Cross-Fertilizing Innovation

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The AgriFoodTech Revolution Takes Root

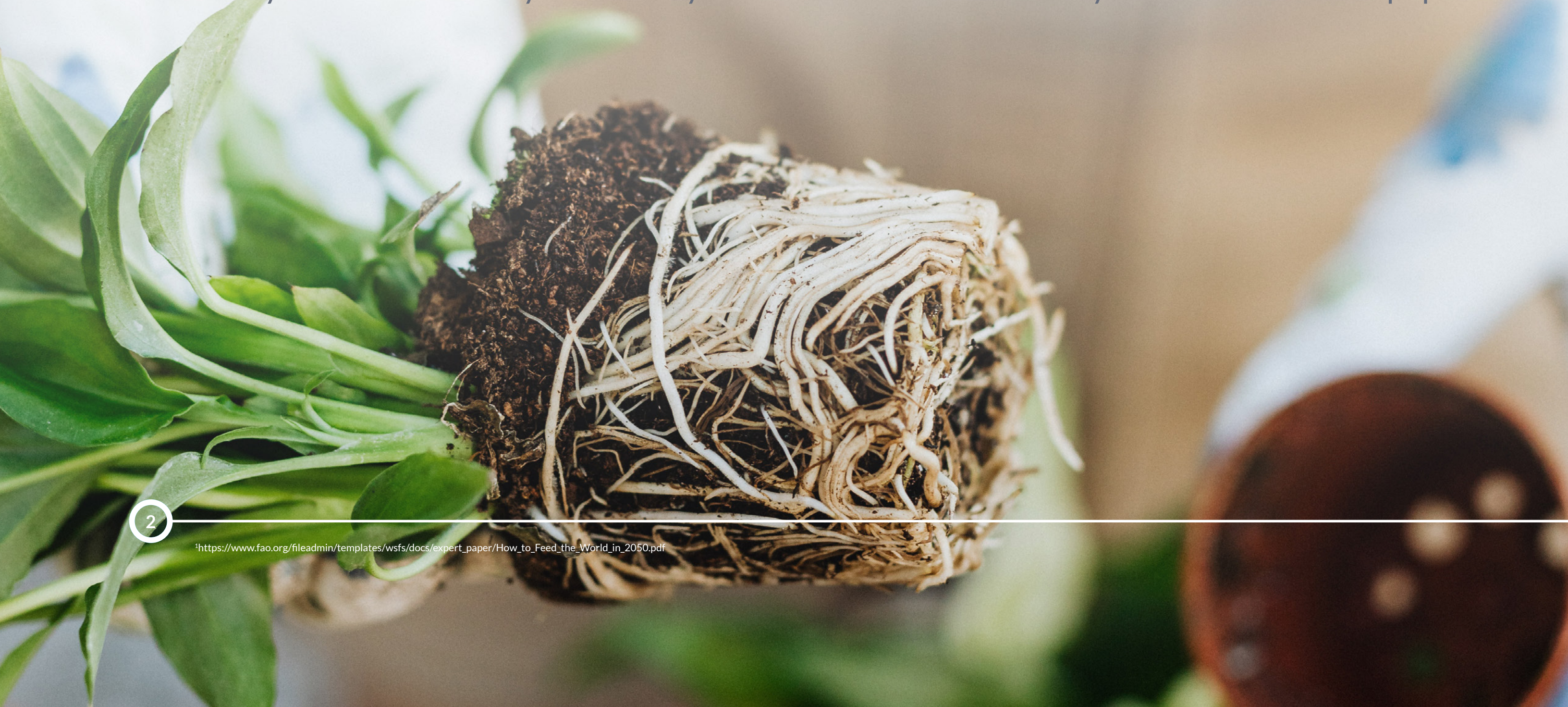
Agriculture has undergone a series of revolutions – amid near-relentless innovation and improvement – since plants and animals were first domesticated almost 12,000 years ago. Through selective breeding, fertilization, and mechanization, farmers have made huge advances. Over the last few decades, significant gains in productivity have been achieved in the United States and other developed countries through research-led development in animal husbandry, crop science, genetics, and veterinary medicine.

The AgriFoodTech revolution now taking root goes deeper and wider, integrating technology – as the term suggests – with agriculture in new ways while also disrupting food production.

Given the scale of the challenges facing the world's food supply systems, this revolution needs to be profound. By 2050 our planet will have more than 9 billion mouths to feed. As such, food production must increase by up to 70% to support this growing global population, according to the Food and Agriculture Organization.[1]

But the challenge is greater than just meeting burgeoning demand. Food systems around the world are major drivers of climate change, which in turn is accelerating the loss of productive land and biodiversity, as well as impacting productivity across the world due to weather variability, extreme events, invasive species, and shifting agroecosystem boundaries.

The new agricultural revolution must harness digital technology and scientific breakthroughs in multiple fields while satisfying changing consumer demands – if the world's food producers are to serve society and sustainability. We survey some of these revolutionary trends in this whitepaper.

