk of viral transmission. There are less ethical concerns, as most individuals are not particularly worried about the breeding, living conditions and death of bacteria or fungi. Finally, it is much more environmentally friendly, with one estimate from Nature stating that replacing 20% of beef consumption with microbial protein by 2050 would result in a 56% reduction in annual deforestation and associated carbon dioxide emissions[111].

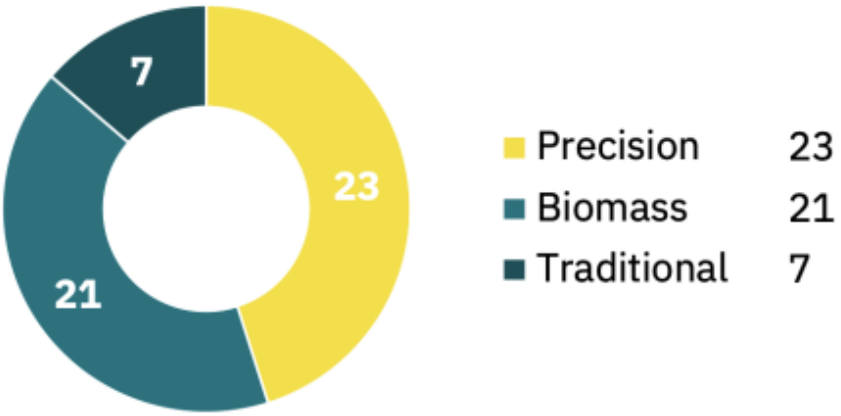
A significant advantage of using fermentation is that like cultivated proteins, there is virtually unlimited potential for variety, especially when coupled with biological synthesis capabilities in precision fermentation applications. There are a myriad of existing microbial species, meaning immense opportunities for novel alternative protein solutions, as well as ingredients that would augment existing or other protein products, such as creating specialised types of fat to enhance the taste of cultivated meat. This also means that fermentation is not necessarily a direct competitor to cell cultivation, and can be a complementary product should cultivated protein become the dominant choice in the future.

110. Specht, L. (2021, March 9). The science of fermentation (2021) | GFI. The Good Food Institute. https://gfi.org/science/the-science-of-fermentation/#:%7E:text=Precision%20fermentation%20uses%20microbial%20hosts,incorporated%20at%20much%20lower%20levels
111. Humpenöder, F., Bodirsky, B. L., Weindl, I., Lotze-Campen, H., Linder, T., & Popp, A. (2022). Projected environmental benefits of replacing beef with microbial protein. Nature, 605(7908), 90–96. https://doi.org/10.1038/s41586-022-04629-w



Alternative Meat Funding[112]
Source: Good Food Institute

Microbial Fermentation also experienced a large rise in funding in 2021, showing a similar growing interest in the field. GFI also conducted a state of the industry report, finding that in 2020, 51 companies focussed primarily on fermentation for alternative proteins, 21 of which use biomass fermentation and 23 use precision fermentation.



Companies by type of Fermentation[113]
Source: Good Food Institute

112. Huling, R. (2022, June 2). The State of APAC's Alt Protein Industry in Four Graphs. GFI APAC. https://gfi-apac.org/the-state-of-apacs-alt-protein-industry-in-four-graphs/
113. Good Food Institute. (n.d.). 2020 State of the Industry Report - Fermentation. https://gfi.org/science/the-science-of-fermentation/#:~:text=Precision%20fermentation%20uses%20microbial%20hosts,incorporated%20at%20much%20lower%20levels

Similar to cultivated meat, a large barrier faced by fermented protein is cost, with few companies having publicly available products that they can already produce at scale. Its major cost driver is feedstock, which provides the nutrients to support these microorganisms' growth. At present, the majority of fermentation relies on refined sugar[114], as it has a long validated use in multiple uses of fermentation.

However, the issue of feedstock is not as severe as that of cultivated meat's issue with FBS, as sugar feedstock is sufficiently cheap and relatively abundant. The problem comes only with potential future scale-up, which would probably require diversification away from sugar. Companies are experimenting with waste products or agro-industrial byproducts, with GFI noting 3F Bio and Mycorena in Sweden using sustainable feedstock. Other startups, including Air Protein, leverage gaseous feedstocks, deriving energy from chemical reactions involving hydrogen, methane, or carbon dioxide gas. In addition, because there are such a variety of microorganisms, companies are also able to tap into a diverse range of unconventional feedstock.

There are also challenges in scalability, as increasing production when dealing with microbes is not straightforward. "Very large scale systems tend to be highly heterogeneous with several gradients (oxygen, food, shear,…) and, thus, require robust and tolerating cells"[115].

Lastly, companies face issues with branding and product image, as consumers do not yet have a good understanding of modern fermentation processes. Perfect Day's cofounder Ryan Pandya says "Because this is the first time in the history of dairy that actual cow's milk proteins have been produced in something other than a cow, there's understandable confusion"[116]. This confusion acts as a barrier to public acceptance, especially as microbes and fungi are not particularly enticing words when it comes to food. It remains to be seen how both brands and the industry vertical as a whole will be viewed, but a marketing push must occur to improve public perception of fermented protein[117].

114. Specht, L. (2021, March 9). The science of fermentation (2021) | GFI. The Good Food Institute. https://gfi.org/science/the-science-of-fermentation/#:%7E:text=Precision%20fermentation%20uses%20microbial%20hosts,incorporated%20at%20much%20lower%20levels
115. A. (2021, November 5). Alternative Proteins, Part 3: Biomanufacturing, Fermentation. ERDYN. https://erdyn.com/us/alternative-proteins-part-3-biomanufacturing-fermentation/
116. Kateman, B. (2021, June 15). Fermentation: The New Game-Changer For Alternative Proteins? Forbes. https://www.forbes.com/sites/briankateman/2021/06/07/fermentation-the-new-game-changer-for-alternative-proteins/?sh=4ed3dd3e3aff
117. foodnavigator.com. (2022, April 19). Experts outline 'biggest obstacles' facing precision fermentation sector: 'We have brilliant people with brilliant innovations, but can this make money?' https://www.foodnavigator.com/Article/2022/04/19/Experts-outline-biggest-obstacles-facing-precision-fermentation-sector-We-have-brilliant-people-with-brilliant-innovations-but-can-this-make-money

6.2.2 Enhanced Farming Practices

Regardless of which alternative sustainable source of protein is used in the future, it is also clear that we have to improve the ways we produce food crops, as they are still instrumental inputs in plant-based, insect-based, cultivated and fermented proteins. In this sense, reducing the carbon footprint, water usage or land usage of traditional farming provides the dual effects of creating more environmentally friendly food as well as reducing the environmental cost of secondary protein production.

Additionally, enhanced farming practices increases the productivity of its inputs, generating more food per gallon of water and acre of land, hopefully decreasing food costs by way of increasing supply, providing more inclusive access to food.

The last crucial need for enhanced farming practices is food security. By making crops and livestock more resilient to extreme weather events and pestilence, or in some cases even completely immune to environmental conditions, we enable the replicability of such food production systems anywhere in the world. Food supply chains will no longer be tied down by geographical restrictions, reducing the need for long distance shipments of food that can only be grown in certain locations. Decreasing reliance on foreign sources of food means that access to food will no longer be subject to geopolitical tensions and strife, as well as extreme climate conditions.

6.2.2.1 Agricultural Biotechnology

The field of agricultural biotechnology is not a new one, with the cultivation of high-yielding varieties (HYV) starting in classical plant breeding where early farmers simply selected plants with particular desirable characteristics and "employed these as progenitors for subsequent generations, resulting in an accumulation of valuable traits over time"[118].

In the modern era, agricultural biotechnology has grown in both breadth and depth, utilising gene editing techniques to precisely add desirable traits and remove undesirable ones, creating vaccines for crop and livestock diseases and harnessing the power of microbes to rehabilitate soil and protect crops from pathogens[119].

In the field of gene editing, progress in using CRISPR/Cas molecular scissors allow scientists to modify genetic information to improve yield, increase robustness to pests, disease and extreme climatic conditions. Research is being done to even remove genes that are responsible for the creation of certain parts of the plant, especially parts that are not crucial to agriculture (not edible)[120].

Prominent companies in this field include Caribou Biosciences, whose cofounder Jennifer Doudna received the Nobel Prize in Chemistry in 2020 for her work in CRISPR and is working with animal genetics company Genus to produce virus resistant pigs[121]. Cibus is a "seed and trait"company that developed their own patent-protected gene editing platform RTDS or Rapid Trait Development System, which the EU referenced as one of few safe gene editing technologies. The novel seed and trait business model is one where companies develop and commercialise "gene edited Crop Protection Traits"[122]; traits can then be licensed to seed firms or the company can release these traits through their own varieties[123].

