TECHNOLOGY IN AGRIBUSINESS

OPPORTUNITIES TO DRIVE VALUE

WHITE PAPER | AUGUST 2017

STANFORD VALUE CHAIN INNOVATION INITIATIVE

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Executive Summary

In this white paper, we examine how new technology will drive value in the evolving agribusiness value chain. We address three areas of value creation: operational excellence, supply chain orchestration, and transparency. We show how future technology developments will contribute to these sources of value and how they will transform the structure of the agribusiness value chain. We show how advancements in artificial intelligence, system design solutions, and orchestration technologies can facilitate intelligent food production and how they'll enable the development of new business models. As a result, food systems will be more productive, efficient, sustainable, inclusive, transparent, and resilient.

The use of new technology is necessary to move the world's agriculture to a more productive path. Over the next few decades, a rising global population will put great pressure on food systems. While the overall demand for food is expected to be met over this timeframe, it is unclear whether it can be met in a sustainable manner. Agriculture is a major contributor to greenhouse gas emissions, a significant consumer of freshwater resources, and it uses 11 percent of the world's land area. Agribusiness is a major employer in developing countries, and yet the proportion of farmers is declining both in developing and developed economies, leading to the potential for social disruption. Technological innovation is one lever that can address some of the environmental, social, and economic challenges and opportunities in the growing food and beverage industry.

As has historically been the case, technology can serve as an enabler for improvements in food system productivity and welfare. Advancements in areas such as seed and food bioengineering, information and communication technology platforms, and robotics present new opportunities to produce food in smarter ways. For such innovations to succeed and scale, however, other factors such as business regulation, workforce development, public sector governance, and trade and tax policies will also be important.

Introduction

Baby salad greens in the United States come primarily from California, which can mean that consumers in other states may have to wait for days before receiving their produce.[1] The value chain that culminates in a nutritious salad is complex and requires multiple resources from water, fertilizer, and fuel to machines, vehicles, and human capital. We can envision an entirely different value chain by 2030, with salad greens (and other food products) sourced in local communities, grown in indoor farms stacked many layers high. Whether using aeroponics, a technology involving spraying water and nutrients on plant roots that is used for greens,[2] or technologies not yet developed that can be applied to other foods, we can imagine a world where food is increasingly grown closer to home, generating benefits of freshness, lower environmental footprint, and higher productivity and efficiency. This value chain structure creates new challenges, such as increased demand for skilled jobs in indoor farming and in new industries that service this new model of production as well as a lower demand for unskilled farm laborers and long-haul truck drivers.

The Food and Agriculture Organization (FAO) of the United Nations (UN) estimates that global demand for food will rise by 50 percent between 2012 and 2050[3] to feed a population of almost 10 billion[4] with rising income levels.[5] Further, a rapid rate of urbanization is expected in the coming years, with approximately 66 percent of the world's population expected to live in urban areas by 2050, compared to 54 percent in 2014.[6] The FAO report suggests that the rising demand for food can be met, but it is unclear to what extent this can be done in a sustainable and inclusive manner.[7]

The next 10-15 years will likely see rapid changes in the food system, driven by changing consumer demand, technological advances, trade dynamics, and other factors. To achieve the United Nations Sustainable Development Goal number two, to "end hunger, achieve food security and improved nutrition, and promote sustainable agriculture" by 2030,[8] the FAO is calling for more productive, efficient, sustainable, inclusive, transparent, and resilient food systems.[9] The FAO has discussed promoting agribusiness development through various initiatives aimed at resolving critical factors across the agriculture value chain to mobilize private sector investment that improves productivity and efficiency.[10]

The agricultural value chain is the sequence of activities and participants engaged in the value-adding process of transforming agricultural goods from inputs — such as seeds, animals, and fertilizer — into food that ultimately reaches consumers.[11] Stakeholders currently operate within an often-fragmented value chain that has undergone rapid changes to meet the emerging challenges and opportunities of the food economy. Opportunities exist for technology to help strengthen agribusiness value chains. While technology is by no means a panacea, it is useful to examine the opportunities it offers in a world where Internet connectivity and mobile phone adoption has accelerated the global flow of information and where advances in automation, artificial intelligence, and continuous monitoring are expected to increase. Human capital combined with technology has historically driven productivity improvements and welfare.[12] In this paper we examine the role technology can play in achieving a more productive, efficient, sustainable, inclusive, transparent, and resilient food system.

The paper is focused on the conversion of inputs for agricultural production into finished goods. We do not examine the processes that take place after finished goods are produced — namely, food retailing and final delivery to consumers — since technologies used for retailing and consumer delivery are similar to those used in other industries. In Section 1, we discuss the current agribusiness landscape and a vision for improvements that can be pursued in the next 10-15 years. In Section 2, we assess the role technology is currently playing to fill gaps between the present and future state, using a framework of three value drivers. Section 3 explores unmet needs that future technologies can potentially address. Finally, Section 4 discusses factors that can foster successful deployment of technology and key limitations.