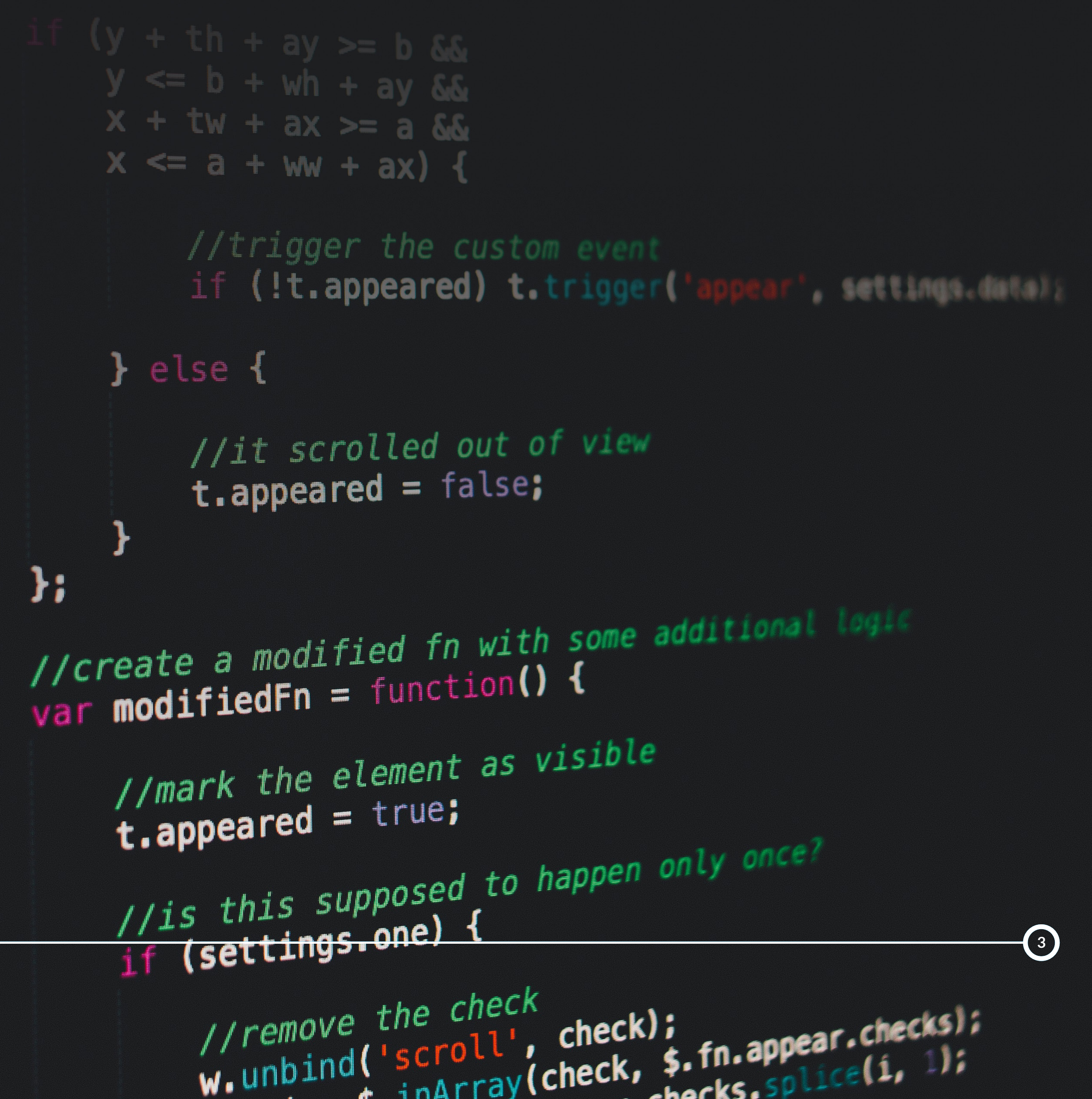


[1]https://www.fao.org/fileadmin/templates/wsfs/docs/expert_paper/How_to_Feed_the_World_in_2050.pdf

Internet of Things

Historically, farmers looked to the sky to gain the knowledge necessary for purposes of tending to their crop yields. Today, a different cloud—one that harnesses data and analytics is becoming critical to a farmer's daily operations

The Internet of Things (IoT) is the key not only to 'smart homes' – equipped with voice- or remote-controlled heating, lights and other devices – but also smarter farming. After years of promise that wireless connectivity would prove a transformational technology, the use of IoT is finally bearing fruit across industries, not least agriculture. For example, improved sensors with embedded software now combine with high processing capabilities, data analytics and web- or cloud-based computing to enable data-driven farming. Solar panel and battery technology have also facilitated the cross-fertilization of these technologies that drive precision agriculture.



Precision Agriculture

The integration of technology and farming sowed the seeds of precision agriculture in the 1990s, with the advent of geographical information systems and global positioning satellite technology. For the first time, complementary sensors and controllers on planting equipment ensured 100% application of seeds while avoiding overplanting, which reduces yields as well as wasting resources.

The sophistication of farming machinery from sprinklers to controls in the cab increased in the meantime, but today the technologies of the IoT are both accelerating and expanding precision agriculture across the globe.

Using applications developed for specific types of arable or livestock farms, sensors transmit data wirelessly to servers, via the cloud. Tailored reports, updates and alerts may be viewed on a smart phone or laptop, on site, or remotely. Farmers can monitor conditions on the ground in real time and make informed decisions to optimize inputs – saving on water, fertilizer, energy, and labor.

Given the technology can pay for itself in lower costs and higher outputs, this plug-and-play revolution can embrace smaller farms and potentially, in time, less developed countries.

Smarter Sensors

Research and development has continued improving the capabilities of sensors' hardware and software, and their applications.

Utah-based manufacturer Monnit[2] offers more than 80 devices for a multitude of commercial applications. These include the monitoring of agriculture and livestock, greenhouses, cannabis grow houses, cold chains, and food service. Temperature updates are provided every 10 minutes for users to view online.

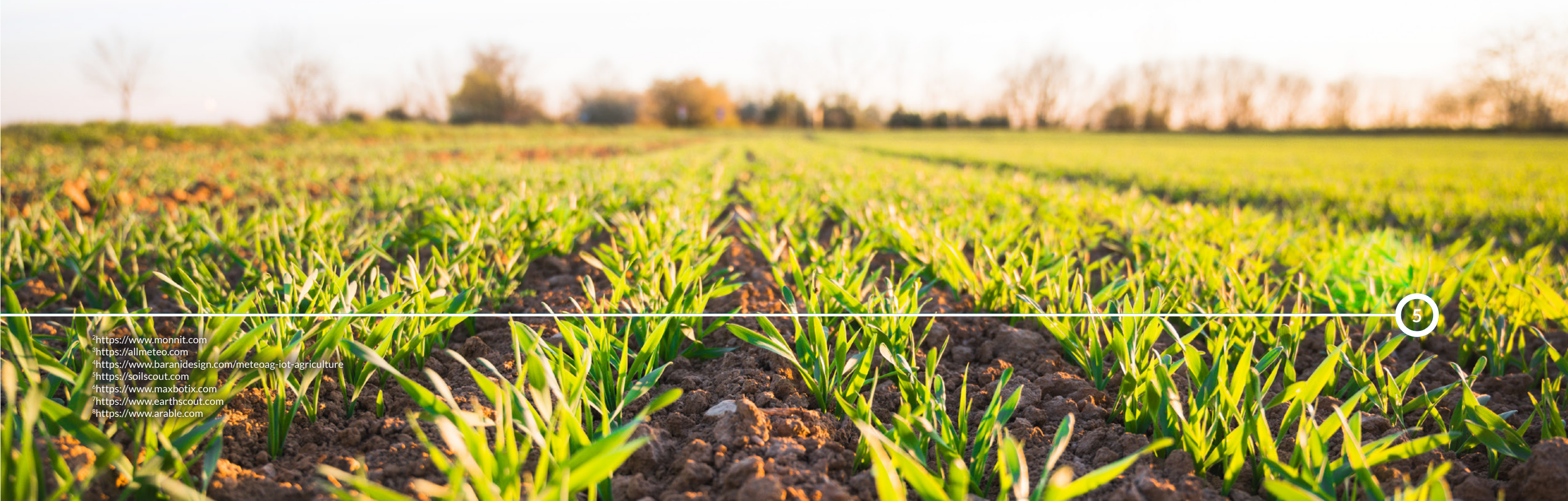
As well as gathering data above ground, including optical sensing to detect disease and pests, sensors also monitor soil conditions.

The Allmeteo[3] range of IoT sensors include open-data weather stations that measure outdoor micro-climates, and parameters such as temperature, humidity, dewpoint, frost-point, atmospheric pressure, solar radiation, sun duration, and precipitation. The New York company also distributes Barani Design[4] sensors for soil moisture and temperature, water tension, and leaf wetness.

Finland's Soilscout[5] uses permanently buried wireless sensors to report water and nutrient uptake in the root zone. Dynamic soil moisture variability maps reveal persistent root causes of yield variation.

Other specialists include Maxbotix Inc,[6] which manufactures sensors in Minnesota for developers, and EarthScout,[7] which offers above- and below-ground meters that send real-time field data on air and soil temperature, humidity, and salinity. Many growers with pivot or drip irrigation over-apply water and nutrients, the company says, claiming 30-60% savings for growers.

These and other sensors provide a platform for agricultural software and smart solutions, including predictive analytics based on historical data and modelling. For example, Arable,[8] with locations in USA, Brazil, and India, provides sensors to monitor more than 40 measurements relating to weather, soil and crop, as well as data analytics and integration with third-party sensors and any viewing device.



