Suren G. Dutia

AgTech
Challenges and Opportunities for Sustainable Growth

Sustainable agricultural technology or, more simply, "AgTech," is an emerging economic sector that has the potential to completely reshape global agriculture, dramatically increasing the productivity of the agriculture system while reducing the environmental and social costs of current ag production practices.

Given that we must produce more food in the next 40 years than during the entire course of human history to date, and must do so on a planet showing signs of severe environmental stress, AgTech innovations will be absolutely essential. We believe humanity can rise to the occasion and overcome these monumental global challenges, but to do so will require sustained attention, significant investment, and AgTech-specific entrepreneur support systems to help spur innovation in the field.

My purpose in writing this paper is threefold. First, I seek to increase awareness of the productivity and sustainability challenges of the food system and inspire entrepreneurs to enter the field. Total demand is expected to rise 70 percent by 2050, and current growth rates in agriculture are not sufficient to meet this goal. However, the ag sector faces an even greater challenge because of the uncertain impact climate change will have on future production and constraints posed by the limited availability of land, water, and other key resources. These twin challenges of productivity and sustainability translate to countless opportunities for innovation across the complete value chain, from inputs and agricultural production to transport, processing, distribution, storage, and waste disposal. Visionary entrepreneurs will have the ability to solve pressing societal challenges while capturing the economic value of their new AgTech products and processes.

My second purpose is to help increase the flow of capital to investments in AgTech. The agriculture sector as a whole is one of the world's largest economic sectors, with net farm income of around $120 billion and farm assets at around $2 trillion, with little leverage. Yet there has been relatively little investment in AgTech compared to other industries, like clean energy. Venture capital firms

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compiling portfolios of new AgTech companies are seeing more startups seeking funding than there is capital available, and other investor groups thus far have not entered the field in significant numbers. Given the size of the potential market and the vital societal need for agricultural innovation, we expect that investors soon will realize the opportunity of AgTech and invest substantially in this emerging field.

My third purpose is to highlight the need for regional AgTech entrepreneur support systems to accelerate innovation. We believe that the American heartland provides an ideal example of a region poised to make great strides forward in developing an entrepreneurial sector for AgTech. The heartland has some of the world's best growing conditions and natural resources, and currently produces 27.2 percent of the world's corn, 29.75 percent of its soybeans, 6.7 percent of its beef, and 6.9 percent of its pork, making this region an epicenter of global agricultural activity. The heartland houses some of largest and most progressive agricultural companies in the world, which are looked upon as leaders in their field. The heartland is blessed with highly developed transportation networks along its waterways and railroads, allowing for efficient logistics and transport of ag products. In addition, the heartland has world-class AgTech research capabilities with its land-grant universities and city-level clusters of expertise, such as plant sciences in St. Louis and animal sciences in Kansas City. Given the overall AgTech entrepreneurial activity in the region and the large number of significant multinational players, the American heartland can be a powerful influence in driving the objectives of the AgTech revolution. Taken together, these resources indicate a regional competitive advantage in AgTech, similar to what the Silicon Valley cluster has provided for the IT industry. For these reasons, we believe a concerted effort to develop a regional AgTech entrepreneurial support system will result in immense benefits for the region itself and set an example for other agricultural communities across the world.

I hope this paper launches a larger dialogue on the monumental challenge of sustainable food production for the next 40 years and opportunities for the AgTech sector to help solve this challenge.

GLOBAL CHALLENGES FOR AGRICULTURE: PRODUCING MORE WITH LESS IMPACT

> Over the next 40 years, land, energy, water, and weather constraints will place unprecedented pressure on mankind's ability to access its most basic goods—food, fuel, and fiber. Humanity must now produce more food in the next four decades than we have in the last 8,000 years of agriculture combined. And we must do so sustainably. "The 2050 Criteria," World Wildlife Fund

The global agricultural system faces tremendous challenges. The United Nations Food and Agriculture Organization (UN FAO) projects that food production

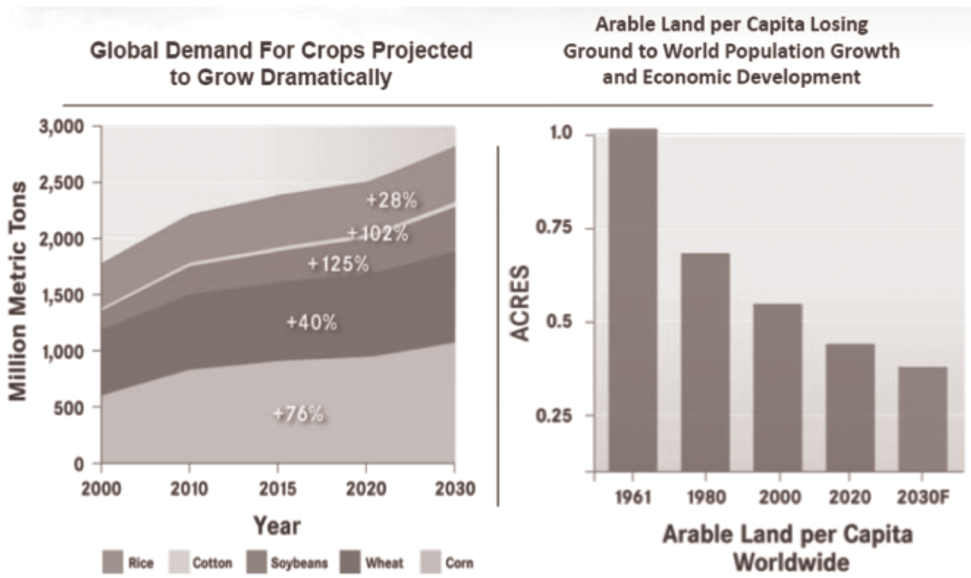


Figure 1. Projected growth in global demand for crops and projected decrease in per capita arable land

Source: IHS Global Insights

must increase by 70 percent over the next 40 years to satisfy increasing demand, due to population growth and rising economic prosperity (Conforti, 2011). The main challenge of global agriculture often is framed in terms of feeding a growing population, which is expected to increase from seven billion people today to approximately nine billion in 2050.

At the same time, there is limited opportunity to expand the land used in agricultural production, and agriculture also must deal with environmental risks such as climate change. To succeed in sustainably increasing food production, major innovations in AgTech are required that increase agricultural productivity and improve the efficiency and resiliency of the entire food system.