Table 1: Focus of Research: Converting Agricultural Inputs Into Finished Goods

Inputs for Agricultural Production	Farming	Storage	Processing/ Manufacturing	Retail/Consumer Delivery *(Not included in this research)*
Seeds, fertilizers, farming equipment, animals, and other products that serve as inputs to the production of food	Planting, growing, and/or harvesting food products	Storage and warehousing of farmed products	Packing or processing of farmed goods into finished products for sale to customer	Selling and delivering finished goods to consumers via physical, online, or omnichannel markets
Supply Chain Management: The orchestration of activities involved in buying, conversion, and logistics[13]				

1. Current Landscape and a Vision for 2030

The food and agriculture industry has experienced increasing disruption in recent years. Consumer behavior and trends are continually evolving and influencing markets. For example, calorie, protein, and oil intake per capita are continuing to grow and are linked with rising incomes, particularly in developing regions.[14] Growing segments of consumers around the world are demanding more local, healthy, and sustainably grown food, with natural ingredients and simpler ingredient labels. The global health food and drink market has been forecast to achieve $1 trillion in sales by 2017.[15]

Key challenges in today's agribusiness value chains often surround the following value drivers: (1) operational excellence (i.e., improving productivity, efficiency and quality), (2) supply chain orchestration, and (3) transparency. Much of the improvement in operational excellence will come from developing countries with a prevalence of smallholder farms that produce significantly lower average yields than farms in developed countries.[16] It is estimated that 80 percent of the needed output growth will come from improved productivity and the remainder will be delivered by expanding farmland.[17] Operational excellence will also help meet the increasing demand for animal products and tackle the global challenge of food waste. One-third of food produced for human consumption is being wasted each year, with developing countries experiencing more waste at post-harvest and processing, and developed countries experiencing more waste in retail and end consumption.[18] We argue that technology will help eliminate waste, enable greater investment, increase productivity and meet rising demand.

With respect to supply chain orchestration, one of the biggest issues facing countries remains the imbalance of food. Millions have access to excess calories while millions of people are experiencing or are at risk of hunger. In 2007 and 2008, the world experienced a food crisis with a severe rise in the FAO's world food price index.[19] Prices spiked again in 2011,[20] highlighting the fact that the global food and agricultural system can be highly vulnerable and signaling stress across the agribusiness value chain. Food supply chains can be long, and several market intermediaries can be involved, some of which do not add significant value. Access to markets can also be challenging for buyers and sellers along the value chain.

Finally, in terms of transparency, food supply chains face many challenges with respect to monitoring for product safety,[21] social and environmental responsibility,[22] and other factors. Data quality can also be weak,[23,24] posing a challenge in generating actionable insights.

Table 2: Driving Value in Agribusiness

Value Drivers	Current Challenges	VISION FOR 2030: Productive, efficient, inclusive, sustainable, transparent, resilient value chains
Operational Excellence	• Gaps in yield between developing and developed countries[25]	• Yields improved and less water/land/energy/pesticide used per ton of food. Outcome: demand for food is sustainably met, and food is affordable.
	• Food waste along the value chain[26]	• Less food waste along the value chain
	• Inefficient access to capital and insurance[27]	• Efficient capital markets and insurance
Supply Chain Orchestration	• Food insecurity, with calorie excesses and shortages coexisting[28]	• Food security improved
	• Long supply chains with high environmental impact[29]	• Greater local production Frictionless markets for non-local production
	• Costly first and last mile delivery[30,31]	• More efficient first and last mile delivery
	• Market intermediaries that do not generate value[32]	• Greater disintermediation Emergence of higher value-added intermediaries
	• Buyers and sellers face limited access to markets in developing economies[33]	• Buyers and sellers better connected
Transparency	• Opaque supply chains: Uncertainty regarding inventory, food safety, labor conditions, environmental impact, other conditions[34,35]	• Transparent and traceable supply chains
	• Poor data:[36] Low quality, frequency, and timeliness of data used throughout the value chain, including data used in inputs design, farming, storage, manufacturing, and logistics	• Connected value chain that collects data in real time for actionable insights

There is an opportunity for agribusiness value chains to efficiently respond to changing demands in the next 10-15 years. The table above describes a future vision for a better functioning value chain, one in which demand for food is met in a productive, efficient, inclusive, sustainable, transparent, and resilient manner. Technology can act as one of the key enablers to achieve this vision and has a role to play with respect to the value drivers of operational excellence, supply chain orchestration, and transparency. For example, productivity and gains in efficiency can be achieved with the help of automation (e.g., self-driving tractors), product technology innovation (e.g., bioengineering of better seeds), and analytics (e.g., precision farming analytics that improve yields). Supply chain orchestration can be improved through platforms that better connect buyers and sellers (e.g., online marketplaces). Improved transparency can come from new monitoring technologies (e.g., satellite mapping).

2. Technologies

Each of the three broad categories of value drivers in agribusiness can be improved during the next 15 years. In this section, we explore improvements that can be facilitated by the use of technology, assuming other factors needed to affect transformation — discussed later — are in place. In Table 3, we present technology categories that can affect one or more challenges. While there are many approaches to categorization, the framework in the table enables us to align technologies with specific challenges. Following the table, we discuss each technology with case examples.

Table 3: Technology Applications

Value Drivers	Current Challenges	Vision for 2030	Technology Applications
Operational Excellence	• Gaps in yield between developing and developed countries	• Yields improved and less water/ land/energy/pesticide used per ton of food. Outcome: demand for food is sustainably met, and food is affordable.	• Analytics Artificial intelligence* Automation Business & operations management Capability building tools Product and process innovations (e.g., engineered seeds, meat and other food) Resource utilization improvement
	• Food waste along the value chain	• Less food waste along the value chain	• Marketplaces (for waste) Product and process innovations (e.g., produce with extended shelf life)
	• Inefficient access to capital and insurance	• Efficient capital and insurance markets	• Marketplaces (for capital and insurance)
Supply Chain Orchestration	• Food insecurity, with calorie excesses and shortages coexisting	• Food security improved	• Marketplaces (e.g., secondary markets) Resource utilization improvement (e.g., indoor farming)
	• Long supply chains with high environmental impact	• Greater local production Frictionless markets for non-local production	• Analytics Artificial intelligence* Marketplaces (e.g. digital farmer marketplaces) Resource utilization improvement (e.g., indoor farming, 3D printing) System design solutions* System efficiency solutions*
	• Costly first and last mile delivery	• More efficient first and last mile delivery	• Resource utilization improvement (e.g., shared transportation platforms)
	• Market intermediaries that do not generate value	• Greater disintermediation Emergence of higher value-add intermediaries	• Marketplaces
	• Buyers and sellers face limited access to markets	• Buyers and sellers better connected	• Marketplaces
Transparency	• Opaque supply chains: Uncertainty regarding inventory, food safety, labor conditions, environmental impact, other conditions	• Transparent and traceable supply chains	• Analytics System efficiency solutions*
	• Poor data: Quality, frequency, and timeliness of data used throughout the value chain, including data used in inputs design, farming, storage, manufacturing, and logistics	• Connected value chain that collects data in real time for actionable insights	• Analytics