[2] https://www.monnit.com
[3] https://allmeteo.com
[4] https://www.baranidesign.com/meteoag-iot-agriculture
[5] https://soilscout.com
[6] https://www.maxbotix.com
[7] https://www.earthscout.com
[8] https://www.arable.com

Live Tracking

Livestock as well as crops are being tracked in real time.

Cowlar[9] – operating from Memphis and Pakistan – aims to streamline dairy production with an animal collar that monitors temperature and behavior and acts as an early alert system for detecting disease and managing stress.

Afflex Livestock Intelligence[10] offers timely insights into reproduction, health, and nutrition for dairy cows, heifers and calves, and beef cattle. With more than 500 million animals tagged worldwide every year, it also provides data as a service to the agricultural services and food production industries including veterinarian groups, genetics companies, food producers, and regulatory bodies. Founded in New Zealand, the global operator's large data sets are used for meta-analysis and benchmarking against performance indicators.

Artificial intelligence ("AI") can harness added value. In the Netherlands, Connecterra[11] says its use of AI drives efficiencies in dairy farming, applying predictive analytics to temperature readings from its Ida[12] system's sensors to identify optimal insemination windows and potential illnesses.

[9]https://www.cowlar.com
[10]https://www.allflex.global
[11]https://www.connecterra.io
[12]https://www.ida.io/en/

Drone Swarms

Precision agriculture is also leveraging advances in drone technology and robotics.

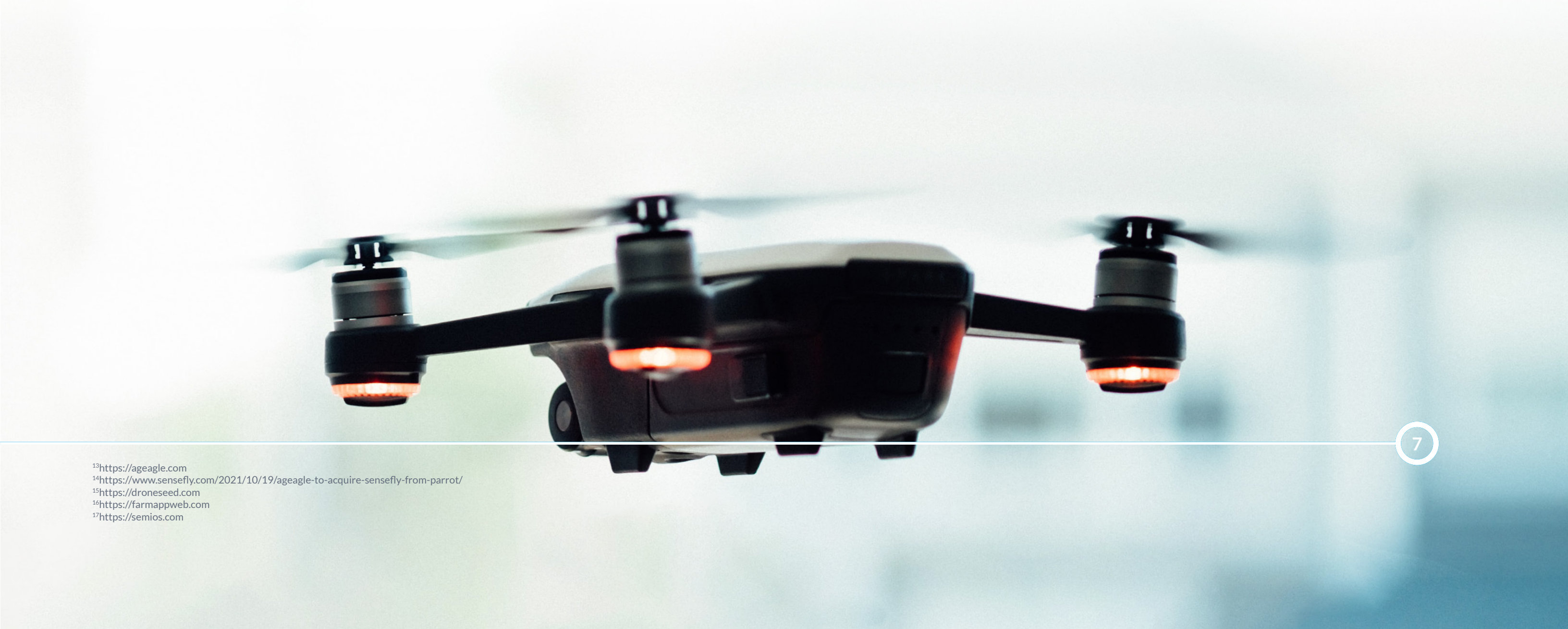
AgEagle[13] was founded in 2010 in Kansas to pioneer fixed-wing drones and data collection through aerial imagery and analytics. Its subsidiary, MicaSense, develops multispectral sensors for vegetative analysis, gathering data on plant stress, growth stages, diseases, and nutrition deficiencies. AgEagle also swooped to acquire SenseFly,[14] which uses similar technology to monitor crop growth, gathering insights for predicting yields and drainage planning. This is said to boost US corn growers' revenue by nearly $500 an acre. Other claims include: a 10% average increase in crop yield on 300 French farms, 20% lower nitrogen input on a Russian agrarian institute's wheat fertilization project, and a 17% boost to a Spanish vineyard's output.

Drones can lighten the load on labor too. DroneSeed[15] has Federal Aviation Administration (FAA) approval to operate heavy-lift drone swarms to reforest land. The Seattle company's novel technology allows a single pilot to operate five aircraft carrying up to 57 pounds of seed vessels. Each drone can plant three quarters of an acre per flight.

Automation of tasks such as irrigation and pest control is a natural progression for data-driven precision agriculture.

With bases in Colombia and Australia, Farmapp[16] has developed an integrated pest management software that combines scouting performance, pests, and fumigation applications with sensors and other IoT devices to automate management of crops and greenhouses.

Vancouver-based Semios[17] manages tree fruit, nuts, and vines, with two million sensors installed across the USA, Canada, Australia, and Europe. As well as informing decisions on watering and plant stress, the platform also includes automated camera traps, spray timing tools, and variable pheromone release to disrupt pest mating that is customized by site.



