Recent Developments in the California Food and Agricultural Technology Landscape

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Three years ago, a global assessment of all industries revealed that food and agriculture had dramatically lagged in the adoption of digital technologies. Recent emerging trends in venture funding for innovative agricultural technologies hope to change this assessment and may well alter California's food and agriculture technology sector. This article investigates those venture-backed, California-based companies that are engaged at various points in the food and agriculture supply chain.

The global economy is going through a process of digitization, but a 2015 assessment by McKinsey revealed the agriculture sector to have achieved the very lowest level of digitization. Given that global food and agriculture (FA) represents approximately a $5 trillion industry (the largest amongst all industries), this evaluation was surprising to many. One possible explanation is that the FA sector has been the recipient of historically low levels of innovative venture investment, averaging less than $500 million annually prior to 2012. Over the last few years, however, venture investors are realizing that new technological innovations in modern biology, information technology (I.T.), machine learning, artificial intelligence (A.I.), and remote sensing have the potential to drastically alter the FA landscape. Such investments have the potential to improve agricultural productivity, introduce new products, and improve supply chain efficiencies linking producers to final consumers.

Between 2012 and 2017, venture capital funding in FA technology (agtech) totaled $22.3 billion, reaching a peak of $10.1 billion in 2017, as shown in Figure 1. Across the United States, the evolution of this emerging trend is reaching far beyond Silicon Valley's early interest in agricultural biotechnology, with major investments in all segments of the FA supply chain. As with much of its history, California FA continues to be a leader in U.S. high-tech production and is the leading state by agtech investments, with $2.2 billion in 2017 (22% of total) and a total of $5.1 billion between 2012 and 2017.

Much of the significant increase in venture agtech capital addresses the challenges of incorporating robotics, information technology, and remote sensing in FA. These investments can be classified within six broad technology categories: precision agriculture, agricultural biotechnology, vertical farming, alternative animal products, decision-making tools, and supply chain management.

Figure 2 shows where each technology category touches a particular stage of the FA supply chain. Inputs, which include biophysical conditions, water, pesticides, and other inputs, are used by different farm production methods to generate raw product, which are either distributed in fresh or processed forms. These products are sold and distributed by food services, farmers' markets, traditional grocers, and internet channels direct to final consumers. It is worth noting that while four of the six areas of innovation focus on input configuration and agricultural production, supply chain management technologies comprise over half of agtech investments.

Precision Agriculture

Precision agriculture addresses variability in biophysical and climatic conditions at the field or crop level by enhancing the ability to apply inputs (e.g., water, pesticides) according to a micro-level recommendation. However, the ability to assess conditions and make treatment recommendations has outpaced application technologies. For instance, using various remote sensing and probe technologies, a thermal image of water requirements at the sub-field level is possible. However, irrigation systems