While many variables will determine the demand for food in 2050 and the ease with which that food can be produced, the general trends suggest that we will need significantly more food while facing an increasingly hostile environment, due to climate change and diminishing resources. Projections from IHS Global Insights show large increases in the global demand for corn and soybeans, while the amount of arable land per capita continues to decline due to population growth and urban development. The UN FAO projects that both per capita and total demand for cereals, meat, and oil crops will rise by 2050, with little increase in the amount of arable land. Climate change will pose a large challenge to these projections: the International Food Policy Research Institute (IFPRI) projects that cli-

	2005/2007	2050
Population (million)- UN 2008 Revision	6 592	9 150
Population (million)- UN 2010 Revision	*6 584*	*9 306*
kcal/person/day	2 772	3 070
Cereals, food (kg/capita)	158	160
Cereals, all uses (kg/capita)	314	330
Meat, food (kg/capita)	38.7	49.4
Oilcrops (oil. equiv.), Food (kg/cap)	12.1	16.2
Oilcrops (oil. equiv.), all uses (kg/cap)	21.9	30.5
Cereals, production (million tonnes)	2 068	3 009
Meat, production (million tonnes)	258	455
Cereal yields (tonnes/ha; rice paddy)	3.32	4.30
Arable land area (million ha)	1 592	1 661

Figure 2. Projections for key agricultural variables in 2050

Source: HIS Global Insights, Agriculture Division.

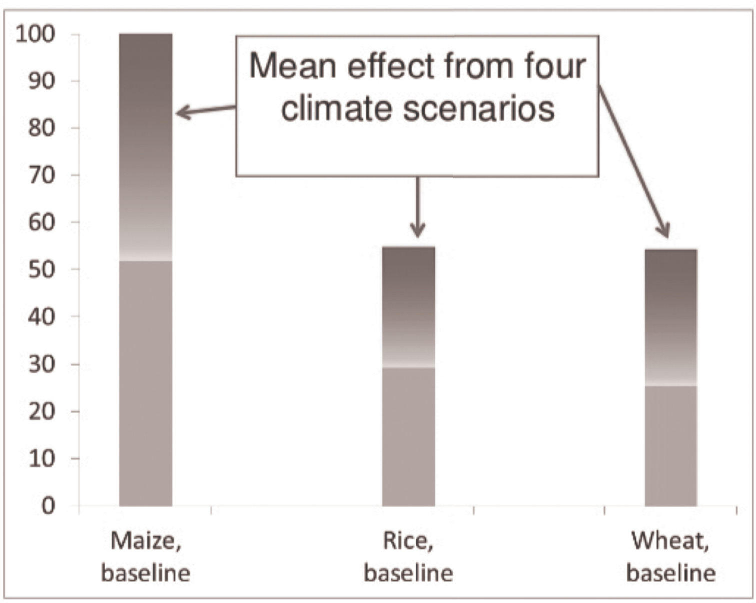


Figure 3. Projected impact of climate change on crop prices.

Source: IFPRI, "Food Security, Farming, and Climate Change to 2050," policy seminar, December 1, 2010.

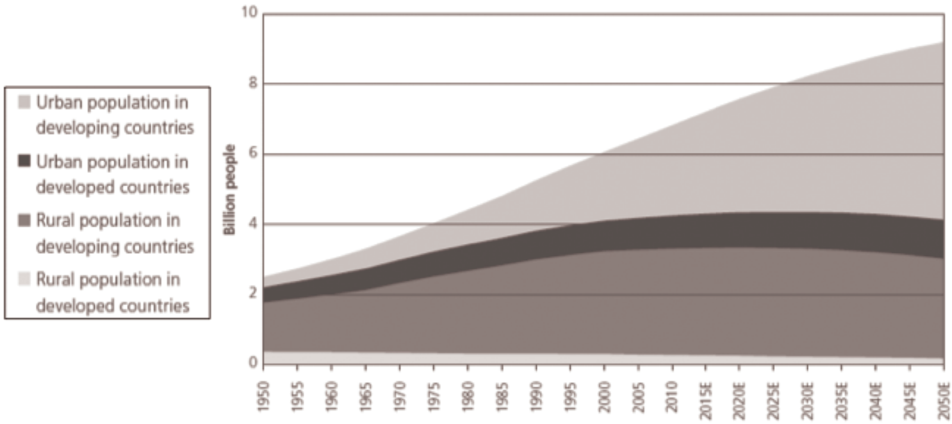


Figure 4. UN projections for urban and rural changes in population

Source: "World Population Prospects: The 2011 Edition," New York: The United Nations, 2011. Alexandratos & Bruinsma, "World Agriculture Towards 2030/2050: The 2012 Revision," UNFAO, 201

mate change will nearly double the price of corn, rice, and wheat. Figures 1–3 showcase these projections.

Recently, Oxfam commissioned modeling to make estimates about what food prices would look like 20 years from now, and determined that under normal circumstances, food commodity prices are likely to increase about 50 percent between now and 2030. And if estimates of climate change are factored in, food prices could be up to 100 percent higher than they are at present. This would put enormous pressure on the world's population, especially its poor.

The Key Demand Drivers: Population Growth, Rising Incomes, and Demand for Renewable Energy

However, the food shortfall challenge will be made even more difficult by the demographic shift in incomes occurring as the population rises; not only will there be more people overall, but more wealthy people who demand more food with greater resource requirements.

Figure 4 shows that the fastest growing segment of world population is urban in the developing world. Billions of people already have moved from the rural countryside into rapidly growing megacities, and billions more are expected to make this transition over the next forty years.

As they gain affluence through rising incomes, the emerging middle classes of the developing world are consuming more meat, fish, dairy, and processed foods, all of which require higher levels of input resources and much higher levels of overall agricultural production.