[13] https://ageagle.com
[14] https://www.sensefly.com/2021/10/19/ageagle-to-acquire-sensefly-from-parrot/
[15] https://droneseed.com
[16] https://farmappweb.com
[17] https://semios.com

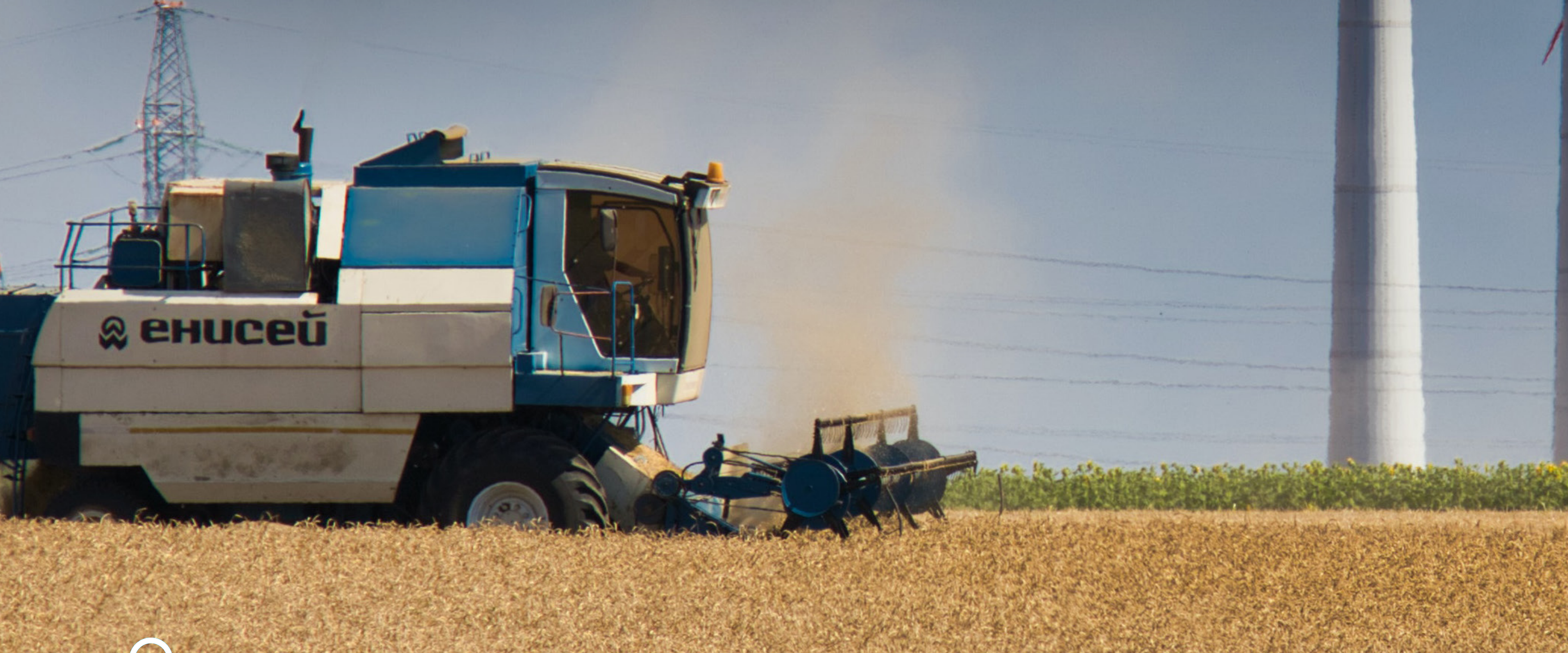
Tech Integration

Crop losses due to disease is estimated at $60 billion a year, according to Syngenta.[18] Headquartered in Switzerland, the global agricultural science and technology provider, which has acquired other digital farm management platforms such as Strider and Cropio, is targeting fungal diseases. In collaboration with Insilico Medicine,[19] which applies AI and deep learning in the pharma and biotechnology sectors, they aim to tackle the growing problem of fungicide resistance through genetic modification and chemistry.

Integration of these various technologies (and providers) within agriculture will accelerate, given the pressure to produce more food from less inputs and land in addition to driving greater efficiency and transparency through supply chains.

Bushel,[20] based in Fargo, North Dakota, absorbed Michigan's FarmLogs[21] in June 2021 to create a seamless digital management system for the grain supply chain. Farmlogs promises to standardize and connect data in the 'siloed middle' of the food and agriculture supply chain to save businesses both time and expense in addition to creating a 'grain passport' automating verification for identity preservation, crop insurance, and sustainability.

The global smart agriculture market is projected to triple in value by 2025 to more than $115,00 million.[22] North America dominates – its share stood at 35% in 2016 – but adoption is growing fast in other regions, especially Asia. By application, yield monitoring is the most valuable, while precision farming accounts for almost half (49%) of the market and is expected to grow the most rapidly (at around 13% a year).



[18]https://www.syngenta.com/en
[19]https://insilico.com
[20]https://bushelpowered.com
[21]https://bushelpowered.com/2021/06/16/bushel-inc-acquires-farmlogs/
[22]https://www.globenewswire.com/news-release/2018/03/22/1444017/0/en/Global-Smart-Agriculture-Market-Will-Reach-USD-15-344-million-by-2025-Zion-Market-Research.html

Profiting the Planet

The growth of tech-savvy agriculture should be beneficial not just for producers' profits, but also the planet. Smart agriculture and precision farming support sustainability by conserving water resources, reducing environmentally harmful nitrate run-off, and perhaps most critically, nurturing soil health.

For example, CropX[23] is another 'AgAanalytics' platform said to have demonstrated 50% water savings across different crops and a 20% increase in yields. The Israeli company signed a deal with PepsiCo in summer 2021 to help its Mexican potato growers achieve similar savings while also improving soil health and lowering greenhouse emissions.[24]

Similarly, Crop Performance[25] – based in Cambridge, UK – provides geospatial analytics enabling growers and the food supply chain not only to increase crop yields and conserve resources, but also to monitor the ecological impact of growing safe and healthy food. The company's system quantifies the environmental impact of food production at the level of the field, farm, and catchment.

Fertilizer provides another example of the potentially significant environmental benefits of smarter farming. It is difficult for growers to strike the right balance between wastage and yield. Use of nitrogen-based fertilizer has risen six-fold over the last 50 years, and over-fertilization is responsible for around 12% of the once-arable land globally that has been rendered unusable, according to Imperial College London.[26]

Soil sampling and laboratory analysis is too expensive and slow to provide actionable information. Instead, smart AI-enhanced sensors developed by the Imperial College London's Department of Bioengineering measure levels of ammonium compound in the soil. These readings are combined with weather and other data and soil measurements for machine learning analysis. The system then predicts total nitrogen content up to 12 days ahead, so farmers can optimize fertilization timing and inputs.

Washed by rain into waterways, fertilizer deprives aquatic life of oxygen, leading to algal blooms and lower biodiversity. Excess nitrogen fertilizer also releases nitrous oxide into the air, a greenhouse gas 300 times more potent than carbon dioxide. Precision agriculture combats these problems and other emerging technologies can drive further efficiencies that will benefit planters and the planet in years to come.

[23] https://cropx.com
[24] https://www.prnewswire.com/news-releases/pepsico-chooses-cropx-to-achieve-global-sustainability-goals-301362544.html
[25] https://crop-performance.com
[26] https://www.openaccessgovernment.org/soil-sensors/128613/

Climate-Smart Agriculture

Methane gas from livestock is another powerful driver of global warming.

Livestock production and agriculture together are responsible for a quarter of the world's global greenhouse gas emissions, and they are also the main causes of deforestation. This vicious cycle of pollution, land degradation, and global heating further drives biodiversity loss and the rise of zoonotic diseases (such as COVID-19).

The global challenge for agriculture is not just about boosting productivity – consuming less resources to produce more food for a growing population – but also sustainability. As defined in US law,[27] a sustainable agricultural system must satisfy people's nutritional needs and enhance the environment, while maintaining the economic viability of farms.

Smart technologies can support this shift, but sustainability requires fundamental and systemic changes to agricultural and farming practice. The World Bank calls this 'climate smart agriculture'. More specifically, the term is defined as "an integrated approach to managing landscapes – cropland, livestock, forests and fisheries – that addresses the interlinked challenges of food security and accelerating climate change".[28] Climate-smart agriculture promises a triple win: increased productivity, enhanced resilience, and reduced emissions.