* Technologies that can enable new opportunities to strengthen the value chain (discussed in Section 3)

> "Technology in and of itself, of course, is somewhat value neutral. What we generally found, both in our core extension activities as well as in our transport logistics, and even more broadly, is that technology is really good as an amplifier of activities people might already be doing to make them more efficient or to reach more people at less cost or to do them faster .[60]"

— RIKIN GANDHI, CEO, Digital Green

2.1 Analytics

Analytics are being used across the value chain to improve operations. Content analysis, for example, focuses on assessing overall food nutrients and quality. Sample 6 and Ancera use synthetic biology-based bacteria diagnostic systems to analyze food. Sample 6 focuses on building integrated systems that detect harmful and unwanted bacteria. The company has promoted applications of its solutions in food production, retailing, healthcare, and anywhere else humans and bacteria intersect.

One major arena for analytics is precision agriculture, also known as site-specific crop management, which involves collecting and analyzing information at the individual botanical plant level for improved agricultural practices. Startups have raised a cumulative total of $825 million in this category.[37] Precision farming technologies use data on nutrients, moisture, yield, and more to optimize profitability and sustainability.[38] A study of 3,380 American farmers found that those implementing precision technology reported an average cost reduction of 15 percent and an increase in average yields of 13 percent; yet 77.5 percent of respondents were concerned about data privacy issues related to using new technology.[39]

MONITORING TECHNOLOGY

Aerial Monitoring Tools

Aerial monitoring, also known as remote sensing, can be conducted by drones, airplanes, and satellites, which monitor conditions from different altitudes to reveal patterns that highlight irrigation problems, soil variation, deforestation, changes in livestock, soil erosion, pest and fungal infestations, and other information that may not be easily apparent at ground level. Airborne cameras can take multispectral images, capturing data from the infrared as well as the visual spectrum. These images can be sequenced to show changes in fields.

Ground-Based Monitoring Tools

In- or on-ground sensors can be deployed to detect crop conditions, weather data, and many other details, which can then be transmitted to decision analytics platforms via the Internet of Things (where computing devices embedded in everyday objects are connected to the Internet to enable analytics). Startup firm Arable, for example, has designed a solar-powered in-ground sensor that can gather data on crop stress, air pressure, humidity, temperature, chlorophyll, canopy biomass, rainfall, and other information which can then be analyzed on its platform to improve precision farming.

DATA ANALYTICS

Many centralized digital platforms are available that use agronomic data gathered from precision monitoring technology, historic weather data, and other sources to conduct detailed analysis, ranging from the descriptive to the prescriptive. By improving the volume, quality, flow, and frequency of information used in farming and other value chain stages, food production can become more efficient, productive, and sustainable. The volume of data for agribusiness is steadily expanding due to sensors, satellite monitoring, and other information-gathering technologies.[40] The quality of information is improving with more sophisticated data-gathering instruments, as well as new sources such as crowd-sourced farmer data.[41] The flow of information is enhanced via platforms that connect various stakeholders across the value chain. Finally, the frequency of information is increasing with improved Internet connectivity, device-enabled products sending data to cloud analytics platforms (i.e., Internet of Things), and many other advancements. As the quantity, quality, speed, and flow of data improves, data analytics platforms and machine learning applications can enable better practices in farming, processing, and manufacturing.

Several companies are expanding the use of farm analytics. The Climate FieldView platform by Climate Corporation combines hyper-local weather monitoring, agronomic data modeling, and high-resolution weather simulations to deliver mobile Software as a Service (SaaS) solutions that help farmers make better informed operating and financing decisions. Farmers Business Network (FBN) is a membership-based company with a network of farmers who share farming data on inputs, soils, yields, and prices to improve performance and productivity across the value chain.

While precision agriculture has made significant inroads and holds the promise of improved returns, producers are faced with assessing the investments needed, profitability, and complexity of new technologies.[42] New investments are thus arising for more cost effective solutions that can appeal to a broader market. Monsanto, Bayer, Pioneer, and Jain Irrigation have all been involved in acquisitions in this arena. DuPont Pioneer has linked up with farm-machinery maker John Deere to advise farmers on seed and fertilizer applications in the field, and Cargill provides in-house crop advisory services as well.

2.2 Automation

Tractors, combines, and other mechanization technologies have long been used for pre-harvest, farming, and post-harvest operations such as processing and food manufacturing. Emerging innovations such as self-driving tractors have the potential to improve farm productivity in new ways, enabling farmers to tend to several fields from one location and operate equipment throughout the day and night[44]. Automated irrigation systems can collect data on soil type, water levels, quality, and accessibility to efficiently deploy water and soil nutrients. When automated machines are connected to the Internet of Things (IoT) and other analytics tools, precision and efficiency in operations can be achieved.