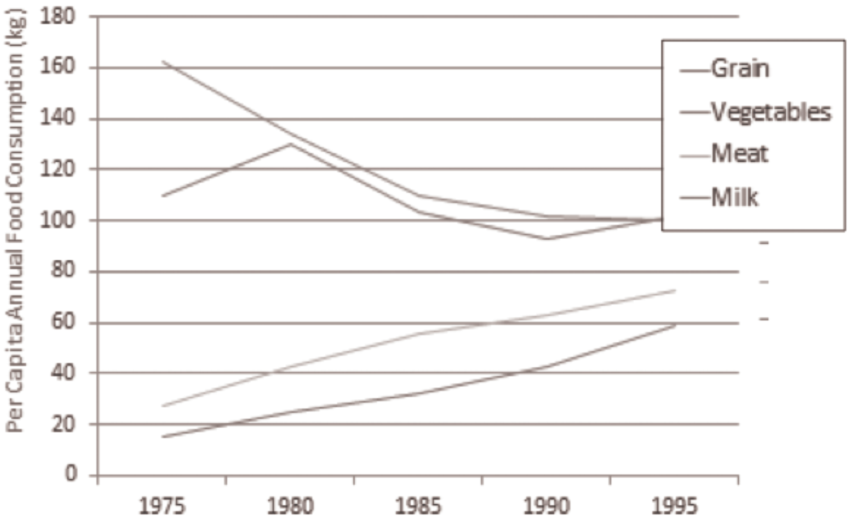


Figure 5. Changing diets in Taiwan, 1975-1995

Source: Taiwan Council of Agriculture, China Statistical Yearbook and Nomura Global Economics.

As a case study of rising affluence driving changes in dietary preferences, consider Taiwan. Between 1975 and 1990, Taiwan's GNI per capita rose from $3,368 to $8,325. In this same period, per capita annual meat consumption rose from 30 kg to 70 kg (see Figure 5). A similar trend emerged in China over the past 30 years, with annual per capita meat consumption growing from 9 kg to 58.2 kg.

A consequence of this rapid growth in meat intake is that China now consumes twice as much meat as the United States. Figure 6 shows total consumption of meat in China relative to the United States. While Chinese per capita meat consumption currently sits at 58.2 kg per year, U.S. per capita meat consumption is double that, at 120.2 kg per year. With increasing populations, even small shifts in meat consumption in the developing world can have a large aggregate impact on total demand.

Increased demand for meat poses a host of challenges to the global agricultural system, as livestock requires up to 8 kilograms of feed for every kilogram of meat produced (see Figure 7 for requirements based on type of meat). Significantly more water is required to produce a kilogram of meat than a kilogram of plant crops. Meat production's high energy, water, and other resource costs thus lead to direct competition between crops grown for direct human consumption and crops grown as inputs for raising livestock or fish in aquaculture.

Biofuels also will be a huge source of competition for diminishing resources available for food production. According to the International Energy Agency, biofuel production will see an 800 percent increase between now and 2050. While

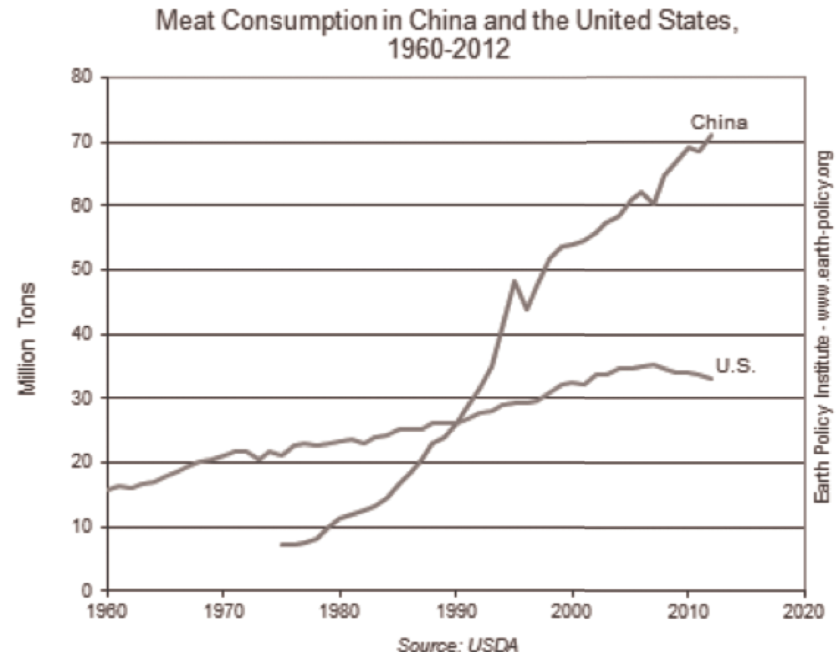


Figure 6. Total meat consumption in the United States and China
Source: Basch et al., "Harvesting Opportunities for a Sustainable Food Supply."

Protein Source	Number of kg of feed required for every kg of meat
Beef	8
Lamb	5
Pork	2.5
Poultry	1.5
Fish	1.2