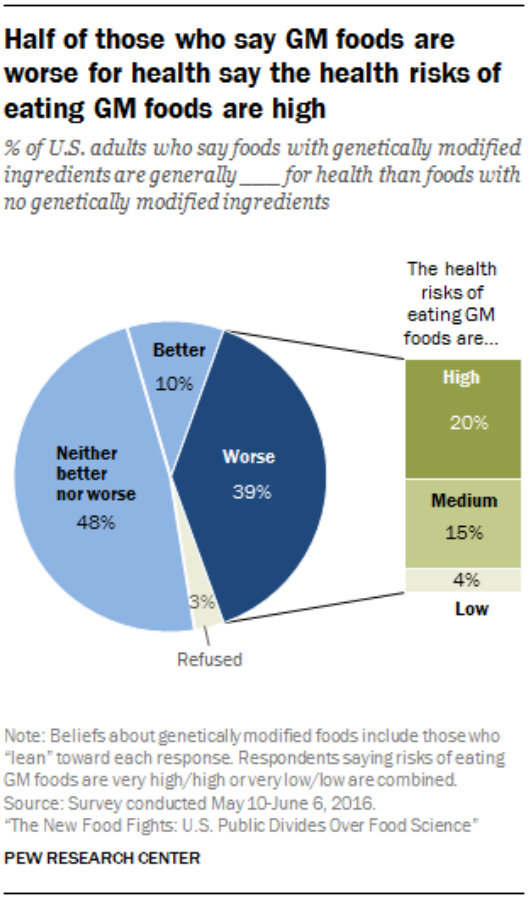
118. Breeding & Genetics | KnowPulse. (n.d.). KnowPulse. https://knowpulse.usask.ca/node/21
119. Yadav, A. N., Kour, D., Kaur, T., Devi, R., Guleria, G., Rana, K. L., Yadav, N., & Rastegari, A. A. (2020). Microbial biotechnology for sustainable agriculture: Current research and future challenges. New and Future Developments in Microbial Biotechnology and Bioengineering, 331–344. https://doi.org/10.1016/b978-0-12-820526-6.00020-8
120. Schindele, A., Gehrke, F., Schmidt, C., Röhrig, S., Dorn, A., & Puchta, H. (2022). Using CRISPR-Kill for organ specific cell elimination by cleavage of tandem repeats. Nature Communications, 13(1). https://doi.org/10.1038/s41467-022-29130-w
121. Caribou Biosciences. (n.d.). Caribou Biosciences - Wiki. Golden. https://golden.com/wiki/Caribou_Biosciences-W4BDMDA(https://golden.com/wiki/Caribou_Biosciences-W4BDMDA)
122. Products - Our Products. (n.d.). Cibus. https://www.cibus.com/crop-protection-traits.php
123. Wilson, W. W., & Huso, S. R. (2008). Trait Stacking, Licensing, and Seed Firm Acquisitions in Genetically Modified Grains: A Strategic Analysis. Journal of Agricultural and Resource Economics, 33(3), 382–401. http://www.jstor.org/stable/41220600

Biotechnology derived vaccines are safer than traditional (live-attenuated or viral-vectored) vaccines, as mRNA is non-infectious and poses no danger for DNA integration[124]. As widely proven in the SARS-CoV-2 vaccines, it is also effective. mRNA vaccines have been used in animals, with promising results in combating rabies, Zika and influenza[125] . What is even more exciting is that RNA vaccines allow the prospect of plant vaccines, as while plants do not have adaptive immune systems like animals, researchers from the Institute of Biochemistry and Biotechnology in Germany found that RNA introduced into plants protected those plants from viruses[126]. However, these are not technically vaccines, and the RNA will only be effective until it biodegrades.

Additionally, RNA can be used to improve agriculture in ways other than vaccines. RNA can be used in pesticides, since RNA degrades quickly in the environment and is extremely targeted, meaning that pesticides can be designed towards specific insects without risk of hurting those that are beneficial to the crops and humans. One startup in this field is GreenLight Biosciences, which closed a $102m Series D in 2020 and opened a large scale facility in New York in 2021 to mass produce RNA to kill the Colorado potato beetle and the Varroa destructor mite, which destroys beehives[127].

124. How does a mRNA vaccine compare to a traditional vaccine? | Vanderbilt Institute for Infection, Immunology and Inflammation. (n.d.). Vanderbilt Institute for Infection, Immunology and Inflammation. https://www.vumc.org/viiii/infographics/how-does-mrna-vaccine-compare-traditional-vaccine
125. Le, T., Sun, C., Chang, J., Zhang, G., & Yin, X. (2022). mRNA Vaccine Development for Emerging Animal and Zoonotic Diseases. Viruses, 14(2), 401. https://doi.org/10.3390/v14020401
126. Gago-Zachert, S., Schuck, J., Weinholdt, C., Knoblich, M., Pantaleo, V., Grosse, I., Gursinsky, T., & Behrens, S. E. (2019). Highly efficacious antiviral protection of plants by small interfering RNAs identified in vitro. Nucleic Acids Research, 47(17), 9343–9357. https://doi.org/10.1093/nar/gkz678
127. Bloomberg - Are you a robot? (n.d.). Bloomberg. https://www.bloomberg.com/tosv2.html?vid=&uuid=1eae4863-0cbd-11ed-bea9-4b7562496958&url=L25ld3MvYXJ0aWNsZXMvMjAyMS0wOS0yMS9iaW90ZWNoLXN0YXJ0dXAtZ3JlZW5saWdodC1pcy1tYXNzLXByb2R1Y2luZy1ybmEtdG8tZmlnaHQtcGVzdHM=#xj4y7vzkg

However, public opinion of genetically modified food or inputs is generally negative. A 2016 study by the Pew Research Centre found that 39% of Americans believe GMO foods are worse for one's health, compared to only 10% who believe that GMO is good for one's health[128].



Public Sentiment towards GM foods
Source: Pew Research Centre[129]

As a result, demand for such foods might not be strong unless there is sufficient public awareness and education regarding the health of GM foods.

Issues with costs are up for debate, as one Harvard study claims that developing a new GMO plant costs USD136m on average[130]. However, this study in the International Journal of Biotechnology estimates costs to be around USD1.4m to 1.6m[131], which would make development of GM crops much more affordable by small startups. After development, production of the GM seeds is scalable, though at much higher prices than conventional seeds - BT corn for example costs $114 per acre to plant, as opposed to $65 per acre for conventional corn seeds.

128. 3. Public opinion about genetically modified foods and trust in scientists connected with these foods. (2020, August 27). Pew Research Center Science & Society. https://www.pewresearch.org/science/2016/12/01/public-opinion-about-genetically-modified-foods-and-trust-in-scientists-connected-with-these-foods/
129. 3. Public opinion about genetically modified foods and trust in scientists connected with these foods. (2020b, August 27). Pew Research Center Science & Society. https://www.pewresearch.org/science/2016/12/01/public-opinion-about-genetically-modified-foods-and-trust-in-scientists-connected-with-these-foods/

However, a possible issue is that these favourable traits do not necessarily work forever. Infamously, the rootworm that the Bt corn was designed to fight off grew resistant to the gene[132]. Research found that a way to prevent this was to rotate the usage of Bt corn with other crops, so that the rootworms would not have the sustained exposure that allowed them to evolve. Regardless, such pest or virus related shortfalls have to be considered. Similarly, crops that may be able to survive a greater variability in temperature are still likely to perish in extreme weather conditions, and cannot be considered as the only solution to achieve food resilience.

130. S. (2015, August 11). The Patent Landscape of Genetically Modified Organisms. Science in the News. https://sitn.hms.harvard.edu/flash/2015/the-patent-landscape-of-genetically-modified-organisms/#:%7E:text=The%20discovery%2C%20development%2C%20and%20authorization,of%20exclusivity%20and%20profitability%20granted
131. Schiek, B., Hareau, G., Baguma, Y., Medakker, A., Douches, D., Shotkoski, F., & Ghislain, M. (2016). Demystification of GM crop costs: releasing late blight resistant potato varieties as public goods in developing countries. International Journal of Biotechnology, 14(2), 112. https://doi.org/10.1504/ijbt.2016.077942
132. Carrière, Y., Brown, Z., Aglasan, S., Dutilleul, P., Carroll, M., Head, G., Tabashnik, B. E., Jørgensen, P. S., & Carroll, S. P. (2020). Crop rotation mitigates impacts of corn rootworm resistance to transgenic Bt corn. Proceedings of the National Academy of Sciences, 117(31), 18385–18392. https://doi.org/10.1073/pnas.2003604117

6.2.2.2 Precision Agriculture (PA) Technologies

Precision Agriculture Technology refers to the use of technology that allows for the conditions of agriculture to be varied and measured in such a granular way that data can be collected for the purposes of optimising crop productivity and resource use. It can increase crop yield and decrease wastage of inputs, allowing food production to become more efficient, and for farmers' businesses to become more profitable. It would also prevent overuse of pesticides or underuse of fertiliser and soil degradation.