Automation can be segmented into two types: basic automation, which simply replaces manual labor to make a process more productive, and intelligent automation, which not only replaces manual labor but makes better decisions using data. Firms such as Compac and Cimbria produce equipment that processes farmed goods into processed food products. Such companies can implement turnkey systems including machinery for produce, grain, or other food product handling, sorting, grading, washing, cutting, and packaging. Complementary software helps to monitor and control operations and conduct analytics — an example of intelligent automation. Startups received a cumulative total of $400 million in this category.[45]

The production of food using 3D printers is a small but growing trend in the additive manufacturing industry. Food ingredients are put into a 3D printer, which then extrudes the inputs into a structural design, enabling production of new types of foods. For example, Culinary Lab is a learning, collaboration, and exploration space where chefs and other food innovators can transform their traditional craft of cooking using 3D printing. If 3D printing ultimately gains wider traction, new food designs could take hold and automated cooking for end consumers could grow.

Analytics: Farmers Business Network

Farmers Business Network offers a membership-based online platform for farmers to share performance data and conduct analytics that can improve productivity and their business. Farmers submit data on yields, seed performance, weather, and other variables affecting farming. FBN analytics tools then help farmers determine the best combination of inputs to generate the highest yields. Other tools are available to obtain pricing data and conduct farm operations management. CEO and Cofounder Amol Deshpande comments that, in his experience, he has observed that farms in the U.S. are getting bigger because they need scale to survive. “As farms grow,” he says, “yields per acre can decline, despite better technologies.[43]”FBN aims to democratize information so farmers improve decision-making and grow profit margins. The average member has a farm size of 3,700 acres, and the growing network of farmers covers over 12 million acres. With each new member’s information on performance, overall agronomics and buying and selling power can become stronger.

The company recently launched FBN Direct, a platform for members to buy farming inputs online at prices negotiated directly with manufacturers. According to the company, this model circumvents non-value-added intermediaries that may charge retail markups and sales commissions. Deshpande says, “The farmer should matter, and the consumer should matter. The rest of the constituents should be creating value in the chain.” Deshpande sees an opportunity for FBN to enable disintermediation, or the reduction of intermediaries in the value chain. He says, “The biggest competitors we see are existing ‘middle men,’ whether they’re retailer, distributor, cooperative, or merchants on the back end.”

2.3 Business and Operations Management

The business of farming is undergoing shifts, not only in developed and commercial agricultural settings, but also on small-scale farms in developing economies. Information technology applications are helping farmers understand different methods of agricultural production and are making them more aware of operating costs and other variables affecting profits. Firms such

Automation: Harvest Automation

Harvest Automation sells mobile robots for labor-intensive industries. The company currently targets agriculture with aims to launch a robot for logistics handling for e-commerce companies. Teams of small, highly “intelligent” machines work alongside laborers to perform the most physically demanding parts of tasks at a reduced cost. The HV-100 model performs material-handling tasks in unstructured, outdoor environments with minimal training required. The result can be reduced headcount and costs, efficient resource management, just-in-time production, and inventory control. The company will soon release a mobile, autonomous, material-handling platform engineered for distribution and fulfillment operations.

as Granular, Conservis, and Agworld provide farm management software that collects, synthesizes, and analyzes data for various farm business processes. The software collects data, tracks resources and productivity, and builds detailed operations plans. Startups received cumulative funding of $129 million in this category[46] with a focus on management across various aspects of the agribusiness value chain using SaaS platforms.

2.4 Capability Building Tools

As discussed earlier, yield gaps in developing economies, compared to developed economies, can be attributed to many factors, with farmer education being one element.[47] Distributing knowledge to remote or rural areas can be costly. New services focused on improving farmer education through technology, such as videos, hotline voice services, and mobile phone applications to leverage trainer and skills in a low-cost manner, have been found to facilitate adoption of improved inputs and have encouraged investment decisions.[48] Organizations such as AgriFind in France use a social networking platform for farmers to share their experiences and to deliver agronomic advice from experts and fellow farmers. Farmers can post their needs and successful solutions. Whereas startup funding has been low in this arena,[49] public sector and nonprofit organizations have played more of a role, potentially due to a lack of commercial viability for the operating model.

2.5 Marketplaces

As in other industries, technology has helped grow agricultural marketplaces from merely physical places to physical and digital markets. Almost 900 startups are involved in digital marketplaces of some kind, and have received cumulative funding of $682 million.[52] Studies have noted that improved market transparency reduce price dispersion and waste.[53] Digital marketplaces can contribute to improved transparency. As seen in Table 3, marketplaces facilitate transactions that (1) improve productivity, efficiency, and quality in operations, and (2) facilitate transactions that promote efficiency across the supply chain.

In the first category, we find marketplaces that improve performance within a particular value chain phase. For example, there are a growing number of online services that provide farmers access to insurance (e.g., Insurance Marketplace) and financing (e.g., ProducePay, which offers cash flow to farmers the day after they ship product). Numerous platforms exist to buy and/or lease equipment such as Agriaffaires, which operates in many countries, France-based Agriconomie, Ravgo in India, and Leboncoin in France. Full Harvest helps to bring excess farmed goods to market. Using a business-to-business platform connecting large farms to food and beverage businesses, Full Harvest sells discounted yet edible surplus and imperfectly shaped produce that would have otherwise gone to waste. This helps bring additional revenue to farmers while reducing wastage of food. Fostering greater access to the products and services described can enable greater investments, and ultimately greater productivity within phases of the value chain.

Automation: Blue River Technology

Blue River Technology sells the LettuceBot, which uses “see and spray” technology to apply chemicals only where needed. Computer vision and robotics help thin lettuce crops with precision or identify unwanted plants and selectively kill them — a more efficient method of plant elimination. Blue River is also working on products for corn and soybean markets. The LettuceBot can be used in organic agriculture and for fields with chemical-resistant weeds.