Figure 7. Animal feed requirements per kg of protein

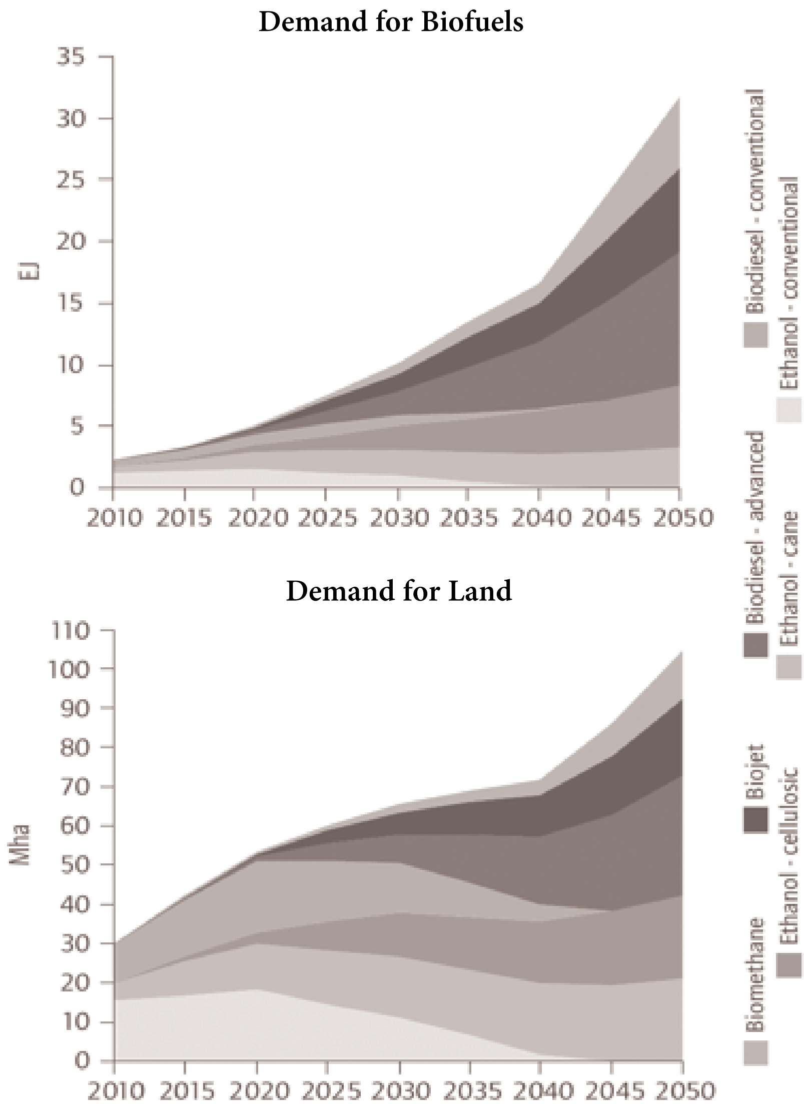


Figure 8. Demand for biofuels (top) and resulting demand for land (bottom)

Source: International Energy Agency, "Technology Roadmap: Biofuels for Transport," 2011.

much of that biofuel will come from nonfood crops and second-generation production techniques such as cellulosic ethanol, most of the current supply of biofuels and production in the near term will provide direct competition with resources used to grow crops for human consumption and feed for livestock. Projected growth in biofuel demand also is expected to require more than triple the land currently used for production, as shown in the bottom graph of Figure 8, further intensifying competition between food crops and biofuel crops.

PLANETARY BOUNDARIES					
Earth-system process	Parameters	Proposed boundary	Current status	Pre-industrial value
Climate change	(i) Atmospheric carbon dioxide concentration (parts per million by volume)	350	387	280
	(ii) Change in radiative forcing (watts per metre squared)	1	1.5	0
Rate of biodiversity loss	Extinction rate (number of species per million species per year)	10	>100	0.1–1
Nitrogen cycle (part of a boundary with the phosphorus cycle)	Amount of N_2 removed from the atmosphere for human use (millions of tonnes per year)	35	121	0
Phosphorus cycle (part of a boundary with the nitrogen cycle)	Quantity of P flowing into the oceans (millions of tonnes per year)	11	8.5–9.5	-1
Stratospheric ozone depletion	Concentration of ozone (Dobson unit)	276	283	290
Ocean acidification	Global mean saturation state of aragonite in surface sea water	2.75	2.90	3.44
Global freshwater use	Consumption of freshwater by humans (km^3 per year)	4,000	2,600	415
Change in land use	Percentage of global land cover converted to cropland	15	11.7	Low
Atmospheric aerosol loading	Overall particulate concentration in the atmosphere, on a regional basis		To be determined	
Chemical pollution	For example, amount emitted to, or concentration of persistent organic pollutants, plastics, endocrine disrupters, heavy metals and nuclear waste in, the global environment, or the effects on ecosystem and functioning of Earth system thereof		To be determined	

Figure 9. Planetary boundaries

Source: Rockstrom et al., “A Safe Operating Space for Humanity,” *Nature* 461 (2009)

* Proposed Planetary Boundaries (starred are relevant to ag, red have been crossed)

Planetary Boundaries and the Risk Posed to Agriculture

In order to continue sustainably, agriculture must exist within a stable environment. Like other biological systems, agriculture is dependent upon earth’s biosphere for resources, such as water and soil. Much of current agriculture also is dependent on manmade inputs like synthetic fertilizer. However, global environmental challenges threaten the sustainability of these inputs.

Recent advances in earth systems science have yielded a new understanding of processes that threaten the stability of the earth’s current biosphere conditions. A landmark 2009 study in the journal *Nature* first proposed the concept of “planetary boundaries,” geophysical thresholds that, if crossed, could be dangerous for humanity (Rockstrom et al., 2009). Some of these planetary boundaries, such as climate change and biodiversity loss, are fairly well known. Other boundaries, such as the nitrogen cycle and global land use change, have received relatively little attention as issues of global concern. The full list of planetary boundaries and their proposed constraints is included in Figure 9 above.

Six of the proposed planetary boundaries are especially relevant to global agriculture:

- *Climate change:* Modern agriculture produces several greenhouse gases, including carbon dioxide, methane, and nitrous oxide. Agriculture contributes 13.5 percent of global GHG emissions (IPCC, 2007).
- *Biodiversity loss:* Agriculture depends on a unique ecosystem of bacteria, fungi, and other microorganisms present in the soil, and this ecosystem often is disrupted by modern agriculture activities.
- *Nitrogen cycle:* The production of nitrogen-based fertilizer through the Haber-Bosch process removes roughly four times the atmospheric N_2 recommended in the proposed boundary.
- *Phosphorus cycle:* The mining of finite sources of P and its concomitant application as fertilizer with subsequent erosion into rivers, estuaries, and oceans. Nitrogen and phosphorus contribute to eutrophication.
- *Global freshwater use:* Freshwater usage can grow only by 1,400 km^3 per year, and agricultural production accounts for roughly 92 percent of total human water usage (Hoekstra & Mekonnen, 2012).
- *Global land use:* Agricultural cropland is 11.7 percent of total global land cover and must not exceed 15 percent, leaving limited land available for agricultural expansion.

Demand for food, fiber, and energy will continue to rise throughout the coming decades, and agriculture's impact on planetary boundaries also likely will rise. However, crossing the planetary boundaries is not sustainable in the long term, as it will trigger geophysical shifts that will decrease agricultural production and lead to other devastating impacts. Ultimately, humanity must operate within the planetary boundaries to allow for a stable global environment and a sustainable civilization.

AgTech innovations can help to reduce or even eliminate the negative global environmental impact of agriculture by reducing the fossil fuel, fertilizer, water, and land requirements for food production. Increasing resource efficiency can help to ensure a more sustainable and more productive food system.

The Dream of the "Evergreen Revolution"

The goal of increasing agricultural production by 70 percent while not pushing the global environment beyond the nine planetary boundaries presents an unprecedented challenge for humanity. We believe innovation in AgTech has the potential to meet both of these challenges, but we will need a new revolution in sustainable agricultural production for this to happen.

Goals for an "Evergreen Revolution"

Food Production: increase total food production by 70 percent by 2050.