The main technologies involved are IoT or internet of things, where multiple sensors allow farmers to monitor a wide range of conditions and metrics, creating a way to study long term patterns and gain better visibility of the possible risks and decisions they need to make. The collection of vast amounts of data also makes the use of AI viable in aiding the decision making process.

In the PA space, there are companies that produce IoT devices, such as sensors and drones, as well as software companies and those that directly use these technologies to produce food. One example is India's Fasal, which has raised USD4m in pre-Series A funding, has helped farmers save 9 billion gallons of water, reduced pesticide expenditure by around 60%, and increased yields across 40,000+ acres of farmland[133]. Another involved in livestock is Bangladesh's Stellapp, which digitalises the entire dairy supply chain, from IoT monitoring for cows to cold chain logistics. In 2021, it raised USD18m in a Series C to follow its 14m Series B round in 2018. There is also potential for general IoT companies to enter the agritech space. IoT developer platform unicorn Helium, has become a standard for which other company's sensors can utilise for connectivity, including agriculture, with companies like Lonestar, Infisense and Lark Alert building compatible sensors on their platform.

The main issue with most such solutions are cost (high initial cost), and farmers' lack of education and expertise.

133. ET Bureau. (2021, November 22). Precision agriculture platform Fasal raises $4 million from 3one4 Capital, others. The Economic Times. https://economictimes.indiatimes.com/tech/funding/precision-agriculture-platform-fasal-raises-4-million-from-3one4-capital-others/articleshow/87842320.cms

The high cost is a barrier for most farmers seeing as how purchasing sufficient sensors for large swathes of land can be prohibitive. Lux Research found that most farmers are very sensitive to changes in price and costs, especially with low commodity prices. For example, for corn, only farmers with over 2500 acres in land could afford to spend capital on sensors. However, when it comes to higher value density items such as premium grapes for wine making, farmers are more willing to make such expensive purchases, with the farm-size threshold sitting at 50 acres[134].

Additionally, there are also PA improvements that are not as costly to implement as sensors. New Zealand's Biolumic studies plant phenotypes to determine specific "Light Signal Recipe"s that enable crops to grow at increased rates and even reduce pesticide use, just by installing lights in the fields. They recently raised USD13.5m in their Series B in 2022[135]. Nevertheless, what are considered affordable technologies in most developed nations are still out of reach for most of the smallholder farmers in developing countries.

Due to IoT being a new developing technology, many farmers are unfamiliar with its utility in the agricultural setting. This effect is compounded by the cost, causing risk-averse farmers to be wary of adopting sensor technology in their work. This study on the rationality of decision-making behaviour among US dairy farmers found that the largest barrier to the adoption of sensor technologies "were being unfamiliar with available technologies, expecting an undesirable cost-benefit ratio, and being provided with too much information without clear relevance for management"[136]. Additionally, studies have found that the majority of benefits from PA technology can be "realized only when the necessary skills and data are available"[137]. Hence, startups must provide demonstrable improvements in yield in order to convince potential customers, as well as simple, clear information and possibly education and training sessions so that farmers can truly utilise PA to its full potential.

134. Price Challenges blocking Adoption of Sensors. (n.d.). Yahoo. https://sg.news.yahoo.com/price-challenges-blocking-adoption-sensors-123000482.html
135. Biolumic. (n.d.). Biolumic. https://www.biolumic.com/
136. Russell, R., & Bewley, J. (2013). Characterization of Kentucky dairy producer decision-making behavior. Journal of Dairy Science, 96(7), 4751–4758. https://doi.org/10.3168/jds.2012-6538
137. Precision Agriculture Adoption and Profitability. (n.d.). Agricultural Economics. https://agecon.unl.edu/cornhusker-economics/2017/precision-agriculture-adoption-profitability

6.2.2.3 Controlled Environment

Controlled Environment Agriculture refers to a system of agriculture where plants are grown in controlled environments to optimise horticultural practices. While not necessarily the case, these are typically used in conjunction with precision agriculture technologies such that the temperature, humidity and other related factors can be monitored and then altered. Similarly, this sector contains both startups that provide specific inputs or services for controlled environment farms, as well as those that aim to own the full tech stack and vertical, from the farming units to retail.

The first controlled environment farms were greenhouses, providing protection from pests without using pesticides, as well as wind and frost. However, greenhouses still relied on natural sunlight, and are typically using only soil instead of hydroponics or aeroponics.

The next wave of innovation in controlled environment farms are indoor farming techniques, which are completely enclosed, and typically use technologies such as hydroponics, aeroponics and vertical farming (note that the former two technologies can also be used in greenhouses). The key benefit of these controlled environment farms is their ability to be absolutely immune to environmental conditions. Sunlight that is out of human control can be replaced with UV lights that are tuned to specific frequencies that best suit the crops and can be left on 24/7 for faster growth. Not only are wasteful irrigation systems unnecessary, water condensation can be recollected. Even the composition of the air can be monitored and controlled[138].

Additionally, vertical farms are particularly promising because they offer 2 additional benefits.

138. Krzemiński, M. (2022, June 16). Heralds the Next Generation of Cloud-enabled Farming. Infarm. https://www.infarm.com/infarm-heralds-the-next-generation-of-cloud-enabled-farming/

First, it solves the problem of land scarcity by stacking several rows of plants to save horizontal space, making agriculture possible even in dense urban areas. Vertical farming companies have managed to achieve the soil-agriculture yield of 360,000 square metres in just 5500 square metres[139], resulting in an almost 99% reduction in land use. This would greatly reduce the amount of land needed to feed our growing population.

Second, it also reduces the need for transport, as such centres can be built very close to cities that rely heavily on imported food from far flung rural areas or other parts of the world. Food transport currently accounts for 5% of the carbon emissions associated with food consumption[140], and the need for complex and long supply chains.

The greatest downside to controlled agriculture is its high costs, both in CapEx and operating costs. Building a sealed environment and then changing the atmosphere requires a significant amount of equipment and energy. According to iFarm, LED lamps (65%), air conditioners (20%) and dehumidifiers (10%) account for 95% of electricity usage, while the remaining devices - pumps, controllers, water purification units - use less than 5%[141]. This report by an agriculture consultant, ex-CFO of a CPG and investment banker finds the following cost table.

Conventional outdoor farm	Hydroponic greenhouse	Vertical farm
$0.65 / lb	$2.33 / lb	$3.07 / lb

Price Comparison: Conventional, Hydroponic, Vertical
Source: Strategic Capital Consultants[142]

With almost five times the cost of current conventional methods, and no material benefit to the consumer, only those who place a significant importance on sustainability would choose to purchase goods grown with controlled environment methods. What's more is that the above costs are already accounting for economies of scale, as the vertical farm in question is a 70,000 square foot facility operated by one of the largest vertical farm companies worldwide, Aerofarm of the United States of America, and the hydroponic greenhouse is a 280,000 square foot greenhouse operated by Brightfarms. Both facilities produce in the range of 2 million pounds of produce a year.

139. Krzemiński, M. (2022, June 16). Heralds the Next Generation of Cloud-enabled Farming. Infarm. https://www.infarm.com/infarm-heralds-the-next-generation-of-cloud-enabled-farming/
140. You want to reduce the carbon footprint of your food? Focus on what you eat, not whether your food is local. (n.d.). Our World in Data. https://ourworldindata.org/food-choice-vs-eating-local#:%7E:text=By%20analysing%20consumer%20expenditure%20data,(0.4%20tCO2eq)
141. How Much Electricity Does a Vertical Farm Consume Using iFarm technologies? (n.d.). iFarm. https://ifarm.fi/blog/2020/12/how-much-electricity-does-a-vertical-farm-consume
142. Tasgal, P. (2021, June 9). The economics of local vertical & greenhouse farming are getting competitive. AFN. https://agfundernews.com/the-economics-of-local-vertical-and-greenhouse-farming-are-getting-competitive

In this vertical, the above-mentioned Aerofarm has raised USD100m in their Series E in 2019 and 40m and 35m in their Series D and C rounds prior[143]. They are an aeroponics-based vertical farmer that has received investment from New Jersey's Economic Development Authority and the Abu Dhabi Investment Office. BrightFarms is a hydroponics greenhouse farmer that has also raised USD100m in their Series E in 2020, and 55m in their Series D[143].