In the second category, we find marketplaces that foster the buying and selling of goods across the value chain. To tackle the challenge of long supply chains, online marketplaces such as La Ruche Qui Dit Oui in France help shoppers buy products within a 150-mile radius, and pick them up from a local distribution point, called a “hive.”[54] Farmers set their prices, paying a commission on sales to the platform manager. The service had over 100,000 users as of 2016. To address the issue of non-value-added intermediaries, marketplaces for farm input products are emerging (e.g., the ones operated by FBN in the United States and startup Ricult in Pakistan). Marketplaces can be based on membership, such as FBN, or be open, such as Ricult.

Capability Building Tools: Digital Green

Digital Green is an international nonprofit organization operating in South Asia and sub-Saharan Africa, producing and sharing locally relevant videos to improve agricultural, health, and nutrition practices in rural communities. The organization partners with local public, private, and civil society groups already working on extension services to create and share quality to create and share knowledge via mobile applications, radio, and other technologies. Digital Green's approach has been shown to be 10 times more cost-effective,[50] with 7 times higher uptake of new practices than traditional extension services. The organization has reached over 1.5 million farmers across 13,592 villages through about 5,000 videos in 29 languages. More than 574,000 viewers have adopted one or more of the promoted best practices. CEO Rikin Gandhi notes the importance of local relevance in building farmer capabilities, saying "The first two questions that people ask are, 'What's the name of the person in the video and which village is he or she from?' They first want to trust the source."[51] The trust that Digital Green created has enabled the organization to grow in resource-constrained, challenging environments.

Ricult offers credit to farmers for purchasing quality inputs, and claims to offer 60 percent cheaper credit and 30-40 percent cheaper inputs compared to middlemen in the traditional Pakistan market. Marketplaces often go beyond simple connections between buyers and sellers, offering services such as management services for contracts and invoices and independent lab analysis of products.[55] Growing smartphone adoption will likely help this category grow as user-friendly applications enable smooth interactions across parties, fostering new marketplaces.

2.6 Product and Process Innovations

Entirely new ways of designing food are being explored, with technologies such as cellular agriculture and gene editing evolving quickly. Cellular agriculture involves producing agricultural food products from cell cultures. Firms such as Impossible Foods, Memphis Meat, and Clarafoods have been transforming the landscape for lab-based meat and food production by designing food-producing systems that use fewer natural resources. Gene editing, which involves modifying DNA in a particular cell or organism,[56] is being explored to improve the sustainability of food, feed, fiber, and fuel. BensonHill, for example, is working on plant biology, using big data analytics and cloud computing to improve productivity, quality, and efficiency of plants. Calysta is designing natural, nutrient-dense alternatives to fishmeal and soy.

New ideas are also emerging for improving the usability of products; extending shelf life is an example. Companies such as Aseptia and Bluwrap are using applications of microwave technology to pasteurize seafood and sterilize other perishable food items, giving packaged foods a longer shelf life. Startups working on biotechnology, agribusiness, and processing technology have benefitted from cumulative investments of $4.36 billion,[57] higher than all other technology categories.

2.7 Resource Utilization Improvement

New technologies are enabling food to be produced using fewer pesticides and less land, energy, and water. Drip irrigation systems help deploy water and fertilizer in targeted quantities to the needed areas, helping to conserve water. This may become an increasingly important tool, especially for areas suffering long-term droughts. Indoor farming, or vertical farming, is gaining acceptance as a means of maximizing land. A natural extension of urban agriculture, indoor farms are designed to cultivate plant or animal life, often vertically, within buildings, lowering the risk of weather aberrations in addition to extending the number of hours per day plants are exposed to light.[58] Using techniques such as aeroponics, water use can be curbed.

Startups involved in indoor farming have received cumulative funding of $755 million.[59] As additional advantages, indoor farming naturally cuts down on the need for pesticides and can allow food to be grown closer to the consumer in urban environments. Companies such as Grove Garden, Sprouts, and Agrilyst are integrating indoor spaces with water systems and intelligent lighting technology that mimics daylight. The profitability of indoor farming will determine the extent to which it can scale over time.

Business and Operations Management: Granular

Granular is a firm that collects, synthesizes, and analyzes data on farm business processes such as planning, budgeting, cost, inventory management, and marketing. Sixty-one crop subspecies are supported. The company's software integrates with a farmer's existing hardware, including tractors, drones, and scales, to collect data from the field. A mobile application can be used to access a real-time work schedule and task list. Company software can import and analyze data collected from precision planting equipment and monitor profit and loss statements at the field level.

3. Opportunities

Most of the technology solutions described have focused on improving one aspect of the value chain or building marketplaces connecting participants across stages. There remains an opportunity for greater system-wide changes that could further enable productivity, efficiency, sustainability, inclusiveness, and/or transparency improvements. There are also opportunities for deeper levels of analytics, with advancement such as artificial intelligence, which can help achieve improvements. We discuss some of these opportunities below.

3.1 Future Technology Enablers

3.1.A. Artificial Intelligence

Artificial intelligence involves the development of computer systems that learn to perform tasks that traditionally required human intelligence, such as visual perception, speech recognition, and most importantly, decisionmaking. Agriculture can involve making judgments based on a large number of variables. While decisions can be made based on valuable experience and instinct, this traditional approach can lead to suboptimal resource allocation. As the integration of IoT and data analytics grows in the coming years, significant improvements in yields may be seen.[61] The company OnFarm projects that the typical farm will produce an average of 4.1 million data points per day by 2050, compared to 190,000 in 2014.[62] Advancements in AI will succeed if they can exploit the growing volume of data to improve decisionmaking. Given the many uncontrollable variables in farming, such as weather and pests, it will be challenging for AI to address all issues.[63] However, AI presents an opportunity for those working in agribusiness to learn from mistakes and make better decisions in the future.