Figure 1. Agtech Investment, 2010–2017

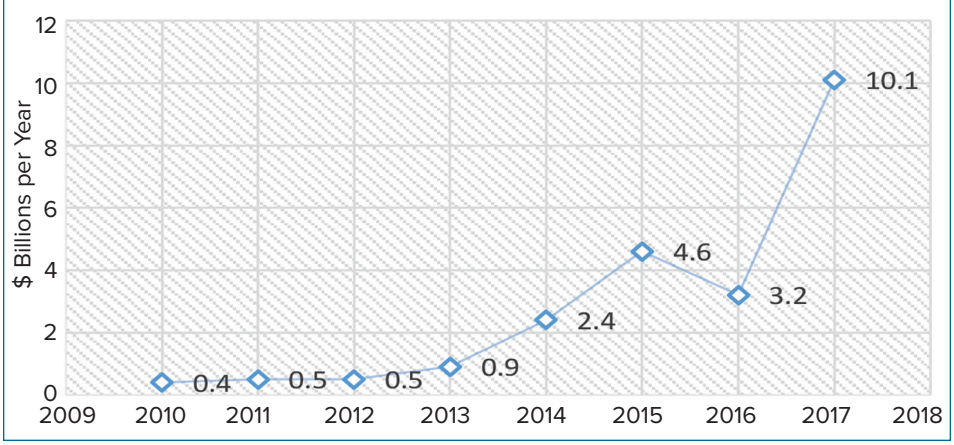
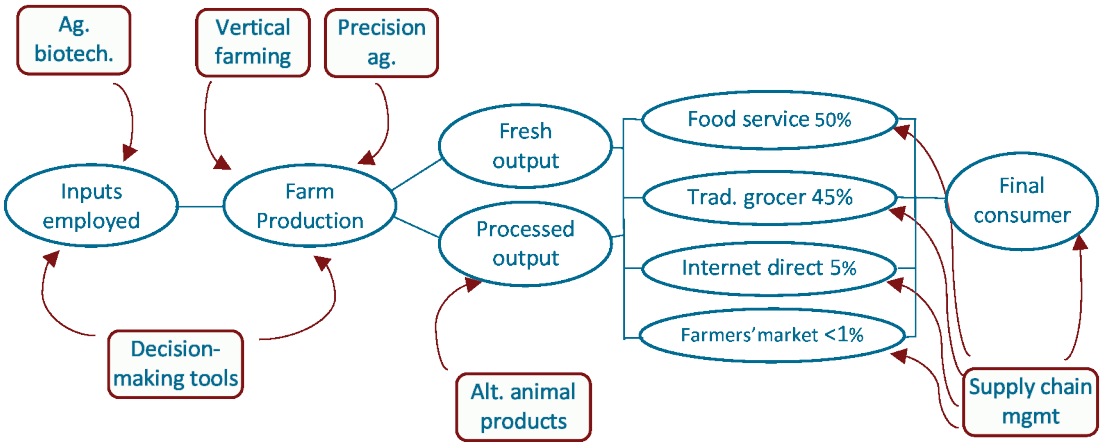


Figure 2. Supply Chain and Agtech Categories



Note: % figures are percent of U.S. sales through each distribution channel.

are not yet able to apply variable water quantities at this granular level.

In some areas of agricultural production, this is beginning to change. For instance, Blue River Technologies developed "see and shoot," which attaches a small robot on the back of a conventional tractor to quickly detect and assess weed growth and then apply a micro-spray of herbicide at the root of the infestation. To further enhance efficiency, the technology is paired with a software program utilizing weather and climate data with remote sensing and GPS to assess the sub-fields most prone to infestations.

Agricultural Biotechnology

Investments in agricultural biotechnology, which was focused on seed modification technologies until recently, have expanded to include new methodologies of gene transfer, gene editing, genomic testing and pathogen identification, and biological imaging. These have been made possible by breakthroughs of CRISPR-Cas9, TALENs, and Zinc Fingers. TALENs and Zinc fingers are gene-editing systems similar to CRISPR that rely on DNA-binding domains to identify target sequences to cleave those sequences. These technologies range in efficiency with CRISPR the most efficient.

Thus far, the political and regulatory framework that has slowed the development of traditional genetic modification techniques has not impeded the early progress of these new technologies. One example is Caribou Biosciences, a UC Berkeley startup, which enhances genetic material of seed varieties using CRISPR-based techniques. Another example is Sostena, a UC Davis startup, which utilizes specialized hybrid breeding techniques in conjunction with their proprietary software to improve the productivity of niche crops such as cantaloupe, watermelon, and pepper.

Moreover, new applications of biotechnology are being applied to algae and mushroom-based products, and the early signs of the growing societal and regulatory acceptance of biotechnology in food products in some parts of the world should allow for greater adoption of these innovations. For example, Synthetic Genomics is developing basic research that may allow algae-based biofuels to be cost effective.

Vertical Farming

Major advances in light diodes, computer-based decision making, and plant genetics hold the promise of allowing vertical farming systems to produce high-value, organic-certified crops in or near urban centers. As a result of consumer preferences being increasingly influenced by the information (certifications) surrounding food product availability, start-up companies in this space have the ability to capture that demand for information through novel applications of vertical farming technology.