One new development in this space is growing vegetables in retail spaces. Aerofarm has hinted at the possibility of expanding into this business model, but this is currently being done by Infarm, a company that provides small vertical indoor hydroponics units that can be placed virtually anywhere so that produce can be harvested fresh where the consumers are, further reducing the need to transport food. Infarm has raised USD200m in their Series D, after USD170m and USD100m in their Series C and B rounds respectively, with the Qatar Investment Authority being one of their investors[144].

While companies that grow their own produce and sell them to retail like Aerofarm, BrightFarms and Infarm tend to have the higher valuations, there are startups who specialise in a specific part of the techstack or supply chain. Artemis, regarded as the "leading enterprise Cultivation Management Platform (CMP)", focuses on the software behind indoor farming and the data collection and analysis that helps such farms improve their processes. It was acquired by iUNU, an Agtech company that provides consultancy services, computer vision technology as well as crop insurance and offering financing to controlled environment farms, for an undisclosed amount in 2021[145].

As we can see, the controlled environment vertical is one with many opportunities for technological innovation. With its replicability and scalability, it is prime for venture capital investment, especially considering its attractiveness to vested interests such as sovereign wealth funds and governments. While its unit costs might be high due to CapEx, as the cultivation process becomes optimised with data and inputs become cheaper with scale, the benefits of controlled environment agriculture cannot be ignored as land becomes scarcer and climates become less predictable, leading many to believe it is poised to be the farming medium of the future.

143. BrightFarms - Funding, Financials, Valuation & Investors. (n.d.). Crunchbase. https://www.crunchbase.com/organization/brightfarms/company_financials
144. Burwood-Taylor, L. (2021, December 16). Brief: Infarm raises $200m Series D from Qatar sovereign fund, others at $1bn+ valuation. AFN. https://agfundernews.com/infarm-raises-200m-series-d-from-qatar-others-at-1bn-valuation#:%7E:text=Infarm%20has%20raised%20%24200%20million,Atomico%2C%20Lightrock%2C%20and%20Bonnier
145. Ellis, J. (2021, September 29). Artemis acquired by iUNU in continued CEA rollup creating $50m+ contracted revenue company. AFN. https://agfundernews.com/artemis-acquired-by-iunu-in-continued-rollup-plots-agrifinance-offering

6.2.2.4 Boosting Pasture Productivity

Boosting pasture productivity involves activities such as fertilisation of pastures, rotational grazing, feed quality and veterinary care. Pasture fertilisation results in both greater yield and prevention of soil degradation over time. Rotational grazing prevents overgrazing, which leads to soil erosion and land degradation as well as improperly fed livestock. Livestock require nutrition to grow, and insufficient nutrition or improper feed can cause health issues or sub-optimal growth. Veterinary care is crucial to allow early detection of health issues and quick medical attention in order to prevent livestock mortality, which is both a waste of resources and immoral should disease cause unnecessary suffering to the animal. Animal health is also reportedly the number 1 cause for low milk production in the dairy industry.

While these may seem like more in line with traditional farming methods that are not suited to monetisation and further innovation, there are in fact startups that are digitising such processes and even integrating them with precision farming devices.

In the field of rotational grazing, True North Technologies' *Grasshopper*[146] system utilises a sensor unit, a plate meter and a data visualisation mobile app to allow farmers to determine the readiness of a paddock for grazing, as well as identify poorly performing paddocks for future . Vence is a company that utilises GPS and IoT devices to control livestock movement with audio cues, allowing the farmers to save costs on physical fences and labour for having to move the fences when grazing is to be rotated.

In the field of feed quality, Pure Cultures is a BioTech company that is developing prebiotics and probiotics using natural supplementation as agricultural laws begin to crack down on chemical use. Insect protein is also gaining popularity as livestock feed, particularly for aquaculture with companies such as InnovaFeed (backed by Temasek in a $140m round)[147], Nasekomo and Hexafly using more sustainable methods to increase protein intake for livestock. As a bonus, insects can also be fed food that would otherwise go to waste, making this a circular economy play as well.

146. True North Technologies – Home of Grasshopper, WeighRite and GrasslandTools. (n.d.). Moregrass. https://moregrass.ie/
147. InnovaFeed - Funding, Financials, Valuation & Investors. (n.d.). Crunchbase. https://www.crunchbase.com/organization/innovafeed/company_financials

In the field of livestock healthcare, the Netherlands' Connecterra's IoT motion sensor and AI algorithm helps dairy farmers monitor the health and well-being of their herds. It allowed farmers to detect issues reportedly 2 days earlier than any symptoms visible to the human eye would appear, resulting in a 50% decrease in antibiotic use[148]. Connecterra has raised USD8.8m in their 2020 Series B. The US' Farrpro specialises in creating products for the perfect environment for pigs, with heating and cleaning solutions, activity trackers and a data dashboard to ensure healthy growth and reduce disease.

As synthetic fertilisers contribute to greenhouse gases, many startups are also innovating to create natural, sustainable fertilisers that can accelerate crop growth and prevent soil degradation. Pivot Bio uses microbes to create nitrogen, and their fertilisers are already cost competitive with existing products, earning them a US430m Series D round led by DCVC and Temasek[149].

Clearly, there is still room for productivity and sustainability improvements in traditional agricultural practices. While some may say that the food of the future will no longer be soil-based (and thus require no fertiliser) or no longer use animal meat, it seems that that future is still far from reach. We cannot place all our hopes on a handful of far-off technologies, and such advanced "stop-gap" measures can help us alleviate several pain points in traditional architecture in the meantime.

Nevertheless, given that certain practices might be overhauled entirely in the future, it is crucial that startups offering such solutions and products be aware that farmers, food producers and investors are also highly cognizant of this. As such, technology that focuses on traditional agriculture cannot be high-cost capital expenditure that would deter forward-looking and risk averse stakeholders. This is a possible reason for the success of Pivot Bio in fundraising and sales despite VCs simultaneously placing faith into vertical farming, hydroponics and aeroponic technologies.

148. Bedord, L. (2020, February 19). Connecterra digitizing dairy to improve animal health and efficiency of cows. Successful Farming. https://www.agriculture.com/technology/livestock/connecterra-digitizing-dairy-to-improve-animal-health-and-efficiency-of-cows

149. Pivot Bio - Crunchbase Company Profile & Funding. (n.d.). Crunchbase. https://www.crunchbase.com/organization/pivot-bio

6.2.2.5 Reduce Enteric Fermentation

Cows are responsible for 40% of the world's methane emissions[150]. Considering that methane traps more than 25x more heat than carbon dioxide[151], reducing the amount of methane produced is paramount to slowing global warming. However, the world's demand for beef is only increasing, and the possibility of convincing consumers to stop for the environment is slim. Thus, scientists have found ways to reduce enteric fermentation, the process by which microbes in the digestive tract of ruminants (cows, sheep, goats and buffalo) ferment food and produce methane as a by-product.

There are 2 main technologies that target reduction in enteric fermentation: feed strategies and wearables.

Feed strategies refer to innovative feed ingredients that reduces methane emissions from enteric fermentation. These ingredients range from seaweed to garlic and citrus extract. Additionally, an important part of these feed strategies is having to ensure that the taste of the milk or meat produced is not affected by the novel ingredients introduced in their feed, otherwise farmers would be deterred. Mootral, which has raised USD7.6m in a corporate round after 3m in venture capital and 2.4m in equity crowdfunding, promises that its $50 per cow per year feed supplement causes a 38% reduction in methane and no effects on the taste of the cow. Another startup, Symbrosia raised USD7m in a Series A and states that their seaweed-based feed additive can achieve an 80% methane reduction, while costing more at 80c to $1.50 per animal per day[152].

Wearables are smart electronic devices that go over a cow's nose to filter the methane released and turn it into carbon dioxide, which is at least a relatively better option. This is effective as as much as 95% of methane created from enteric fermentation is released as burps[153]. The main advantages of wearables are that they can monitor methane emission, and be used in conjunction with feed strategies to further reduce emissions. Monitoring the eventual emissions is important because farmers can then use these numbers to produce carbon credits that can help offset the additional cost of feed or wearables.