3.1.B. System Design Solutions

Given issues of food imbalances across the world and food waste at various stages of production and consumption, increasing attention is being placed on the design (and redesign) of food systems. Yet, startup funding for infrastructure investments and other system-based solutions has only totaled $39 million to date.[64] Growing focus is being placed on promoting a circular economy — a system focused on designing waste out of products and services and reducing negative effects.[65] There is a large potential to build an increasingly circular economy, and technology can play a role. Production and process innovations are needed to close the loop, redirecting byproducts and waste back into the production system. UK-based RG Recycling Group, for example, deploys small mobile recycling equipment to segregate and process waste, which can then be sold for profit.

Close to 795 million people experience chronic undernourishment.[66] While food banks and pantries address this issue, there may be an opportunity for technologies such as digital marketplaces to improve information flows along the food system and better connect buyers and sellers. To address hunger, for example, expanding secondary marketplaces can redirect food that goes unpurchased at the consumer level to lower-income consumers who cannot afford full price. For food-insecure populations affected by war, natural disasters and other crises, technology is helping to better monitor food stock and match

Marketplaces: Aggrigator

Aggrigator is a B2B digital marketplace that enables sellers and buyers of fresh produce to transact with one another. Sellers are typically small farmers, cooperatives, and community-supported agriculture associations (CSAs). Aggrigator buys product from farmers and sells directly to commercial buyers such as grocers, restaurants, and other institutions. Buyers are able to save up to 90 percent in food miles through the system. The platform's farm-to-shelf two-sided marketplace also provides critical services such as financing, logistics, and certified food safety, areas that pose challenges for small businesses. According to the company, its aggregated markets provide better value and higher profitability, foster inclusion, and decrease risk.

Product and Process Innovations: Impossible Foods

Impossible Foods, a California-based firm, is a key player in the growing trend of developing plant-based meat substitutes that can appeal to non-vegetarians and the mass market. An ingredient called heme, abundant in meat and plants, is genetically engineered and infused into the product to provide the color and taste of meat. Engineered meat products from Impossible Foods and its competitors are promoted for their health, sustainability, and taste. They do not require antibiotics or hormones and are less resource-intensive to produce than meat from conventionally farmed animals. The company claims that compared to cows, their burgers require 26 percent of the water and 5 percent of the land of conventional burgers, and producing them emits 13 percent of the greenhouse gases. The company is planning large-scale production to make one million pounds of engineered meat per month. Currently, the company sells its burgers to restaurants in New York, California, and Las Vegas and plans to expand to grocery stores and international markets. The firm also plans to develop other plant-based meat and dairy products, substitutes for poultry, pork, fish, and yogurt.

the stock to the need. The World Food Program, for example, manages the Vulnerability Analysis and Mapping system, which uses satellite data to gauge rainfall and vegetation and assess the food needs in communities. The system also offers interactive visualizations of food price information to inform assistance efforts.[67]

System Design Solutions: AeroFarms

AeroFarms engages in the cultivation of leafy crops indoors, using layers of growth medium, ventilation, and LED lighting for a vertical farming system. A closed-loop system called aeroponics is used to mist the roots of plants with nutrients, water, and oxygen, generating no waste. The system uses 95 percent less water than field farming, 40 percent less water than hydroponics, and no pesticides. The company recently won the Future of Sustainability award from the U.S. Green Building Council for rethinking how to sustainably grow fresh and affordable produce through vertical farming. AeroFarms plans to produce 1.7 million pounds of greens this year, with products available in select stores for around $3.99 per package.

3.1.C. System Orchestration Technology

Creating an efficient supply chain involves fostering an efficient flow of information, materials, and money between suppliers and customers. Efficiency is only one element of supply chain performance. Research has shown that agility, adaptability, and alignment of supply chain actors are more critical in developing a competitive advantage for firms.[68] While strong management is needed to foster a triple-A supply chain, technologies such as IoT-based solutions can play a role in improving the monitoring and orchestration of supply chains.

There is an opportunity for nascent and yet undeveloped technologies to facilitate traceability, finance, logistics, trade, and other activities across the value chain to improve system orchestration. Blockchain is one technology that has the potential to be applied to improve system orchestration in several areas. Initially used as a key component of the digital currency system known as Bitcoin, blockchain works as a decentralized database with a shared distributed ledger. Digital transactions are stored in sequentially ordered and cryptographically protected blocks, building traceability across the value chain and reducing the need for intermediaries.[69] Companies in agribusiness have begun to use blockchain to create systems that will record the journey taken by food through the supply chain. Given that transactions are unchangeable under blockchain, it can play a key role in getting trusted information to end consumers.

Trade transactions can be complex and cumbersome, involving numerous entities, including buyers, sellers, logistics providers, banks, customs offices, and other third parties. Lack of trust, long shipment distances, and slow feedback loops add cost, complexity, and time to the process. Trade transactions are largely still paper-based, with original documents forwarded around the world. Blockchain has the potential to be applied for monitoring social and environmental responsibility, improving provenance information, facilitating mobile payments, credits and financing, decreasing transaction fees, and facilitating real-time management of supply chain transactions in a secure and trustworthy way. Firms such as Provenance and Skuchain are working on tracking and tracing systems for agribusiness companies to build trusted relationships between stakeholders.

System Design Solutions: WISErg

WISErg, a Redmond Washington-based company, converts excess food scraps from grocery stores into a nutrient-rich liquid. The company uses a machine to capture nutrients in the food waste stream. Materials are then transferred to a nearby WISErg facility, where they are processed into fertilizer. The machine ingests and processes food scraps in an odorless, pest-free, self-contained system and stabilizes nutrients that would otherwise be wasted. Benefits include reduced greenhouse gas emissions, odors, and pests, with an end-product fertilizer that is approved for use on certified organic crop production.