For instance, vertical farming companies in California, such as Local Roots Farm in Los Angeles or Plenty in South San Francisco, are producing organic and non-GMO certified products, attempting to capture a higher willingness to pay for these characteristics and to bypass the traditional supply chain to dramatically reduce transportation costs. Overall, these systems drastically reduce water and other input use but face significantly more energy cost than conventional farming in production (due to the need to create light). Light diodes and advances in solar and bio-energy production may increase efficiency of indoor agriculture.

Alternative Animal Products

Alternative animal products comprise a growing range of approaches to create animal-free meat using molecular biology and tissue engineering to generate plant-based meat. These technologies respond to not only environmental consequences of animal products but also to expensive cost

structure of animal meat production. These available technologies utilize advances in genomic and tissue engineering to produce meat products that are converging to the taste, texture, and smell of animal meat. There are two principal methods. One uses all plant-based materials, while the other uses meat tissues combined with cyanobacteria (the only photosynthetic prokaryotes able to produce their own oxygen) to produce meat products in laboratories.

While most venture capital in this space is allocated to alternative terrestrial animal products, such as Memphis Meats and Beyond Meat, Finless Foods is producing fish. Overall, these technologies offer novel methods that may decrease marginal costs, especially in important states like California with increasing strict land and pollution standards.

These firms must also contend with consumer preferences that present challenges in acceptability, especially if there is an early "mistake" or the timing of broader market introduction happens to align with a mishap in another related sector (e.g., Mad Cow Disease occurred the year after the introduction of GMOs in Europe, and became a major target by non-GMO activists, despite the two being unrelated).

Decision-Making Tools

Going beyond the laboratory, farm-level technologies are responding to the increasing milieu of tools at a farmer's disposal. One of the key issues with the introduction of many new technologies is the ability for the farmer to incorporate them in their production systems. Dominant firms in this sector include Farmer's Edge, who utilize Variable Rate Technology to improve crop production and reduce waste, and Farmers Business Network (FNB).

FBN is leveraging modern agronomic and statistical techniques to provide farmers with the most accurate information for improved farm decision-making. For example, FBN shares chemical price data with their members to restructure the current asymmetric information between chemical suppliers and their customers.

Supply Chain Management

Supply chain management technologies promise to provide food distributors and retailers more efficient ways of inspecting, certifying, and preparing food for consumption, and providing final consumers with new levels of convenience and ease of shopping. Business-to-business relationships have also experienced

Table 1. California Agtech Investments

Company name (*acquired)	Invested Capital* ($ millions)	Company name (*acquired)	Invested Capital* ($ millions)
Precision Agriculture		**Vertical Farming**	
Blue River Technologies*	30.8/335	Back to the Roots	19.31
Granular*	24.9/325	Local Roots Farm	-
Abundant Robotics	12.00	Plenty	226.00
TerrAvion	10.50	Crop One Holdings	12.73
Hortau	76.20	California Safe Soil	14.44
PowWow	4.30	Edyn	4.22
Apeel Sciences	40.00	Farmshelf	0.76
Aqua Spy	10.80	Iron Ox	5.00
Vinsight	1.50	**Decision-Making Tools**	
Embodied	3.79	Farmers Business Network	193.90
Agricultural Biotechnology		Climate Corporation*	108.8/930
Caribou Biosciences	44.55	Astro Digital	20.65
TL Biolabs	4.00	Ceres Imaging	7.70
Sostena	8.10	IntelinAir	5.00
Biome Makers	2.20	PastureMap	3.10
Bioconsortia	27.00	OnFarm Systems	1.43
Arcadia Biosciences	101/131	HeavyConnect	0.13
Marrone Bio Innovations	55/107.2	Harvesting Inc	-
Boost Biomes	2.10	**Supply Chain Management**	
Pivot Bio	16.75	Helium	38.8
LumiGrow	19.50	Lineage Logistics	25
Synthetic Genomics	40.00	Haven	13.8
Cibus Global	118.69	Source Intelligence	17.5
Alternative Animal Products		Aera	93.7
Beyond Meat	104.00	Elementum	67
Memphis Meats	20.00	Instacart	875
Impossible Foods	389.00	Sun Basket	108.6
Just (Hampton Creek Farms)	240.00	Flexport	204
Soylent	72.40	Aromyx	5.8
Calysta	93.00	Impact Vision	1.4
Perfect Day	26.80	Astrona	0.2
Ripple Foods	109.00	Clear Labs	36.55
Imperfect Foods	11.70	Mojix	85.5
Clara Foods	1.75	Nima	13.5
Geltor	2.50	Safe Traces	8
		iTradeNetwork*	-
		AxleHire	4.42
		Agralogics	4.18
		trellisgrows.com	2.5