150. CBS News. (2021, October 21). Genetics can determine how much methane cows release when burping and passing gas, researcher says. https://www.cbsnews.com/news/cows-methane-emissions-gas-study/
151. Importance of Methane. (2022, June 9). US EPA. https://www.epa.gov/gmi/importance-methane
152. Horton, C. (2022, June 23). Symbrosia raises $7 million to reduce livestock methane emissions. Reuters. https://www.reuters.com/markets/deals/symbrosia-raises-7-million-reduce-livestock-methane-emissions-2022-06-23/
153. Disruptive Technology Can Decrease Enteric Methane Emission | Feeding Intelligence. (n.d.). Cargill. https://www.cargill.com/feedingintelligence/disruptive-technology-can-decrease-enteric-methane-emission

One example design, created and manufactured by Zelp[154], is placed above cows' mouths. Once the wearable is in place, a set of fans powered by solar-charged batteries draws up the burps and traps them in a chamber with a methane-absorbing filter. When the filter is full, a chemical reaction turns the methane into carbon dioxide, which is then released into the air.

The main issue with enteric fermentation reduction solutions is that there is simply no business case for them until countries adopt carbon markets, and specifically agricultural carbon markets. Few farmers would be willing to take additional costs and more importantly, additional risk of getting their livestock unwell or having their meat taste different, for no conceivable commercial benefit. Likewise, few consumers are likely to pay extra to share this additional cost burden with farmers if there are no obvious taste or health benefits. Only when the authorities begin to monitor agricultural carbon output and quantify the reduction in greenhouse gas emissions that can be achieved through these solutions will farmers begin to see the merits of these solutions.

Nevertheless, feed solutions can actually be quite cost-effective, meaning that while they may not present material benefits in the immediate term, they also do not move the needle in terms of cost, making them viable for the sustainability-inclined farmer. For startups, a possible strategy is to qualify for government subsidies, making them a costless alternative to traditional feed for farmers. This is not an outrageous strategy by any means, considering major agricultural countries have long subsidised the livestock industry, with the most recent headliner being Russia's approval of a $150m subsidy on cattle feed[155].

154. Zelp. (n.d.). ZELP - Reduce methane emissions while improving animal welfare. https://www.zelp.co/
155. Vorotnikov, V. (2022, February 16). Russia to approve record-breaking subsidies on cattle feed. All About Feed. https://www.allaboutfeed.net/market/market-trends/russia-to-approve-record-breaking-subsidies-on-cattle-feed/

6.3 Decreasing Food Waste

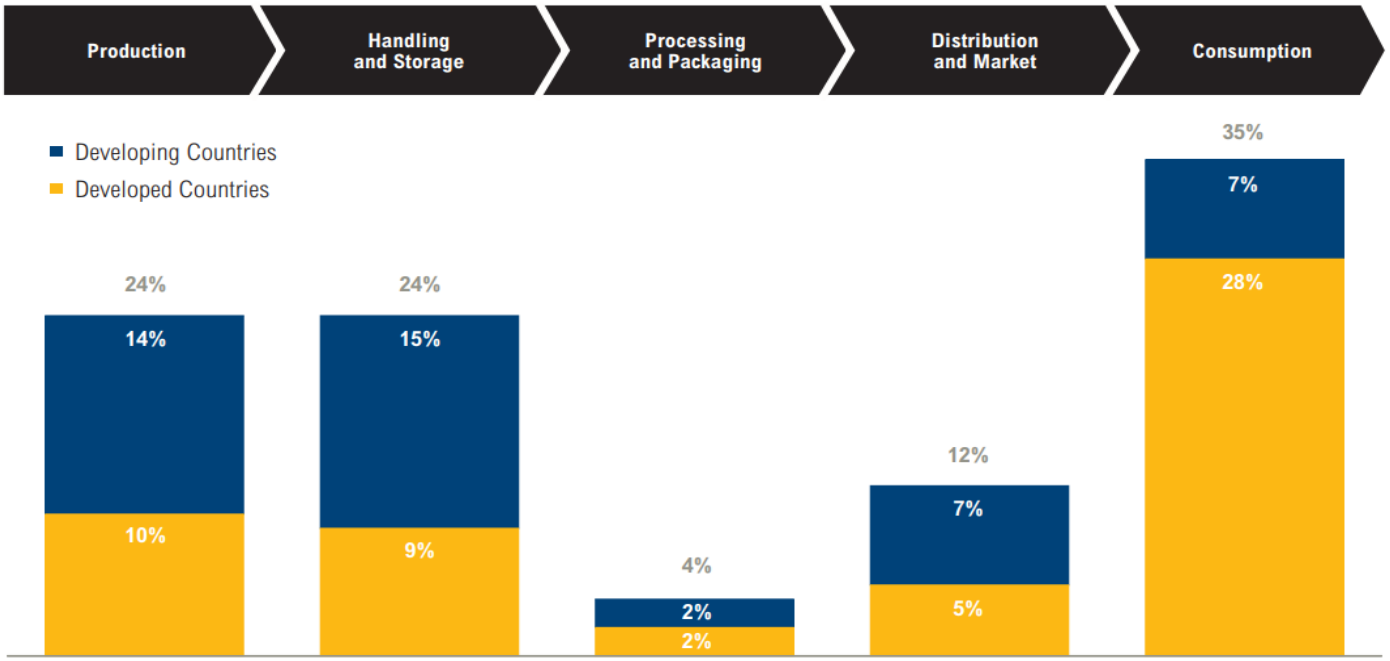
One-third of the world's food is wasted globally, accounting for 1.3 billion tonnes and approximately $1 trillion per year. That is a number sufficient to feed 2 billion people, or twice the number of undernourished people in the world[156]. Food waste represents a social cost when we consider the billions we could feed, and an economic cost when we consider the wasted investment, labour and resources that went into uneaten food, representing lost wages for farmers. But the environmental cost is large as well; the WWF estimates that 6-8% of global GHG emissions could have been avoided without food waste, when we consider the energy and water used to grow it, as well as the transportation of uneaten food and the additional GHG emissions while wasted food rots[157].

While many consider food waste as mainly that which consumers have discarded rather than eaten, there are two categories of food waste, according to the Harvard School of Public Health[158].

1. Food "loss" occurs before the food reaches the consumer as a result of issues in the production, storage, processing, and distribution phases.
2. Food "waste" refers to food that is fit for consumption but consciously discarded at the retail or consumption phases.

156. 5 facts about food waste and hunger | World Food Programme. (2020, June 2). World Food Programme. https://www.wfp.org/stories/5-facts-about-food-waste-and-hunger#:%7E:text=1.,worth%20approximately%20US%241%20trillion
157. Fight climate change by preventing food waste. (n.d.). World Wildlife Fund. https://www.worldwildlife.org/stories/fight-climate-change-by-preventing-food-waste
158. Food Waste. (2019, September 4). The Nutrition Source. https://www.hsph.harvard.edu/nutritionsource/sustainability/food-waste/

In developing countries, over 50% of waste occurs at the handling, processing and distribution stages, while in developed countries, more than 50% of waste occurs at stage 2, consumption.



Food Wastage: By Development and Stage of Supply Chain
Source: World Resources Institute[159]

According to the World Food Programme, lack of skills to handle and store harvested crops is one of the biggest challenges smallholder farmers face[160]. Even in larger habitations with more capable farms, lack of cold storage means rotting produce and poor roads mean less excess food can make it to those who need it. Notably, India loses 30-40% of its produce because retail and wholesalers lack cold storage[161]. And according to McKinsey, India is not alone, with 40% of all food loss occurring in the post-harvest agricultural supply chain, with numbers being even higher in developing economies in Africa, Asia and Latin America[162].

159. World Resources Institute. (2013, June). Reducing Food Loss and Waste. https://wriorg.s3.amazonaws.com/s3fs-public/reducing_food_loss_and_waste.pdf
160. 5 facts about food waste and hunger | World Food Programme. (2020, June 2). World Food Programme. https://www.wfp.org/stories/5-facts-about-food-waste-and-hunger#:%7E:text=1.,worth%20approximately%20US%241%20trillion
161. Erdman, J. (2018, December 2). We produce enough food to feed 10 billion people. So why does hunger still exist? Medium. https://medium.com/@jeremyerdman/we-produce-enough-food-to-feed-10-billion-people-so-why-does-hunger-still-exist-8086d2657539#:%7E:text=The%20world's%20farmers%20produce%20enough,this%20excess%2C%20hunger%20still%20exists
162. Feeding the world sustainably. (2021, May 27). McKinsey & Company. https://www.mckinsey.com/business-functions/sustainability/our-insights/feeding-the-world-sustainably

Food wasted at the post-production stages incur a cost for food distributors, while food wasted at harvest incurs a cost for farmers. As a result, solutions to food wastage pre-consumer are inherently revenue generating, meaning that the crucial factor is the cost of implementation. The following solutions: packaging innovations and coatings, upcycling food and logistics innovations all incur some level of cost, and as a result startups in these verticals must understand the unit economics of their customers - how much waste must a solution prevent in order to make the cost tolerable?