Climate: turn global agriculture from a net carbon source to a carbon sink.

Nitrogen: reduce yearly atmospheric N_2 converted to fertilizer by 75 percent.

Water: keep global consumption of freshwater below 4,000 km^3/year. Current consumption is 2,600 km^3/year, leaving 1,400 km^3 remaining.

Land use: cropland can only expand from 12 percent to 15 percent of Earth's surface.

THE MAIN TAKEAWAY:
Sustainable higher yields must be achieved by increasing productivity.

Figure 10. Global goals for an "evergreen revolution" in agriculture

Source: Rockstrom & Karlberg, "The Quadruple Squeeze: Defining the safe operating space for freshwater use to achieve a triply green revolution in the Anthropocene," *Ambio* 39, no. 3 (2010): 257-265.

The Green Revolution of the mid-20th twentieth century provides a recent example of what can happen through technological innovation. In the 1960s, scientists grew increasingly concerned about the growing world population and warned that mass famines were imminent. Yet since 1960, the world population has doubled while the food supply has tripled (UN FAO, 2012). Even more astounding, land under cultivation only grew by 12 percent from 1960 until today; most of the growth in yields came from increases in productivity. The Green Revolution saved many ecosystems from destruction, for without this dramatic increase in productivity, hungry nations likely would have converted more rainforests and wetlands to cropland.

However, the Green Revolution also had significant environmental consequences. Improvements in yields from the Green Revolution required heavy use of fertilizer, disrupting the nitrogen cycle and leading to eutrophication and "dead zones" of oxygen-deprived, largely lifeless areas in the ocean. Green Revolution increases in yields also relied on chemical herbicides and pesticides, contributing to local air and water pollution. In addition, Green Revolution crops demanded large amounts of irrigated water, which in some areas has dramatically lowered water tables and depleted aquifers. Finally, the various technologies used in the Green Revolution, from fertilizer to herbicides to irrigation, all require large amounts of fossil fuel energy, leading to further greenhouse gas emissions and climate change.

Our new agricultural revolution must be an "evergreen revolution," one that increases food production while ensuring environmental sustainability. It must go further than reducing agriculture's negative impact; ultimately, agriculture must contribute positively to the global environment.

Johan Rockstrom, lead author of the group of scientists who created the planetary boundaries concept, proposes the following global goals for an evergreen revolution (Rockstrom & Karlberg, 2010 see Figure 10).

Meeting these goals requires AgTech innovations that can produce food with significant improvements in resource efficiency. To put it another way, we will need to produce more units of output with fewer units of input. Through innovations along the entire agriculture value chain, we can increase the productivity of our farming systems while simultaneously transforming agriculture into a source of environmental health. But achieving the dream of the evergreen revolution will not be easy; it will require sustained investment, increasing collaboration, and enlightened public policy. We also must know the current progress of innovations in AgTech, the subject of the next section of this paper.

AN OVERVIEW OF THE AGTECH SECTOR

The global imperatives presented by the soaring demand for food and the danger of crossing planetary boundaries underscore the need for an evergreen revolution in agriculture. This revolution largely will be driven by innovations in sustainable agriculture technologies. In this paper, we refer to this sector as AgTech, with a clear implication of environmental, social, and economic value. AgTech describes innovative technologies in the agricultural sector that demonstrably enhance the sustainability of the practice by increasing productivity, improving the efficiency of resource use, and reducing ecological impact. They also yield sustained or enhanced profitability to investors by increasing the long-term value of ag production.

Global agricultural production is far from monolithic and involves many different production methods, ranging from the advanced technology and high-yield mainstream U.S. model to low-yield subsistence farming, with many variations in between. In this paper, we focus solely on advanced technology agricultural production, as we believe that this is the best method to produce 70 percent more food while also respecting the planetary boundaries for climate change, biodiversity, nitrogen, water, and land. With this focus, our view of AgTech centers on North America, where adoption of advanced technology for agriculture is most prevalent.

Recent trends in U.S. agriculture illustrate the potential for improvements in AgTech to move us toward meeting the global imperatives of the evergreen revolution. Figure 11 indicates changes in environmental impact of three U.S. crops (corn, soy, and wheat) over the last 25 years. While productivity has risen for these three crops, the environmental impact of growing them has decreased. Corn and soybeans show greater improvement than wheat because of the adoption of

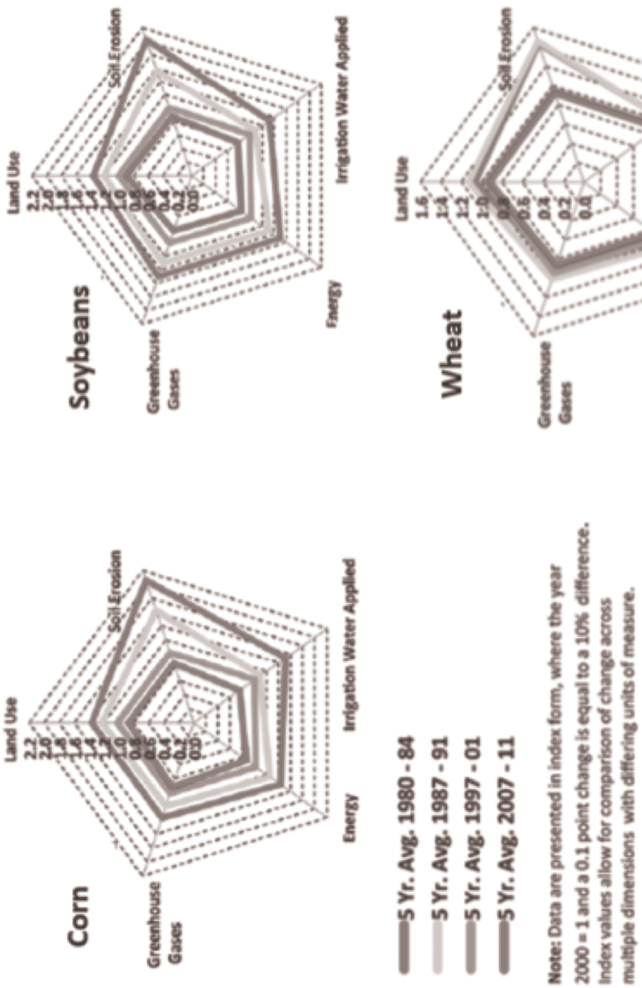


Figure 11. Changes in the environmental impact of three U.S. crops (corn, soy, and wheat) over the last 25 years