a dramatic landscape change with innovative supply chain technologies revolutionizing their transactions.

Companies in this segment brought in roughly 60% of the $10.1 billion of total U.S. venture funding. These companies are e-grocers, retail chains, and restaurants, which are introducing digital and automated means to conduct purchasing, distribution, and point-of-sale to end-users. This is a major shift in the magnitude and direction of funding—prior to 2015, downstream and midstream investments accounted for less than $5 billion in activity and about one-third of total agtech investments. One consequence of this shift in investment activity could well allow FA to achieve some convergence with other industrial sectors.

An example of a firm in this category is Helium, a smart sensing technology company that monitors and analyzes the temperature of refrigerators, freezers, and other potentially wasteful temperature-sensitive appliances. Companies like Helium are also at the cutting edge when it comes to integrating blockchain technology. Blockchain allows for real-time data collection across smart devices cataloguing information in the cloud to improve traceability and transparency.

With cannabis sales expected to reach $75 billion in the next 12 years, it is unsurprising to see applications of these new technologies in the cannabis industry. For example, Trellis, an Oakland-based seed-to-sale cannabis platform that uses data analytics to track the crop's performance from the plant to the dispensary. The beneficial aspects of the new technologies in this category would be the minimization of the "bureaucracy" or transaction costs within the supply chain. For example, firms can now market directly with their end-users in the case of B2B or access consumers by direct marketing. However, to leverage this potential capability these firms must also augment their skill sets. For example, Sun Basket, a firm specializing in farmer-to-consumer distribution, must incorporate in their streamlined business model the functions performed by the intermediaries they are supplanting, i.e., food safety and processing, packaging, and controlled storage.

Acquisitions

In addition to venture capital funding, a few major buyouts of early stage companies stand out. First, Monsanto purchased Climate Corps for $930 million in 2013, indicating the growing value of timely information technology in farm management. In 2017, John Deere purchased the "see and spray" technology from Blue River Technologies indicating the value of using advanced robotics in the application of pesticides and fertilizers. DuPont Pioneer acquired farm management software company Granular for $300 million, showing a continued focus on augmenting farmers' decision-making efficiencies. These three buyouts total $1.53 billion, with an average multiple of more than nine times the invested venture capital.

Finally, nine major companies recently announced major collaborative investments to develop blockchains as a way to manage global FA supply chains. While these acquisitions speak to the success of these technologies, there have been a number of noticeable failures. For example, SpoonRocket, a premade meal delivery service, shut down in 2016 after failing to raise sufficient capital. Even with a profitable product on the market and $13.5 million in venture funding, SpoonRocket was unable to overcome the cost of capital-intensive on-demand services.

Conclusion

Major challenges remain in finding complementarity between the diverse set of new innovations. For instance, the range of precision agriculture technologies still require the creation of decision rules. While a software program may recommend a certain treatment schedule, a final decision must still be made. New tools may aid this decision, but risk and uncertainty considerations will remain. In addition, farmers will need to sift through a growing set of technologies and companies to decide which ones are best suited for their operation, market, and biophysical conditions.

However, the rate of technological change further complicates the adoption process that is critical for bringing current technologies to scale. Given the rapid expected evolution, many farmers may decide to delay adoption of current technologies, especially those requiring significant upfront investment costs. In a forthcoming *ARE Update* article, we will investigate the incentives for adoption of these technologies across the supply chain.

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For additional information, the authors recommend:

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