Food wasted at the consumer level is more difficult. There is no monetary benefit to a consumer who has already spent the money to buy the food, and too late realises that the food has spoilt due to improper storage conditions or gone over the expiry date, or they have simply purchased or prepared too much food. It might be possible for business model innovations to somehow monetize reduction of food wastage, but a more conceivable solution is for food upcycling or recycling services to be as convenient and cost-free to the consumer as possible. Otherwise, proper trash disposal habits have to be inculcated, such as in Korea, where in 2005, dumping food in landfill was banned, and in 2013 the government introduced compulsory food waste recycling using special biodegradable bags[163].

163. South Korea once recycled 2% of its food waste. Now it recycles 95%. (2020, February 8). World Economic Forum. https://www.weforum.org/agenda/2019/04/south-korea-recycling-food-waste/#:%7E:text=As%20far%20back%20as%202005,that%20helps%20encourage%20home%20composting

6.3.1 Packaging Innovation and Coatings

Packaging Innovation and Coatings typically attempt to reduce food wastage after the 3rd stage: processing and packaging, where such packings are used and coatings are applied. These innovations can protect the food, delay ripening, rotting of produce and spoilage of meat.

Due to the complex supply chains that facilitate the international movement of food from producer to distribution centre to consumer, freshly harvested food can be exposed to the environment for extended periods of time before being on the plate of the end consumer. Additionally, food can be damaged or wasted due to poor handling, such as spillage, stacking and packing force or storing food at improper temperatures and humidities. Packaging innovations can reduce these problems.

For example, Amcor's Eco-Tite R[164] is a PVDC-free and fully recyclable shrink bag, which is designed to maximise shelf-life, maintain food safety and reduce food waste. Amcor is a publicly listed global packaging company, which illustrates the possible exit opportunities and customers that startups in this space can have.The US' Hazel Technologies[165] raised $70m in their Series C in 2021 with a packaging insert that inhibits ethylene, which plants produce as they age, and recently set up an APAC HQ in Singapore with funding from EDBI. Hazel estimates that by Q4 2022, its products will be used with over 5.7m pounds of fresh produce.

One additional concern is the use of single-use plastics, which harms the environment directly due to its non-biodegradability, as well as indirectly due to having to remove such packaging from the wasted food if the food is to be disposed of properly. The process of removing food waste at an industrial scale can be expensive in terms of money and energy[166]. Innovation in the fields of reusable and recyclable food packaging is brewing to reduce the prevalence of single-use plastics in our food system.

164. Eco-Tite R: PVDC-free recyclable packaging for meat and cheese. (2021, May 3). Amcor. https://www.amcor.com/insights/blogs/eco-tite-shrink-bag-amcor
165. Hazel Technologies, Inc. (n.d.). Hazel Technologies. https://www.hazeltechnologies.com/
166. Soma, T. (2022, June 16). A bad wrap? Using packaging well to reduce food waste. Eco-Business. https://www.eco-business.com/opinion/a-bad-wrap-using-packaging-well-to-reduce-food-waste/

Companies that provide such goods or services include Norway's government-backed Packoorang[167], which provides circular, returnable packaging as a service as well as a reusable pallet wrapper, Singapore's own BarePack[168] which offers silicone or steel food containers for food delivery which consumers do not have to wash and can return to 150+ outlets or use their home pick-up services. The UK's CLUBZERO[169] is similar, providing reusable takeaway boxes that can then be returned or picked up for future use.

One interesting example is Chile's Algramo[170], which attempts to reduce wastage at the consumer level. It sells reusable, refillable, smart packaging with RFID technology and has refill dispensers that recognise the smart packaging. Working with Unilever and Nestlé, Algramo's technology can be applied not just to food, but any consumer packaged goods.

Our current state of food supply chains already implement many innovations to combat food waste, from basic packaging to cold chain storages. However, there is room for improvement. For example, "Intelligent Packaging" is defined by the European Food Safety Authority as "materials and articles that *monitor the condition of packaged food* or the environment surrounding the food"[171]. These solutions tend to use a multitude of technologies, from sensors to RFID tags. As the largest hurdle is that devices such as IoT sensors are expensive and usually reserved for high value density items, startups aimed at the food logistics sector have to utilise such technology in a very cost-effective manner.

Examples of products in this space include Innoscentia's IoT sensor[172] that monitors food status and shelf life in a dynamic way. They have partnered with Ynvisible, a dynamic display label startup, to create dynamic expiry date labels for food products, that are also RFID enabled to connect to smartphones and digital systems. This allows producers and distributors to safely store a large number of products without using a static expiry date that comes with a large safety margin, and consumers to more accurately know the real expiry date at purchase.

167. About us â ‟. (2021, December 15). Packoorang. https://www.packoorang.com/about
168. Singapore's #1 app-enabled reusable food delivery option. (n.d.). barePack.Co. https://www.barepack.co/
169. CLUBZERÃ˜, Formerly CupClub | Returnable Packaging for Takeaway. (n.d.). ClubZERO. https://www.clubzero.co/
170. Algramo. (2022, May 12). Home - Algramo. Algramo - Refill the Future. https://algramo.com/en/
171. Guidelines on submission of a dossier for safety evaluation by the EFSA of active or intelligent substances present in active and intelligent materials and articles intended to come into contact with food. (2009). EFSA Journal, 7(8). https://doi.org/10.2903/j.efsa.2009.1208
172. Dynamic shelf life labelling to reduce food waste. (n.d.). Innoscentia. https://www.innoscentia.com/

In order to eliminate the widely used plastic packaging used to protect produce from the environment, food coatings can be sprayed, dipped or brushed on produced to prevent or slow down gaseous diffusion. These also have the additional benefit of not requiring specialised capital machinery or skilled staff to package goods.

For example, Nabaco's Natuwrap uses natural polymers and a natural clay nanoparticle that self-assemble into a structure which acts as a barrier to the exit of water and the ingress of oxygen, while only being 1-3 microns thick and adds no taste, odour or change in colour[173]. Thailand's Eden Agritech develops similar products that work not just for fresh fruit but cut fruit as well[174].

Such products are not only cost-effective, they are also easily utilised at multiple stages: harvest, post-harvest, distribution and at retail centres. This means that there is a large possible customer base, depending on the customer's individual supply chain circumstances. If a farmer finds they lose some produce because they have to wait an extended period before delivery to a distributor/packager/consumer, they can apply the coating. The same applies if a distributor realises that they will have excess inventories for longer than usual or a retail supermarket finds their produce sitting unsold.

173. The Science. (n.d.). NABACO®. https://www.nabacoinc.com/the-science
174. EDEN AGRITECH |. (n.d.). Eden Agritech. https://edenagri.co.th/

6.3.2 Food Logistics

Considering that a majority of food waste occurs in between harvest and consumption, improvements in the supply chain are undoubtedly necessary for the reduction of food waste. After all, it is impossible for all food consumption to be limited to one's local farmer's markets, or even just domestic production. Complex, international logistics are and will still be necessary for food.

In 2014, a study was done on the Norwegian food supply chain, which is burdened by long travel times due to the existence of many fjords, intermittent road and bridge transportation halts in winter, and the use of ferries[175]. The study first categorises food into 2 types: products with fixed shelf life and those with age dependent deterioration rates. For example, canned food would be in the former and fresh vegetables in the latter. They also split the stages into in-warehouse, transportation, pre-store rejection, and in-store food waste.

	In-warehouse	Transportation	Pre-store Rejection	In-store
Fixed Shelf Life	Short remaining shelf life	Inappropriate handling	Short remaining shelf life	Short remaining shelf life
Age Dependent Deterioration Rates	Insufficient quality		Insufficient quality	Insufficient quality

Food Wastage: By Cause

Source: Norwegian University of Science and Technology[176] (table our own)

As we can see, most of the food wastage results from the same reasons. The researchers found that in warehouses, low visibility of inventory leads to high safety stock levels to prevent stock outs. This increases the number of fixed shelf-life goods with low remaining shelf life due simply to being unable to clear stock. For products with age dependent deterioration rates, this issue is compounded by the fact that there are no clear expiration dates to use for planning purposes.