Committed to halving carbon emissions economy-wide by 2030, the Biden administration also adopted the term. But rather than impose federal targets on the industry, increasing financial incentives for farmers to adopt climate-smart agricultural practices is more likely to garner bi-partisan political support.[29]

[27] US Code Title 7, Section 3101
[28] https://www.worldbank.org/en/topic/climate-smart-agriculture
[29] https://www.politico.com/news/2021/04/22/climate-change-biden-agriculture-484351

Sustainable Practices

Such eco-smart practices have been identified through decades of scientific research – notably in agroecology – the science of managing farms as ecosystems. By working with nature rather than against it, farms can avoid damaging impacts without sacrificing productivity or profitability.[30]

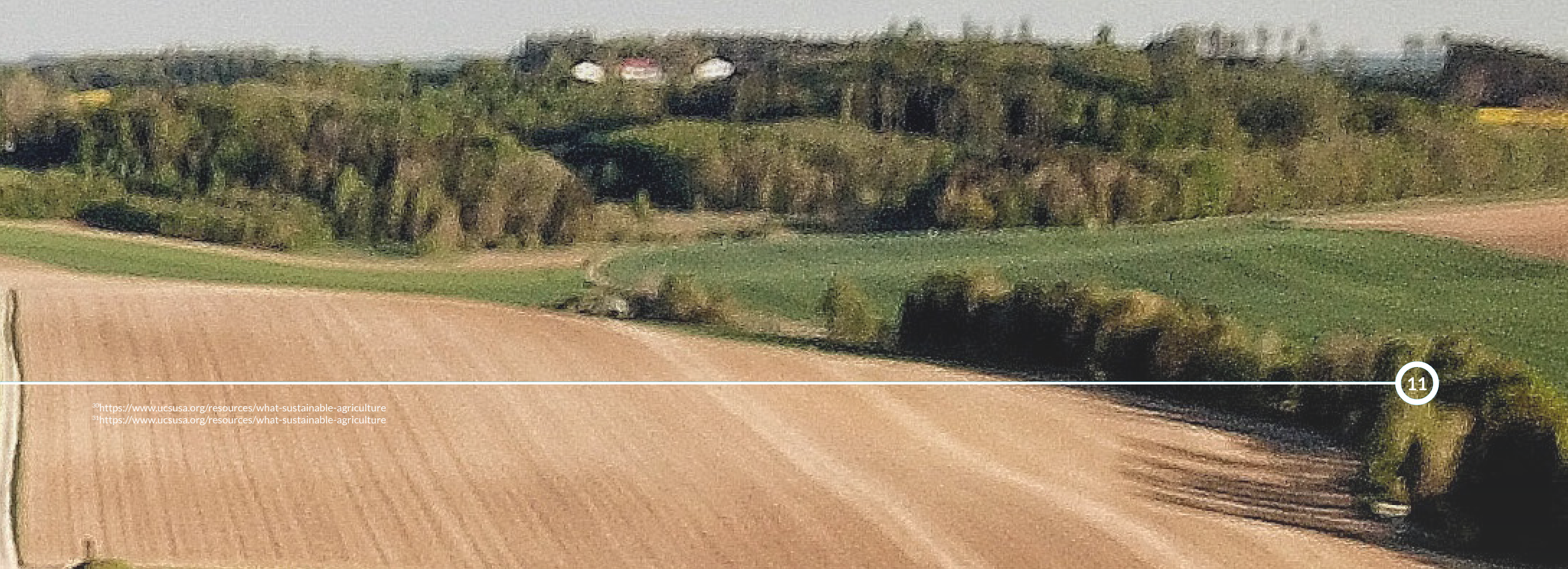
Many sustainable practices involve time-honored farming methods, such as crop rotation.[31] Monoculture tends to degrade soil and biodiversity. Planting a variety of crops can enhance soil health and pest control. Crop diversity may involve intercropping (growing a mix of crops in the same area) or complex multi-year crop rotations.

Cover crops, like clover or hairy vetch, are planted off-season when soils would otherwise be left bare. These and 'alley' crops also protect and build soil health by preventing erosion, replenishing nutrients, and limiting weed growth, reducing the need for herbicides.

Traditional plowing can cause soil loss. No-till or reduced-till methods, inserting seeds directly into undisturbed soil, reduces erosion and improves soil health.

Integrated pest management, using mechanical and biological controls, can keep pest populations under control while minimizing use of chemical pesticides.

A growing body of evidence also shows that a smart integration of crop and animal production – silvopasture rather than the specialized, industrial approach – can lead to more efficient, profitable farms.



[30] https://www.ucsusa.org/resources/what-sustainable-agriculture
[31] https://www.ucsusa.org/resources/what-sustainable-agriculture

Agroforestry practices – introducing trees or shrubs in pastures and arable farms – can provide shade and shelter to protect plants, animals, and water resources, while offering additional income.

More holistic management of farms and landscapes – including uncultivated or less intensively cultivated buffer zones — can enhance their role in controlling erosion, reducing nutrient runoff, and supporting pollinators and biodiversity.

Sustainable practices – which can also be described as regenerative agriculture – are able to sequester carbon, increase resilience to climate change, improve the water cycle, and boost output from healthier soil and crops.

By eschewing chemicals and fertilizers, and promoting composting, organic farming is also part of the sustainable solution to food production. The organic movement's growth shows the shared appetite among consumers and producers for cleaner, more natural foods. Sales of organic food in the US grew by 12.8% in 2020 to more than $56 billion.[32]