Other solutions focus on improving transparency regarding food safety, social and environmental responsibility, inventory placement, and other system-wide issues. IdentiGEN, for example, provides DNA-based solutions to the agri-food industry. Its flagship product, DNA TraceBack, uses DNA analysis to enable food retailers and producers to trace the source of meat products through the entire supply chain and validate meat product attributes such as natural and organic. OptiGene offers products that conduct real-time analyses of plant materials to detect pathogens.

There is potential for digital platforms to provide greater value chain orchestration and reduce system frictions. Not only can platforms connect buyers and sellers, but also they can streamline supporting services and improve overall system efficiency. For example, Aggrigator combines its marketplace with options to create contracts, conduct traceability, and access finance and insurance. Since the company brings small sellers together to provide large buyers the volumes they need, small sellers may be able to take advantage of supporting services at lower costs than they would by selling independently.

System Orchestration Technology: Skuchain

The firm Skuchain builds blockchain-based products for business-to-business (B2B) trade and supply chain finance. The company uses a decentralized blockchain system to build trust between buyers, sellers, and banks. In October 2016, cotton bales were the first physical commodities to be traded and settled by banks using a blockchain-based smart contract system. Skuchain's system was used for the transaction, which enables lending against trade instruments such as purchase orders, invoices, inventory assets, and payment obligations. Loans become collateralized assets whose performance can be assured through automated release of funds triggered by real-world movement of goods.
"If you take a typical supply chain, today almost everybody views this supply chain as having independent transactions – the shipment of cotton, the manufacturer who purchases the raw material cotton, and the value addition party who has a deal with the end buyer. Except that they all belong to the same digital thread. What we can do with Skuchain's technology is link that thread, and there is a significant amount of value to all parties when that happens." Srinivasan Sriram, Founder and CEO, Skuchain.

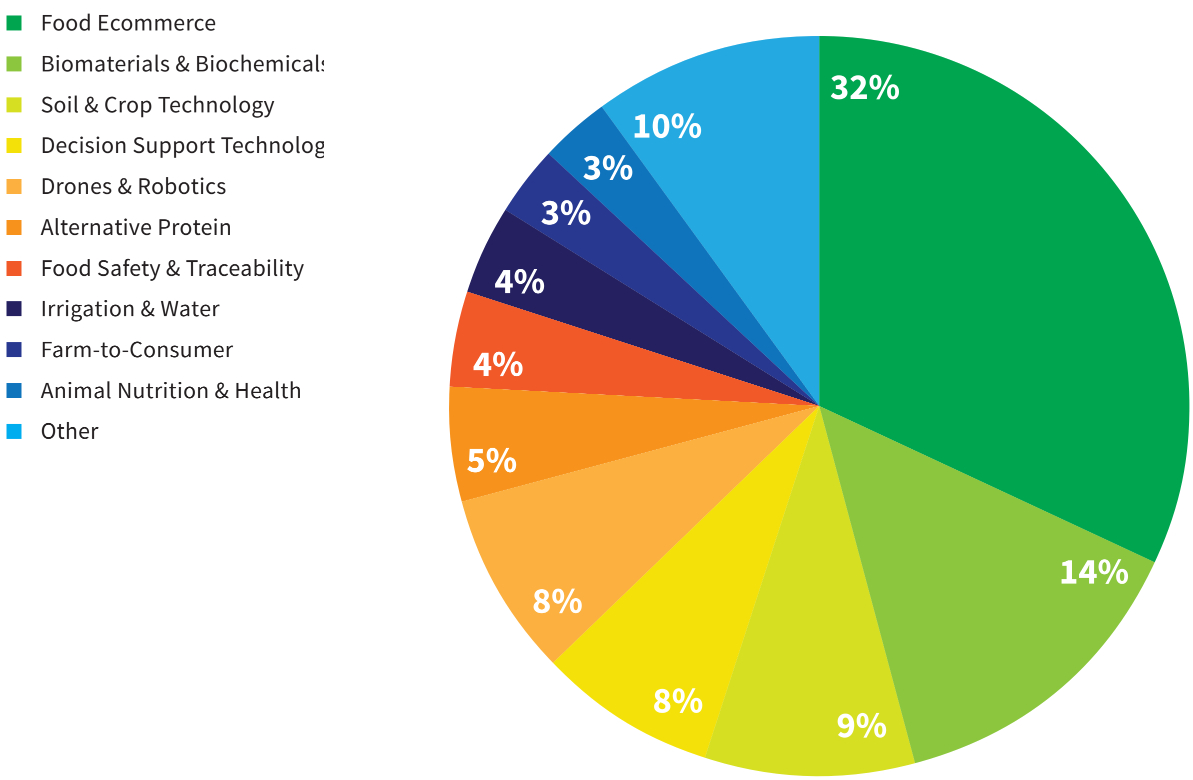
The first mile of agriculture in developing countries, when farmed goods are delivered to the local market, is often expensive, time-consuming, and challenging. It can take from half to a full day to sell produce at the nearest market in rural India.[70] Digital platforms can enable efficiencies in the first mile, as with Digital Green's Loop system, a mobile phone application that helps farmers aggregate perishable produce via transporters already working in communities. Village entrepreneurs arrange transport of aggregated goods, selling produce directly to wholesale buyers. The entrepreneurs return to the villages to deliver same-day payment for a commission.[71] Value-added services such as access to credit, inputs, and mobile payments are layered on top of the distribution platform, delivering additional benefits.[72] In addition to platform solutions, as drone technology costs decline, there could be a role for drones in the first mile, saving farmers time and cost of transporting product to market.