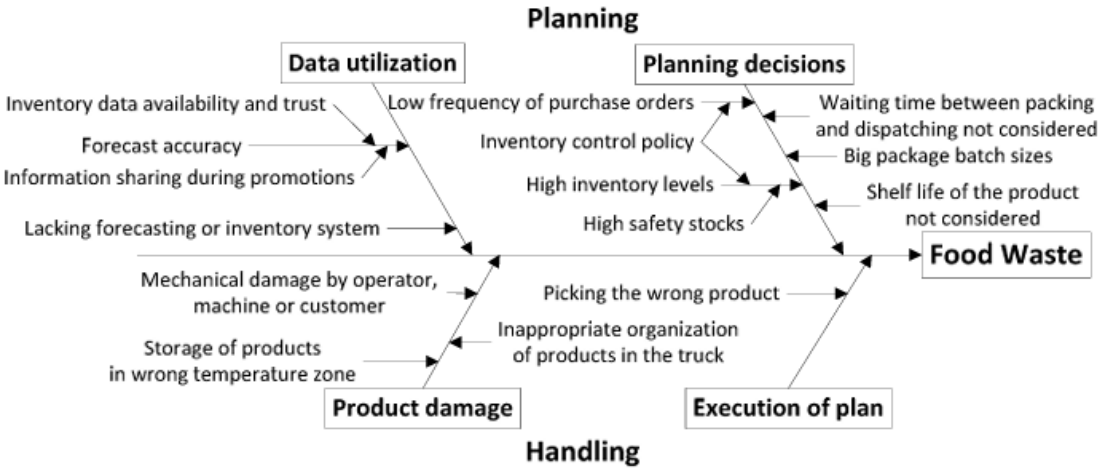
175. Chabada, L., Damgaard, C. M., Dreyer, H. C., Hvolby, H. H., & Dukovska-Popovska, I. (2014). Logistical Causes of Food Waste: A Case Study of a Norwegian Distribution Chain of Chilled Food Products. SpringerLink. https://link.springer.com/chapter/10.1007/978-3-662-44739-0_34?error=cookies_not_supported&code=09c93d5c-da71-40b8-93ad-550da4a735b2
176. Chabada, L., Damgaard, C. M., Dreyer, H. C., Hvolby, H. H., & Dukovska-Popovska, I. (2014). Logistical Causes of Food Waste: A Case Study of a Norwegian Distribution Chain of Chilled Food Products. SpringerLink. https://link.springer.com/chapter/10.1007/978-3-662-44739-0_34?error=cookies_not_supported&code=09c93d5c-da71-40b8-93ad-550da4a735b2

At the pre-store rejection stage, wholesalers or stores do not consider the eventual remaining shelf life of the goods ordered after the goods are placed at temporary waiting areas. They do this because stores tend to lack automated forecasting or inventory systems, and order goods imprecisely. Food then has a reduced shelf life or has deteriorated due to improper conditions and ageing by the time it reaches the store.

In-store food waste is where information about current stock levels and expiry dates are checked manually and forecasts are done based on experience, resulting in the lack of precision in the pre-store rejection stage.

Inappropriate handling in transportation, as well as in the warehouse stage, refers mainly to when pallets are organised before loading in temporary areas, and during loading in the trucks. In these periods, temperature sensitive goods are placed against the isolated partition panel between 2 temperature zones or against outer walls, exposing products to inappropriate temperature levels. This issue is exacerbated for longer delivery routes.

Therefore, the researchers have boiled it down to 4 underlying causes: planning decisions, data utilisation, execution of plan and damaged products.



Food Wastage: Underlying Reasons
Source: Norwegian University of Science and Technology[176]

Looking at the above table, startups can help reduce human error in planning via improved data collection methods such as using RFID or similar trackers, improved data visibility via ERP systems and data dashboards, improving forecast accuracy via use of AI and other data analytics and prevent handling errors using temperature sensors to monitor the condition of the food pallets.

In the data collection and tracking vertical, there are startups like China's Maka RFID, which offers RFID smart labels (that can be embedded in objects like cable-ties) for time-sensitive food products and analytics algorithms to reduce spoilage and misplacement by identifying freshness issues in the transportation process. Germany's Asynos goes against the grain of reusable packaging, and promises a disposable "1c IoT for trillion dollar supply-chain losses", and provides a complete tech stack to create a digital twin to reduce food loss.

In a much more specialised niche is Nanolike, a real-time silo monitoring solution that helps to simplify inventory and order management processes for farmers[177]. The traditional method of checking silo levels is for a worker to climb to the top of each silo and visually estimate how much was left, and forecast when to order more feed. Such an innovation would save them labour and time, and provide valuable data for the farmer to estimate costs and make better planning decisions as well as to feed producers who can provide automatic replenishment and vendor-managed inventory. This shows that such solutions are not limited to warehouses and distribution centres, but can be useful to any business that has to monitor inventory levels.

A company that is improving data visibility in the field of food transportation is publicly traded Samsara, which raised 700M in their Series F before their IPO resulting in a greater than $10B valuation in 2021[178]. They have created a platform for real-time visibility, cold-chain monitoring as well as compliance and driver safety, providing the sensors as well as the data monitoring dashboard to allow distributors to make better decisions in planning and reduce spoilage. Another is foodlogiq, now a customer of Whole Foods, Chipotle and Five Guys. that provides a supply chain transparency software focussed on food safety, sustainability and traceability. It has achieved a 90% reduction in time to locate tainted food, thus reducing waste during product withdrawals by 30-50%, and has raised $33m in its Series B[179].

177. Induportals Media Publishing. (2021, June 18). Nanolike digitizes silo monitoring for optimum efficiency. Food Process & Packaging Automation | EMEA. https://foodpackautomation.com/news/42401-nanolike-digitizes-silo-monitoring-for-optimum-efficiency
178. Samsara - Crunchbase Company Profile & Funding. (n.d.). Crunchbase. https://www.crunchbase.com/organization/samsara-2
179. FoodLogiQ: Food Safety, Traceability and Sustainability. (2022, May 20). FoodLogiQ. https://www.foodlogiq.com/

In the space of improving forecast accuracy, one company, Wasteless, uses an AI pricing engine to dynamically change prices of perishable goods as they near their due dates[180]. It tracks inventory data and expiry dates, while learning consumer behaviour for that specific store in order to markdown prices in a principled and rigorous manner, much unlike how store managers eyeball stock levels and reduce prices with guesswork.

The main advantage of such companies is that at large scale logistical operations, it almost always makes fiscal sense to reduce waste. As network availability increases and IoT devices become even cheaper to implement, the sheer amount of data that can be collected in order to increase visibility and better optimise processes makes such solutions very appealing and viable.

However, the issue with such solutions is that they are not suitable for regions which lack sophisticated supply chains, distributors or wholesalers. Recall that the issue of food wastage in the logistics chain is particularly bad in developing countries, where there is even a lack of refrigeration and road infrastructure, let alone cold chain transportation. This means that where these solutions are needed the most are also the regions which lack the sophistication needed to implement them. Regardless, these solutions would go a long way to reducing food waste in developed countries.

180. Wasteless. (n.d.). Wasteless. https://www.wasteless.com/?utm_source=hs_email&utm_medium=email&utm_content=2&_hsenc=p2ANqtz-_HWQnOqHC1v8KpEOl1xSvFqjKsjlJemYM2tlaYfcCd3yxrVVSbKSKSF1RVixdkLBRQViYvZP_YOiy2C2T5W8DphGl1cQ

6.3.3 Upcycled and Recycled Food

Regardless of how we improve the way we package and transport our food, we cannot reduce food wastage to zero. Food wastage can be recycled, whether in the form of compost or more recently, as feedstock for insect farms. They can also be upcycled, by startups using innovative methods to turn undesirable food waste into other food products, or even into other materials.

Due to its relative novelty, there is no single definition of upcycled foods. The Denver-based Upcycled Food Association defines it as ""Upcycled foods use ingredients that otherwise would not have gone to human consumption, are procured and produced using verifiable supply chains, and have a positive impact on the environment."[181]

The advantage of such startups is that obtaining the raw material tends to be cost-effective, especially if they can be collected from large food manufacturers and distributors. Some collect the food waste from retail centres or even direct from consumers, which would be more time consuming and more logistically difficult. Food producers and farmers are able to sell more of their product, not just discard those that are aesthetically lacking, and food businesses will be able to create more products from the same ingredients.