[32] https://www.statista.com/topics/3480/organic-farming/#dossierKeyfigures

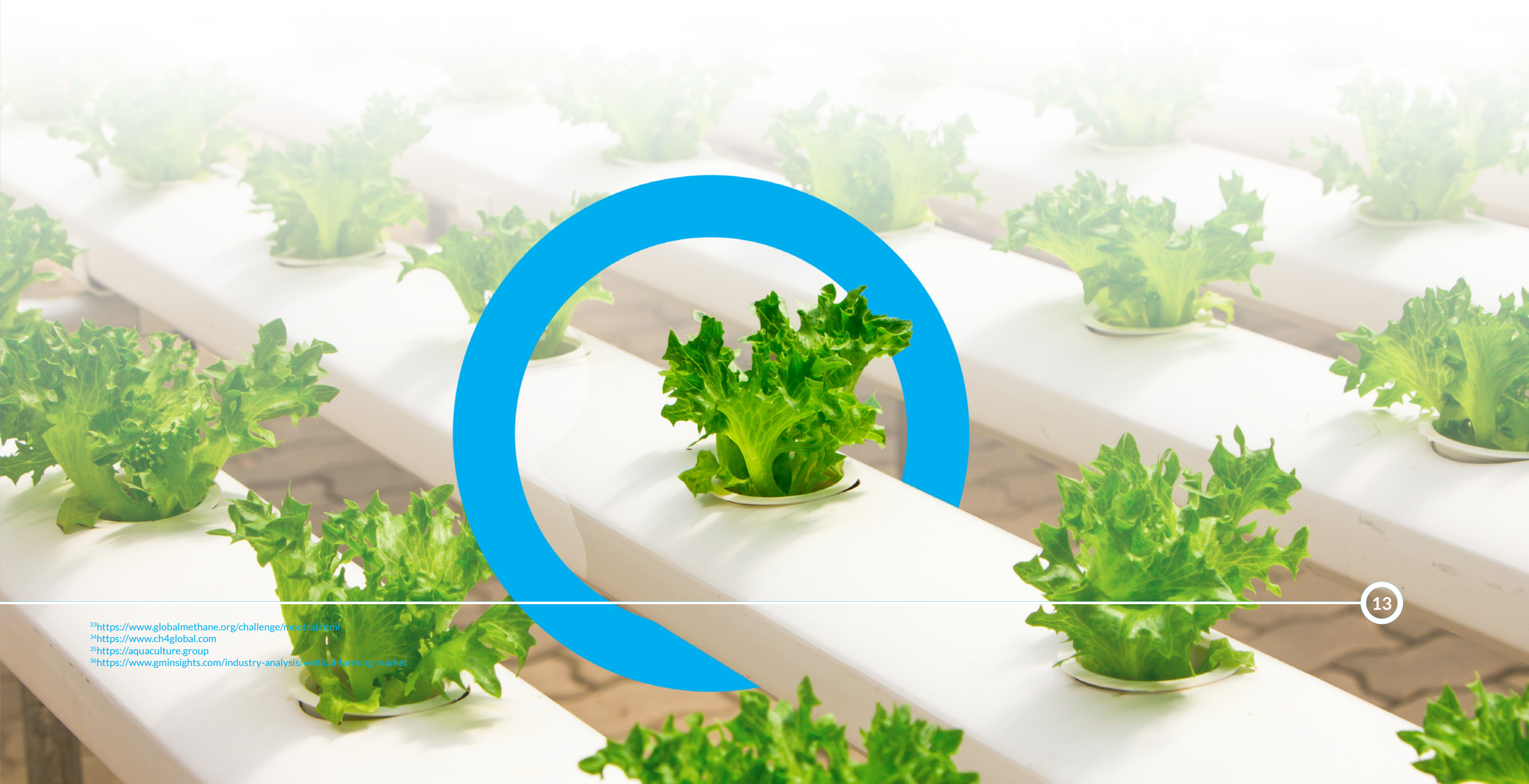
Diverse Solutions

The reality is that, given the scale of the global food and climate challenge, the agricultural revolution requires numerous sustainable solutions to suit different terrains, markets, and socio-economic circumstances.

Some solutions will involve adaptations to make existing practices more sustainable. In some areas, for example, rotation can be applied to grazing lands, so herds are moved between pastures to improve soil fertility and allow grasses to re-grow.

Livestock feed additives could mitigate methane emissions. Mootral, an Anglo-Swiss agritech start-up, claims that cows fed with its supplement – made from garlic powder and citrus – burp 38% less methane in real farm conditions.[33] Hopes are even higher for asparagospis, an abundant red seaweed, that in trials has almost eliminated methane from beef and dairy cattle and sheep. Several groups including CH4Global[34] and Singapore's Aquaculture Group[35] are working to commercialize this inexpensive marine bio-product, which may also improve protein conversion and cut costs.

More veg and fruit can be cultivated closer to market and even on urban land in vertical farms using hydroponics, aquaponics, or aeroponics. Growing plants in controlled indoor environments anywhere eliminates the need for pesticides and uses a fraction of the soil and water required by traditional horticulture. Valued at $4.5 billion in 2020, the vertical farming sector is projected to grow by 23% a year to reach $19 billion by 2027.[36] Asia, North America, and Europe are seen as the fastest-growing markets.



[33] https://www.globalmethane.org/challenge/mootral.html
[34] https://www.ch4global.com
[35] https://aquaculture.group
[36] https://www.gminsights.com/industry-analysis/vertical-farming-market

Plant-Based Growth

Spreading climate-smart practices will allow more food to be produced in a sustainable way, while shrinking agriculture's carbon emissions. However, the carbon savings will be outweighed by livestock's massive carbon hoofprint unless there are wider systemic changes in the world's food markets and systems.

Global meat production more than tripled in 50 years (to 340t million in 2018),[37] and the United Nations has projected it to double again by 2050.[38]

Livestock is not only the most carbon-intensive protein source – methane from cattle is 28 times more potent as a greenhouse gas than carbon dioxide – it is also the most inefficient in terms of feed conversion, energy, land, and water use.

While half the world's habitable land is used for agriculture, already, 80% of this is for livestock, dairy, and animal feed. Less than half (48%) of the cereals grown worldwide are for human consumption; 41% is fed to animals, and 11% used for biofuels. In the US, the human share is just 10%.[39]

The sustainability argument for feeding plant protein to people rather than animals is compelling.

Counterintuitively, agriculture will need less land, not more, to produce this plant-based food. The total would fall by 75% – from 4 to 1 billion hectares – in the hypothetical scenario of a global vegan diet. Even if the two-thirds of pastureland not suitable for arable farming were returned to nature to support biodiversity, the world can capably grow enough nutritious food for everyone on the cropland left.

This is because meat production is inherently inefficient in terms of land use, inputs, and protein. It takes 100 times as much land to produce a gram of beef or lamb compared with peas or tofu. Beef has an energy efficiency of just 2%: for every 100 kilocalories in cattle feed, 2 kilocalories ends up on the plate. The efficiency of protein conversion is only slightly better: for beef, it is 3.8%; rising to 8.5% for pork, and 19.6% for poultry. Whole milk and eggs score around 25%.[40]

Yet the taste for meat is embedded, and that appetite will continue increasing with rising incomes in the developing world. Alternative proteins that mimic meat can provide at least part of the answer. Demand has been growing strongly over the last decade for substitutes – from meat and fish to milk and eggs.

[37] https://ourworldindata.org/meat-production
[38] https://gfi.org
[39] https://ourworldindata.org/land-use-diets
[40] https://www.sciencedirect.com/science/article/pii/S0959378016302370