3.2 Investments in Future Technology Enablers

Given the current technology applications discussed in Section 2 and potential areas for future growth discussed in Section 3.1, it is useful to examine where investment dollars are being deployed. According to a report by McKinsey & Co., the size of the global food and agribusiness market is $5 trillion.[73] Since 2004, corporate and venture-backed investments focused on the food and agribusiness sector have grown significantly, tripling to more than $100 billion in 2013.[74] Corporate and venture capital investments in agriculture technology companies around the world totaled $25 billion in 2015.[75] As of 2017, 13 investment funds were dedicated to agricultural technology.[76]

McKinsey & Co. projects opportunities in machine automation, irrigation, storage infrastructure, animal breeding, and more.[77] Investment opportunities in blockchain,[78,79] artificial intelligence,[80] and the circular economy[81] are also expected to grow, creating potential to drive value. As seen in Figure 1 below, venture capital investments are currently heavily concentrated in e-commerce and biotechnology. While the figure shows there is some focus on system orchestration solutions (such as supply chain technologies) and system design solutions (such as innovative food and mechanization), there is an opportunity for new technologies to focus on system design, system efficiency, and artificial intelligence. Uptake of new innovations will depend on how cost-effectively they address stakeholder problems.

Figure 1 – 2016 Agribusiness Technology Investment by Category



Source: AgTech Investing Report, Year in Review - 2016, January 31, 2017, p. 16. Reprinted with permission.

4. Conclusion

Table 5: Agribusiness Value Chain: Current Technology Applicatons and Future Opportunites*

Inputs for Agricultural Production	Farming	Storage	Processing Manufacturing
Seeds, fertlizers, animals, farming equipment, and other products that serve as inputs to the production of food	Planning, growing, and/or harvesting food products	Storage and warehousing of farmed products	Packing or processing of farmed goods into finished products for sale to customer

Supply chain management: The orchestration of activities involved in buying, conversion, and logistics[13]

CURRENT TECHNOLOGY APPLICATIONS

Analytics | Automation | Business and Operations Management | Capability Building Tools | Marketplaces | Product and Process Innovations | Resource Utlization Improvement

FUTURE TECHNOLOGY OPPORTUNITIES

Artficial Intelligence | System Design Solutions | System Orchestration Technology

**Retail/consumer delivery not in scope of this paper*

While technological innovation has always been important in agriculture,[82] the scale and complexity of food production is increasing alongside natural resource constraints. This raises new questions on the role that technology can play to foster changes in efficiency and productivity in a sustainable and inclusive manner. The World Trade Organization has noted the potential for information technology to play a major role in the future course of global supply chains.[83] We have outlined key types of technology that can support high-performing value chains. There remain opportunities for system-wide disruptions and deeper insights into better food production. We discussed some technologies addressing those needs, recognizing there are needs unmet by today's solutions.

Many other factors must be in place to complement technology if improvements are to be achieved, including business regulation, skills development systems, public sector governance,[84] trade and tax policies, and other elements. Technology infrastructure (e.g., internet and mobile phone access in developing countries) must also support expansion. Building data standards that promote cooperating and data sharing will also be increasingly important.[85]

With new technologies, new challenges can arise. Agribusiness is a major employer in developing countries. Yet, the proportion of farmers is on the decline globally — going down from 35 to 4.2 percent in the developed world between 1950 and 2010, and down from 81 to 48.2 percent in developing nations.[86] The gap between developed and developing countries can be explained by large differences in productivity.[87] As adoption of automation and data-driven agricultural practices increase, questions arise as to the implications on workforces in this industry. What will be the impact of automation on the number and type of jobs available in the future agricultural economy and the skills needed to succeed? How will impacts differ in developed versus developing economies?

Environmental implications also exist. Given that agriculture contributes to 13.5 percent of global greenhouse gas emissions,[88] uses 92 percent of the world's freshwater resources,[89] and occupies 11 percent of the world's land area,[90] there is an opportunity for technology to mitigate environmental effects. Yet, increasing the use of hardware such as drones, sensors, servers, automated machines, and other tools can leave their own environmental footprint. While technological advances in agricultural conversion have the potential to improve returns, they also have social and environmental consequences that can be positive, negative, or neutral.

Technological developments in alternative sources of food supply (e.g., insect-based foods, algae products, engineered meats), indoor farming, and many other advancements are aimed at addressing food availability and accessibility. Value chain development programs focus on expanding inclusion. Rikin Gandhi, CEO of Digital Green, envisions opportunities to build value chains from the bottom up to improve inclusiveness, commenting: "Connect them [farmers] to the next level, get volumes up, and then maybe connect to institutional buyers and e-commerce. ... [This will] make the value chain itself more inclusive for a broader segment of people." Gandhi believes labor will still play a role, given the high costs of automation for small-scale farmers. He sees opportunity for the sharing economy (e.g., shared tractors and transportation) to improve system efficiency.

Opportunities persist to cultivate a more comprehensive food system that can be designed for optimally meeting demand.[91] Higher public and private investments in developing countries will be needed[92] to close yield gaps. Technology investments in both developing and developed countries will be part of multipronged approaches to sustainably feeding a growing population with a productive, efficient, inclusive, transparent, and resilient value chain.

Authors and Acknowledgments

Hau L. Lee, Co-Principal Investigator
Thoma Professor of Operations, Information and Technology
Faculty Co-Director, Value Chain Innovation Initiative
Stanford Graduate School of Business

Haim Mendelson, Co-Principal Investigator
Kleiner Perkins Caufield & Byers Professor of Electronic Business and Commerce, and Management
Faculty Co-Director, Value Chain Innovation Initiative
Stanford Graduate School of Business

Sonali Rammohan
Staff Director, Value Chain Innovation Initiative
Stanford Graduate School of Business

Akhil Srivastava
MS '17
Stanford Graduate School of Business

The authors would like to acknowledge Kira Oskirko for her document review.

Please contact Sonali Rammohan at sonalir@stanford.edu with inquiries.

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