Many low-hanging fruit with simple processing methods have already been picked. WTRMLN WTR, that raised $3.8m in venture funding before exiting via acquisition by another juice company, simply took misshapen and cosmetically imperfect watermelons and turned them into juice[182]. Matriark Foods has raised 400k and takes farm surplus and fresh-cut remnants and turns them into vegetable stock concentrate.

Others utilise more complex methods to extract value from what is otherwise discarded. Austria's Kern Tec processes fruit pits, a completely unavoidable food waste, and turns them into edible products, such as the seeds themselves, food and cosmetic oils, protein powder and baking flour and many more[183] Comet Bio from the US, which has raised $22m in its Series C in 2021, uses a proprietary process to turn agricultural leftovers from farms into many different products such as prebiotic dietary fibre, sugar syrup alternatives and livestock feed supplements.

181. Schatz, R. D. (2020, May 23). How 'Upcycled' Ingredients Can Help Reduce The $940 Billion Global Food Waste Problem. Forbes. https://www.forbes.com/sites/robindschatz/2020/05/19/how-upcycled-ingredients-can-help-reduce-the-940-billion-global-food-waste-problem/?sh=f661a433ac9b
182. WTRMLN WTR. (2022, June 15). Wtrmln Wtr. https://wtrmlnwtr.com/product/wtrmlnwtr
183. Öle. (n.d.). Kern Tec. https://www.kern-tec.com/en/oele/

However, when it comes to food products that utilise upcycled waste, there is the possibility that consumers might not view this as particularly appetising. In fact, this study finds that people have a decreased willingness to pay for upcycled food compared to conventional alternatives[184], and that that effect decreased with rational messaging, but not with emotional messaging. This means that startups in this vertical can consider diversifying into products that are not directly consumed by humans, such as feed for animals or as ingredients rather than finished food products, or entirely non-food products, and that startups that do create foods for the consumer have to consider marketing the objective health and environmental benefits.

For example, Germany's Wood K Plus is experimenting using corn cobs to create lightweight walls, doors and furniture. A Thai company Kokoboard uses waste material from sunflower crops to produce boards from rice straw, peanut shells and rice husks for floors, ceilings and internal walls. Qwstion, a Swiss brand, has created BANANATEX, a durable fabric made from banana plants[185].

Additionally, it is difficult to imagine that individuals would be willing to pay a higher price for goods made from conventionally undesirable or inedible food waste than for the original good itself. However, obtaining said waste or byproducts, on top of the additional logistics and proprietary processing does not come cheap. This could indicate that the profitable products would be high value items that can command high prices or products created with cost-effective processes.

184. Bhatt, S., Ye, H., Deutsch, J., Ayaz, H., & Suri, R. (2020). Consumers' willingness to pay for upcycled foods. Food Quality and Preference, 86, 104035. https://doi.org/10.1016/j.foodqual.2020.104035
185. Axminenko, A. (n.d.). BANANATEX®. BANANATEX. https://www.bananatex.info/

6.3.4 Marketplaces

Marketplaces attempt to reduce food waste directly at the retail level, by sourcing produce that grocers or F&B businesses would otherwise reject or be unable to sell due to being misshapen, damaged or close to expiry: what is known as "suboptimal" food. The reason for needing a 3rd party platform for these sales is that retailers do not want to be seen selling produce that is aesthetically lacking, or goods nearing the end of their shelf life, and do not want to risk getting customers sick. By positioning themselves as eco-friendly, food waste reducing companies, their customer bases are specifically individuals who do not mind produce that might be misshapen or ugly, and are willing to take the risk of consuming out-of-date foods.

Such marketplaces have the distinct advantage of aggregating goods that individual farmers and producers might not otherwise be able to sell, and market them towards the exact customer base that would be willing to take them. They also do not suffer from the same worries as conventional food businesses about loss of reputation.

From a food waste perspective, this is also a better solution than upcycling for foods that are edible and only suffer from aesthetic defects. Upcycling is then perhaps a better solution for food waste that is unavoidable. Financially, this does not require the same amount of capital machinery that upcycling does, thus reducing cost and logistics, while selling goods that are still familiar to the average consumer, rather than derived powders or oils.

One such startup, Misfits Market has rescued more than 170 million pounds of food in 2020 alone, selling anything from vegetables to meat to pantry staples, and raised $425m in their Series C in 2021[186]. They work directly with farmers and food producers so as to rescue conventionally undesirable foods at the earliest possible time, and offer them to customers at up to 40% off grocery store prices. Another startup, UK's Too Good To Go also sources from retailers and restaurants. They saved 52 million meals in 2021 alone, raising $45m in the same year[187].

186. Hamstra, M. (2021, October 26). How Startups Are Monetizing the Booming Food Waste Business. Https://Www.Uschamber.Com/Co. https://www.uschamber.com/co/good-company/launch-pad/food-waste-startups
187. Too Good To Go - Funding, Financials, Valuation & Investors. (n.d.). Crunchbase. https://www.crunchbase.com/organization/too-good-to-go/company_financials

However, the fact is that these "rescued" foods are rejected by wholesalers or retailers for a reason. Consumers are picky with what they buy, and the sustainability-conscious individuals who would pay for goods that no one else wants are by definition a minority. If the mainstream consumer were accepting of aesthetically damaged or soon expiring goods, then savvy wholesalers or retailers would be selling those goods as well.

According to this study[188], the greatest consumer barriers to purchasing suboptimal food are "abnormal appearance" and "approaching expiration date", both of which are what defines suboptimal food in the first place. What is more damning is that "many consumers even remained reluctant to choose SF after tasting fruits with blemished appearance that were objectively optimal in taste"[189]. This indicates that consumers are not simply unaware of suboptimal food's qualities (that they still taste identical and are safe to consume), but that the aesthetic quality of produce is inherently desirable. This serves as yet another barrier to such marketplaces.

Additionally, as it stands right now, the only barrier to entry or moat for these sustainable surplus or food waste marketplaces are that they target a niche market that is undesirable for mainstream retailers. If their marketing is successful in increasing the number of consumers that are willing to pay for "rescued" food and the market becomes large enough, existing food retailers can easily move into the same space and offer the same products.

In order to improve their moat, suboptimal food marketplace companies have to create a public image of food safety and reliability. If they can convince consumers that they have a QC process that is perhaps more stringent than what mainstream retailers can provide, or that they have first pick of suboptimal food at the wholesale or even farm level, then they would have a strong competitive advantage that existing competitors would have to surmount.

188. Hartmann, T., Jahnke, B., & Hamm, U. (2021). Making ugly food beautiful: Consumer barriers to purchase and marketing options for Suboptimal Food at retail level – A systematic review. Food Quality and Preference, 90, 104179. https://doi.org/10.1016/j.foodqual.2021.104179
189. Symmank, C., Zahn, S., & Rohm, H. (2018). Visually suboptimal bananas: How ripeness affects consumer expectation and perception. Appetite, 120, 472–481. https://doi.org/10.1016/j.appet.2017.10.002

7. Evaluation and Conclusion

This paper aims to elucidate on the current conditions and viability of various innovative technologies and business models that, with private sector support and investment, can scale to solve hunger globally. The analysis done above can be summarised as follows.

	Current Viability or Viability Issues				
Solutions	Solutions that are viable/ viable if used at scale (for B2B)	(B2B)Solutions that do not generate profits for customers	Companies have yet to attain sufficient scale	Require further R&D	Lack consumer demand/ knowledge/ trust
	○ Precision Agriculture ○ Agricultural Biotechnology ○ Boosting Pasture Productivity ○ Food Logistics ○ Packaging Innovation and Coatings ○ Financing Small Farmers ○ Insuring Small Farmers	○ Reduce Enteric Fermentation	○ Alternative Proteins ○ Controlled environment ○ Upcycled and recycled food ○ Marketplaces for small farmers ○ Marketplaces for suboptimal food	○ Alternative Proteins ○ Agricultural Biotechnology ○ Cultivated Protein ○ Fermented Protein	○ Alternative Proteins ○ Agricultural Biotechnology ○ Upcycled and recycled food ○ Marketplaces for small farmers ○ Marketplaces for suboptimal food ○ Financing Small Farmers ○ Insuring Small Farmers

Food and agriculture form a key pillar in the support for all human life. As technology advances in all aspects of humanity, entrepreneurship needs to be the guiding force that augments such developments into forces that will benefit mankind at large. This research paper is by no means a definitive rulebook, because the combined potential of human ingenuity and entrepreneurship is boundless.