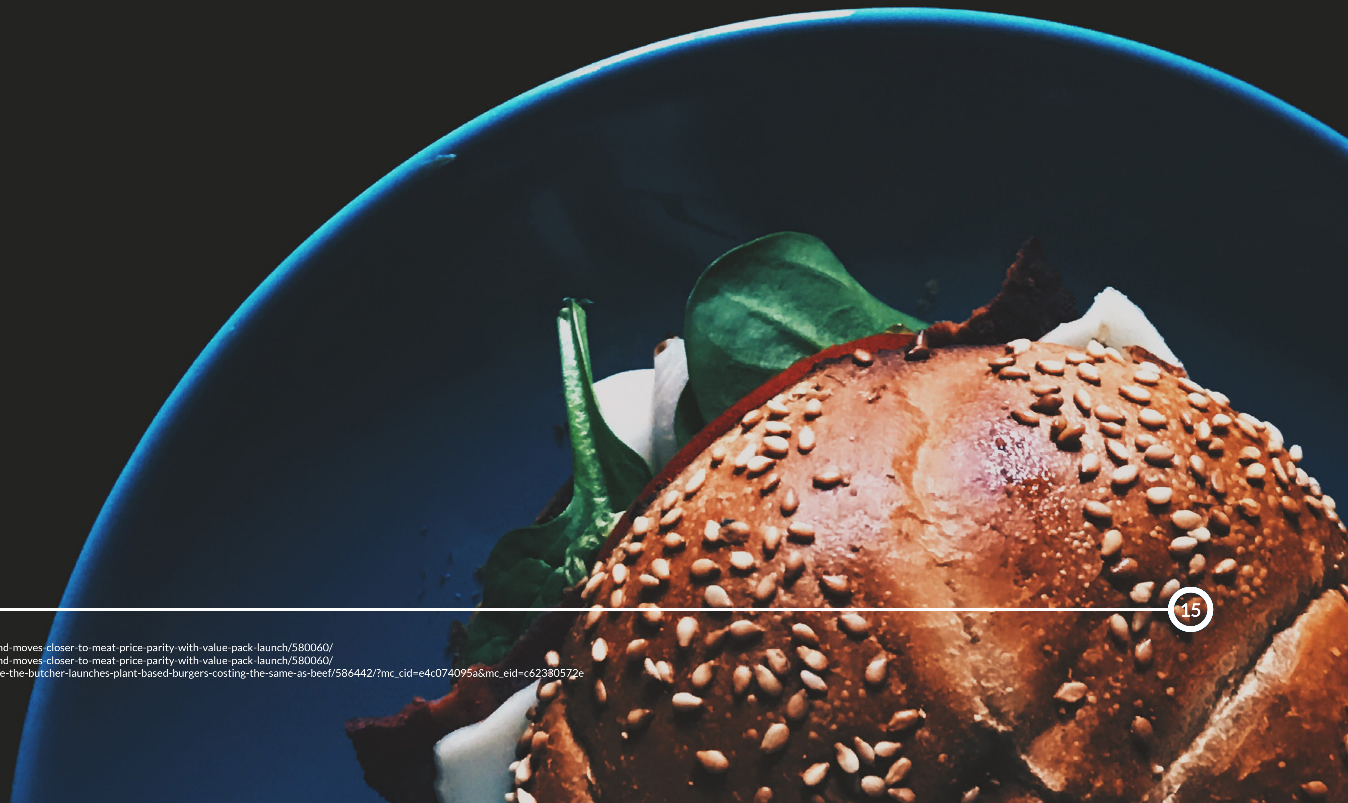
In 2020, US sales of plant-based foods grew by 27%, almost twice the rate of the total food retail market, according to the Good Food Institute (GFI).[41] Plant-based ‘meat’ substitutes leapt by 45% to $1.4 billion. The global market was worth $4.2 billion, up 23.5%.

Around the world, more than 800 companies and brands are primarily focused on plant-based alternatives, or have a business unit or product line dedicated to replacing animal products.

The North American food producers that pioneered plant-based alternatives have taken alt-proteins into mainstream stores and fast-food outlets, and are now pushing prices closer to parity. Impossible Foods,[42] Beyond Meat,[43] and Before the Butcher[44] have all made significant adjustments to overcome this major barrier to wider adoption.

The GFI, which promotes meat protein alternatives (including cultured meat and fermentation), has argued that this industry attracts less than its fair share of the overall R&D investment in carbon-neutral solutions. But 2020 was a record year for investment in the plant-based space, with a healthy $2.2 billion invested – almost half of all capital generated since 1980. The number of new investors increased by 44% to 196, including major multinationals and conventional meat companies as well as foodtech start-ups.

Ongoing plant-based innovations range from crop breeding and optimization to end-product manufacturing. There is also an increasing focus on products that reproduce the fibrous muscle textures of meat cuts, through developments in shear-cell technology, spinning, and 3D printing.



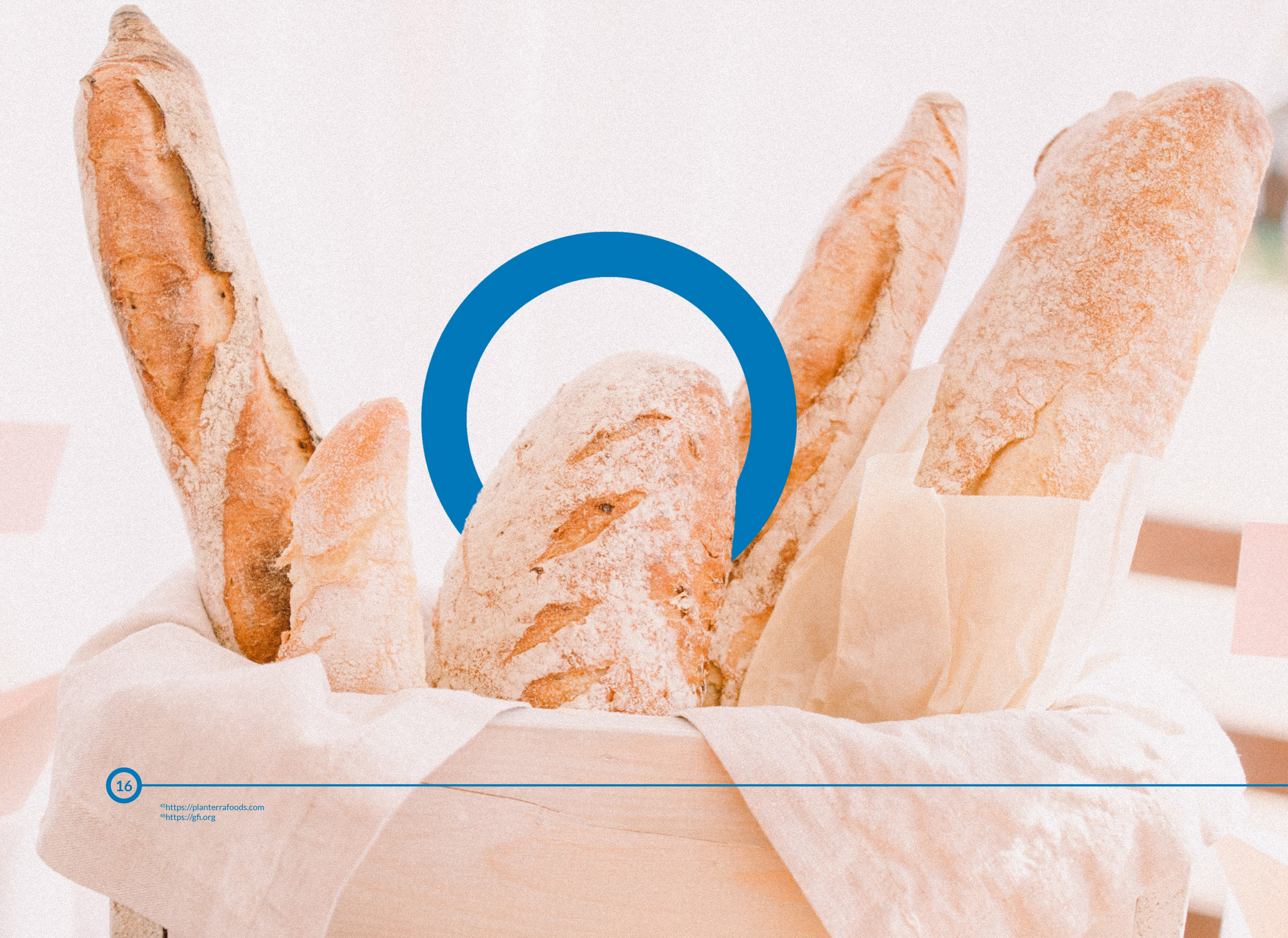
[41] https://gfi.org
[42] https://www.fooddive.com/news/beyond-moves-closer-to-meat-price-parity-with-value-pack-launch/580060/
[43] https://www.fooddive.com/news/beyond-moves-closer-to-meat-price-parity-with-value-pack-launch/580060/
[44] https://www.fooddive.com/news/before-the-butcher-launches-plant-based-burgers-costing-the-same-as-beef/586442/?mc_cid=e4c074095a&mc_eid=c62330572e

Fermenting Change

Fermentation-derived protein and cultivated meat are also championed as better for the planet and people.