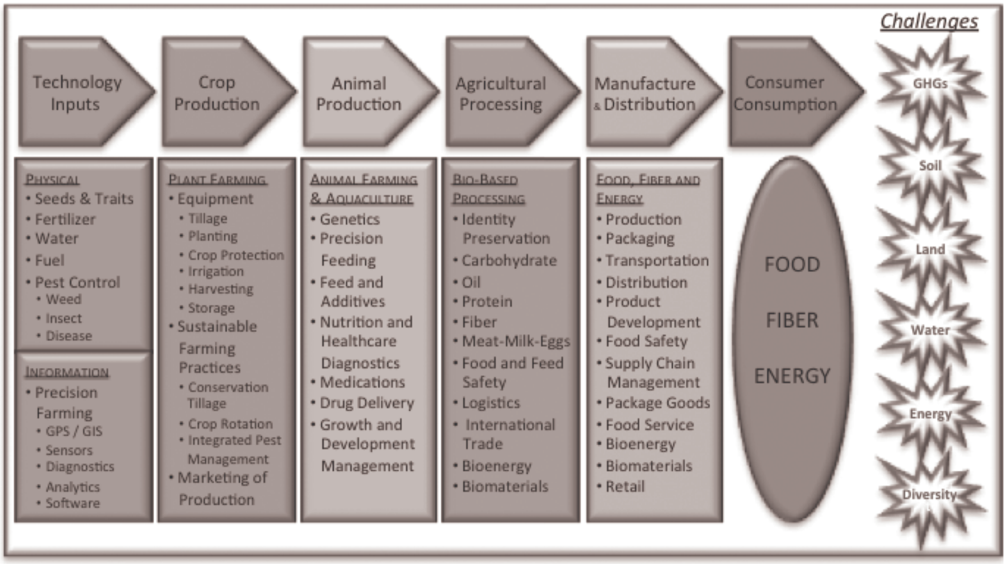


Figure 12. The AgTech value chain

biotechnology products and techniques made possible by these products, such as no-till agriculture.

However, these diagrams also represent the environmental impact per unit of production, meaning that, as production has increased, the total aggregate environmental impact still has continued to rise. As the planetary boundaries framework shows, the rising aggregate environmental impact is not sustainable. Further innovations in AgTech will be necessary if the U.S. agriculture sector is to achieve full environmental sustainability at the production levels needed to meet the world's growing demand.

The AgTech Value Chain

In order to better understand the potential for AgTech innovations, we crafted an AgTech value chain diagram that traces inputs to their final products. This value chain contains seven intermediary steps: physical inputs, information inputs, plant farming, animal farming, bio-based processing, food processing, and logistics (see Figure 12). The value chain can produce three final products: fossil-fuel substitutes (such as biofuel), plant-based food, and animal-based food. Each of the steps in the supply chain has inefficiencies and environmental impacts that must be improved if global agriculture is to reach the goals of an evergreen revolution. Thus, each step in the value chain has the potential for innovation.

One Vision for AgTech: Integrating Genetics, Physical Inputs, IT, and Smart Machinery

Innovations in AgTech do not need to be limited to only one step in the value chain; rather, the most disruptive breakthroughs in AgTech may come from combining innovations in multiple areas. One particular exciting illustration of this combination is an idea known as "integrated farming systems," which will integrate genetics, physical inputs, IT sensing, and smart machinery. Through advances in software and environmental testing, farmers will be able to create custom field prescriptions for seeds, fertilizer, and pest controls. Smart machinery then will carry out the prescribed treatment, all the while collecting further data that will provide feedback to the farmer. This data also will allow seed and farm input companies to develop custom products for farmers. Figure 13 demonstrates this AgTech vision.

The idea of "integrated farming systems," which currently is being advanced by several established companies and by entrepreneurs, still is in early development. This idea of combining advances in genetic engineering, information technology, and smart machinery likely will be pursued by many established companies and startups, due to the vast potential for investment and innovative new products in these three areas.

AgTech and the Controversy Surrounding Genetically Modified Foods

We would be remiss if we did not acknowledge an ongoing debate around genetically modified (GM) foods. GM foods have been sold commercially for about two decades in the United States and there is broad scientific consensus that these foods do not pose greater risk than conventional foods. However, a simmering debate continues about the potentially adverse impact these products could have on the environment and human health, with public opinion deeply divided over safety concerns.

While we recognize the importance of reviewing a wide range of scientific studies and opinions on the use of GM foods, it is beyond the scope of this paper. However, we should note that no major scientific body ever has found that GM foods pose a risk to public health. The U.S. National Academy of Science noted that, after billions of meals served with GM ingredients, "no adverse health effects attributed to genetic engineering have been documented in the human population." European scientific agencies agree with this conclusion, and the scientific advisor to the European Commission has stated that "there is no more risk in eating GMO food than eating conventionally farmed food."

Furthermore, scientific analysis of the environmental impact of GM crops has, to date, not found evidence of environmental harm caused by the products. Instead, a U.S. National Academy of Science 2010 report, "Impact of Genetically Engineered Crops on Farm Sustainability in the United States," found that GM crops reduced agriculture's environmental impact by reducing insecticide and toxic herbicide use, increasing the use of conservation tillage and no-till farming,

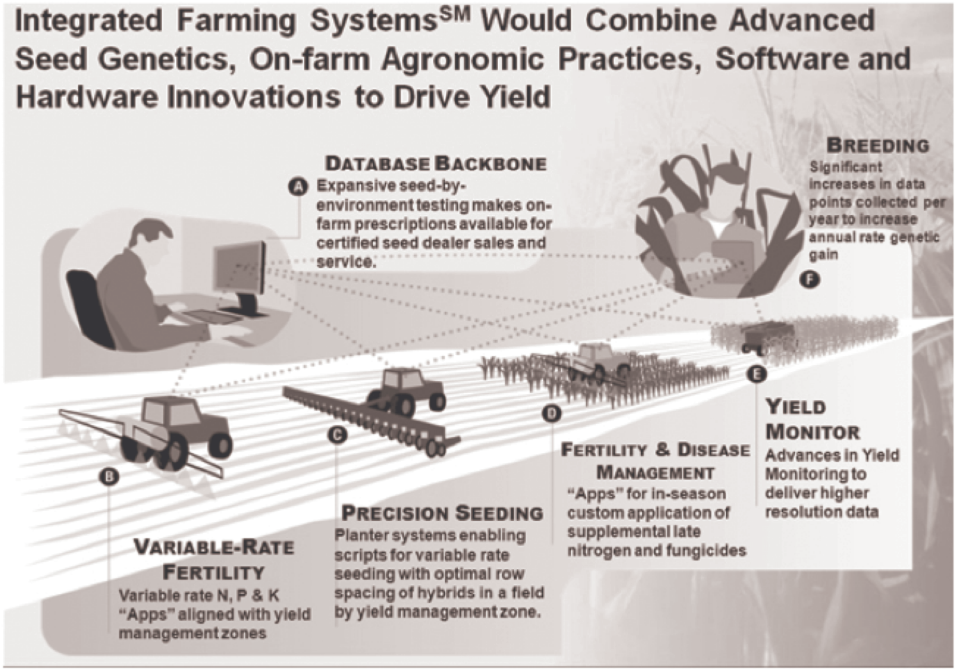
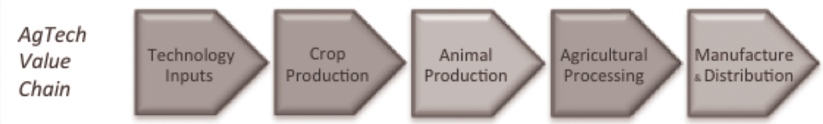


Figure 13. Integrated farming systems

reducing carbon emissions and soil runoff, and improving soil quality. Given the monumental challenge of sustainably producing 70 percent more food over the next 40 years, we believe that no potential tools should be excluded. Without the use of GM foods or other biotech products, meeting the global agriculture challenge will become significantly more difficult.

As outlined in this paper, it is our strong belief that during the 21st century, humankind will be confronted with an extraordinary set of challenges. It is essential that we improve food, feed, fiber, and energy production while reducing environmental impact and enhancing societal development. Meeting these challenges will require new knowledge generated by continued scientific advances, the development of appropriate new technologies, and a broad dissemination of this knowledge and technology, along with the capacity to use it, throughout the world. It also will require that wise policies be implemented through informed decisionmaking on the part of national, state, and local governments in each nation. Regulatory oversight of technology development should continue to be science based, while recognizing the responsibility of government, industry, and the scientific and medical communities to educate the public and improve the availability of unbiased information.

Genetically modified foods have the potential to solve many of the world's hunger and malnutrition problems, and to help protect and preserve the environ-



Year	Technology Inputs	Plant Farming	Animal Farming	Bio-Based Processes	Wellness Foods & Distribution	Total
2006-08	27	21	64	81	55	248
2009	28	8	34	23	46	136
2010	19	4	17	30	21	91
2011	25	13	27	45	20	130
2012	31	15	39	28	20	133
Totals	131	68	202	234	159	794

Figure 14. AgTech startups

To provide an overall state of the innovation ecosystem for AgTech, we analyzed a dataset from the agriculture venture capital group Cultivian of over 900 AgTech startup companies from around the world. This dataset consists of companies that Cultivian considered investing their funds in, and was obtained through direct contact, conferences, referrals, and other methods. We have removed any identifying information from the data and present only aggregate information.

We categorized each of the startup companies by its position in the AgTech value chain. After sorting the data, we were left with 738 companies that fit within the value chain framework. The database also contains the year that Cultivian first became aware of the venture or when the venture was seeking investment. We used this as a proxy to signify the year when the venture perceived itself as mature enough to seek funding. From this data, we created Figure 14, which summarizes Cultivian's deal flow from 2006 until 2012.

From this dataset, it is evident that there is robust stream of new business startup activity occurring across the agricultural value chain in technology inputs, crop production, animal production, processing, and manufacture and distribution. This innovation activity has occurred over a sustained period of six years, averaging 132 startups per year for a single venture firm.

ment by increasing yield and reducing reliance on chemical pesticides and herbicides. Yet there are many challenges ahead for governments, especially in the areas of safety testing, regulation, international policy, and food labeling. Many people feel that genetic engineering is the inevitable wave of the future and that we cannot afford to ignore a technology with such enormous potential benefits. However, we must proceed with caution to avoid causing unintended harm to human health and the environment as a result of our enthusiasm for this powerful technology.

Examples of AgTech Startup Activity

To showcase some of the many innovation opportunities in the AgTech sector, we chose from the agriculture venture capital group Cultivian's dataset of over 900 AgTech startup companies (see Figure 14) four examples of startup companies from different steps in the AgTech value chain. The quoted description for each company comes directly from Cultivian's portfolio website.

- *Information Technology Inputs:* AquaSpy—IT and irrigation. "AquaSpy develops, manufactures, markets and distributes moisture sensors and smart information technology for the irrigation market. Its intelligent water monitoring systems have broad agricultural applications and are designed to help farmers manage and reduce irrigation costs."
- *Physical Technology Inputs:* Divergence: genomics and pest control. "Divergence is a research and development company employing comparative and functional genomics to identify compounds, proteins, and genes to control parasitic nematode infections in plants, animals, and people." Divergence was wholly acquired by Monsanto in 2011.
- *Plant Production:* Harvest—robotics for ag activities. "Harvest develops novel robotics and materials handling systems for agriculture and greenhouse applications."
- *Bio-Based Processing:* Allylix—bio-based production technique of terpenes. "Allylix Inc. develops terpene products and their derivatives for the flavor and fragrance, food ingredient, pharmaceutical, agricultural and biofuel markets. Allylix's technology produces high-value natural terpenes in greater quantities, of higher quality, and at significantly lower cost than traditional sources."

While we believe that these four companies are a good representation of the diversity of activity in the AgTech sector, the inclusion of these companies should does not represent an endorsement.

The AgTech space has the unique opportunity to gain ground by counteracting the fearmongering about genetically engineered crops and bringing about more openness, education, and transparency while working with farmers and innovators. While biotech advances in medicine and pharmaceuticals have been well received by the public, individuals view innovations in plants and food more skeptically. We must bring about a broad-based understanding of the enormous challenges that lie ahead to create meaningful change. It is essential to bring a congruence of pragmatic innovators, humanitarians, and environmental organizations together with entrepreneurs and ag companies to achieve the common objective of producing adequate food for the next century.