From beer to bread, and yogurt to Indonesian tempeh, fermenting food is ancient. Modern processes using mycelium, microalgae, microbes, and fermented plant proteins have the potential to match meat's taste and nutritional value, but without cholesterol, antibiotics or hormones. Fermentation also offers the advantage of using low-value agricultural by-products and minimizing waste. Colorado-based Planterra Foods,[45] for example, ferments rice and pea protein with shiitake mycelium for its plant-based Ozo meat lines.

Despite attracting some $587 million in 2020 – more than half total investment to date – the protein fermentation sector remains in its infancy.[46] Exploitation of the technology at scale will depend on the development of efficient bioreactor designs.



[45] https://planterrafoods.com
[46] https://gfi.org

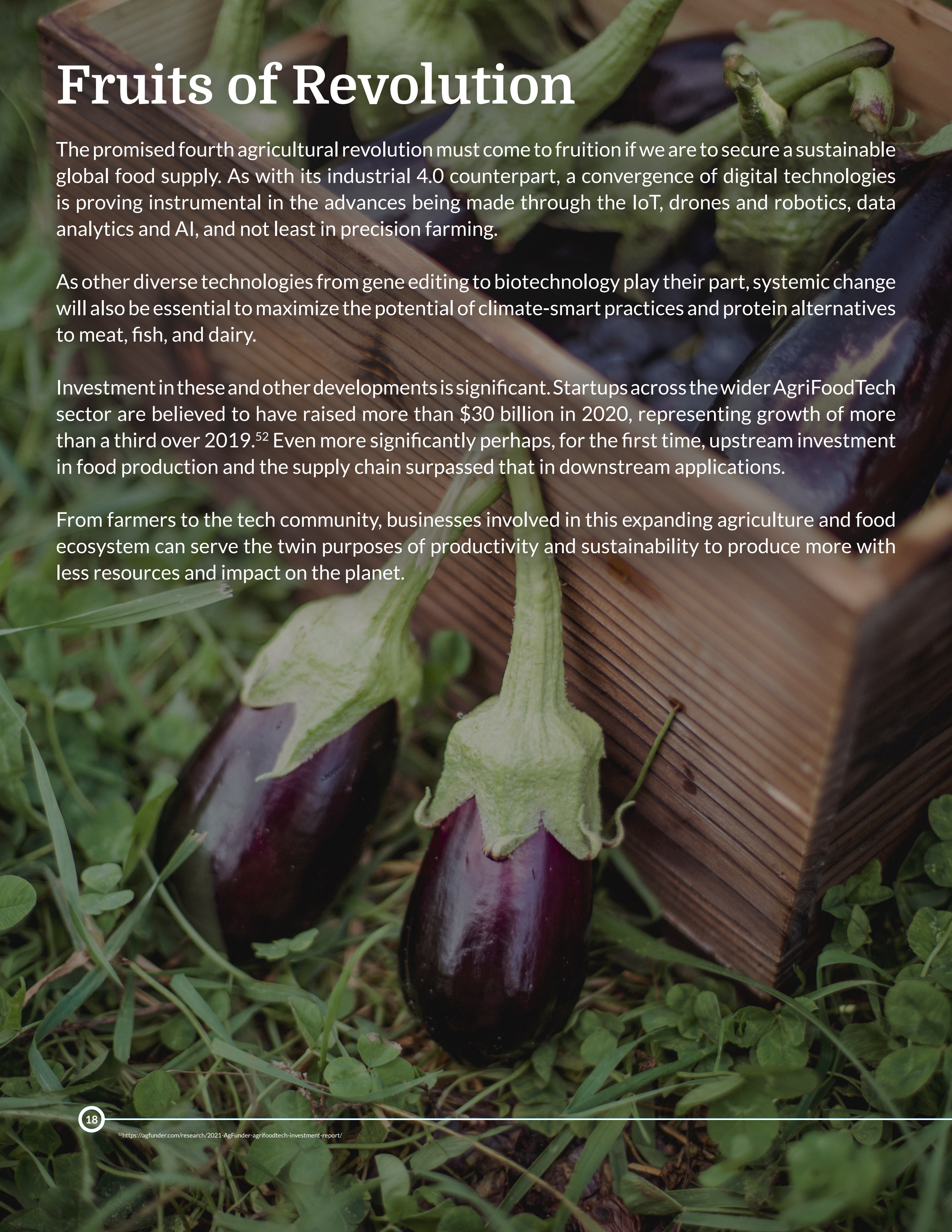
Cultured Approach

Growing meat directly would also be vastly more efficient than farming animals. Since a team at Maastricht University cultivated the first synthetic meat burger in 2013, a series of company launches have followed; notably, Mosa Meat[47] in the Netherlands, Berkeley, California's UPSIDE Foods,[48] and Israel's Super Meat.[49] In 2020, Singapore was the first country to approve a cultured meat product for sale[50] – San Francisco-based JUST Foods' chicken nuggets.[51]

There are dozens of cultivated meat companies around the world, but none have yet reached commercial production in terms of both scaling or cost. Apart from consumers' sensibilities and regulatory hurdles, there are formidable technical challenges to solve if cultivated meat is to be scalable and affordable.

Other alt-protein sources – from insects to aquacultural innovations including microalgae – can help grow other sustainable food systems for the planet. In the meantime, plant-based solutions seem to offer the most viable way to wean the world off meat.

[47] https://mosameat.com
[48] https://upsidefoods.com
[49] https://supermeat.com
[50] https://www.channelnewsasia.com/singapore/eat-just-lab-grown-chicken-cultured-meat-first-approval-sfa-450071
[51] https://www.ju.st/eat



Fruits of Revolution

The promised fourth agricultural revolution must come to fruition if we are to secure a sustainable global food supply. As with its industrial 4.0 counterpart, a convergence of digital technologies is proving instrumental in the advances being made through the IoT, drones and robotics, data analytics and AI, and not least in precision farming.

As other diverse technologies from gene editing to biotechnology play their part, systemic change will also be essential to maximize the potential of climate-smart practices and protein alternatives to meat, fish, and dairy.

Investment in these and other developments is significant. Startups across the wider AgriFoodTech sector are believed to have raised more than $30 billion in 2020, representing growth of more than a third over 2019.[52] Even more significantly perhaps, for the first time, upstream investment in food production and the supply chain surpassed that in downstream applications.

From farmers to the tech community, businesses involved in this expanding agriculture and food ecosystem can serve the twin purposes of productivity and sustainability to produce more with less resources and impact on the planet.

[52] https://agfunder.com/research/2021-AgFunder-agrifoodtech-investment-report/