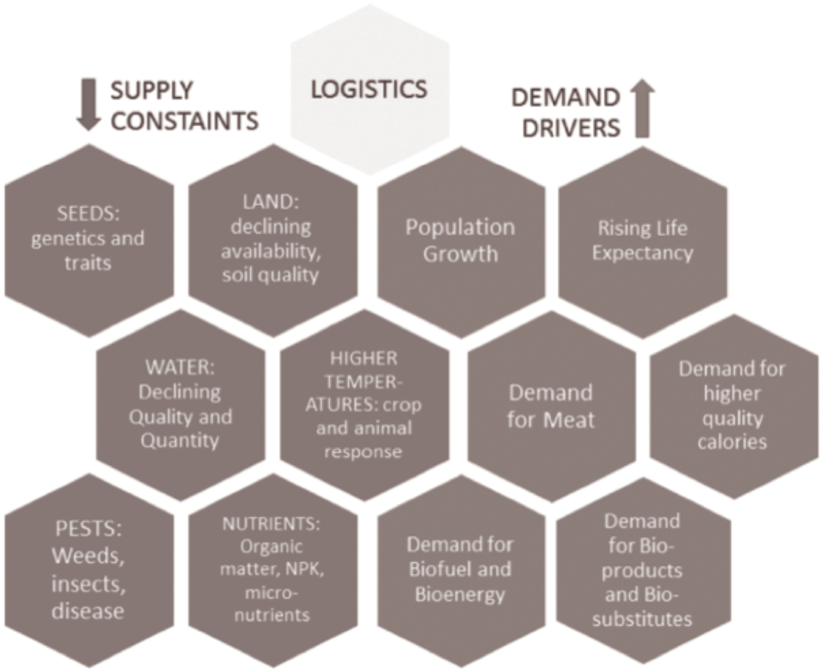


Figure 15. AgTech Supply Constraints and Demand Drivers

THE INVESTMENT CASE FOR AGTECH

The AgTech sector has tremendous opportunities for investment. The demand for sustainable food, fiber, and energy production has been growing throughout the twenty-first century, making agriculture a stable and reliable investment. Below are five reasons why we believe AgTech innovation is a smart investment:

- Grain consumption is increasing worldwide.
- Demand for sustainable energy is growing.
- Access to quality arable land and soil is constrained.
- Access to adequate water quality and quantity is decreasing.
- Current cultural practices are not sustainable in the face of increasing environmental challenges.

Figure 15 provides a glimpse of the various demand drivers and supply constraints for the entire agriculture system. Because of the factors shown on the figure's right side, demand for agricultural products will continue to rise, while the supply constraints will make meeting the demand extremely difficult. AgTech innovations that help meet these challenges will offer investors and entrepreneurs a fertile opportunity for investment and invention.

Logistics, which coordinates the movement of ag products and support availability and the timely balance of supply and demand, is another area essential to the success of AgTech innovations. Because of its critical role, we have given logistics special prominence in the above graphic.

Changes in U.S. Public and Private AgTech R&D Spending

Throughout most of the 20th century, much research and innovation in agriculture was funded with public money. Since the early 1980s, however, public expenditures on agriculture R&D have stagnated, even as demand for ag products continues to rise. As public funding has ebbed, new flows of capital from the private sector have increased. This is particularly evident in developed countries like the United States, where private spending on agriculture R&D has been consistently higher than public spending for the past three decades. The decline in public R&D is a trend affecting primary research in the United States for all types of science and is not just an issue for AgTech. However, the needs and opportunities present in the AgTech sector deserve special attention from policymakers (see Figure 16).

The Important Contribution of Private R&D Spending to Global Agricultural Growth

Global gains in agricultural productivity realized during the Green Revolution of the 1960s, 1970s, and 1980s were driven by input intensification and crop-area expansion. In comparison, the productivity gains achieved in the 1990s and 2000s largely were driven by innovations (total factor productivity) and less from input intensification or new land being brought into cultivation. Figure 17 highlights the shift away from heavy spending on increasing fertilizer and pesticide inputs to investments in genetic engineering and other high-tech improvements that increased yields with fewer units of input. This trend toward greater resource efficiency is encouraging, but much more needs to be done.

With public R&D spending in advanced developed countries stagnating or declining, private investment may be the best way to spur further innovations in AgTech and achieve the growth in production needed to sustainably meet the rising demand for ag products. Figure 18 demonstrates that private-sector investment in food and agriculture has increased steadily in the past decade, reaching $8 billion annually for crop inputs and $2 billion annually for animal inputs by 2010. However, private investment must increase even further if advances in innovation are to continue.

Overall Comments on the Future of AgTech Investment

As can be seen from the top-level investment data in Figure 18 and the micro-level Cultivian data, AgTech investments are being made across the supply chain. There also are interrelationships between supply chain categories. For example, the value of new seed traits may not be fully realized without other equipment and information innovations needed to advance precision agriculture. Additionally, advances in logistics will be needed to segregate outputs as crops become optimized for specific uses such as animal production, human nutrition, or bio-based substitutes. Furthermore, as climate change negatively affects current production methods, still more innovations will be needed.

Some Areas of Opportunity for Ag Tech Investment

The AgTech sector holds many opportunities for investment, with innovation needed throughout the entire value chain. Specific areas available for investment include the following:

Animal Nutrition and Health
Aquaculture
Bioenergy
Biological Pest Control
Biomaterials
Bionutrition
Biotechnology
Crop Nutrition
Crop Protection
Decision Support Technologies
Feed Efficiency
Fertilizer Efficiency
Food Traceability and Safety
Food Storage and Preservation
Information Systems
Integrated Pest Management
Irrigation Efficiency
Land Management
Machinery
Precision Agriculture
Robotics
Seeds and Genetics
Soil Amendments
Soil Health
Sustainable Production Systems
Technology Transfer
Urban Agriculture
Water Quality and Preservation
Waste Mitigation and Manure Management

Crucially, demand necessitates innovations. Over the past five years, innovations in agriculture technology (precision ag innovations, data analytics and processing, platforms for the collection and distribution of complex data streams, and IT-driven extensions) are on the rise in the heartland, and in California and North Carolina. Pressing needs and challenges often fuel research and innovative outcomes in various global farming hubs. New Zealand is one of the world's largest producers of dairy, lamb, and sheep, while Australia is a leading producer of wheat and animal feed. Investment authorities and private wealth funds from Singapore,

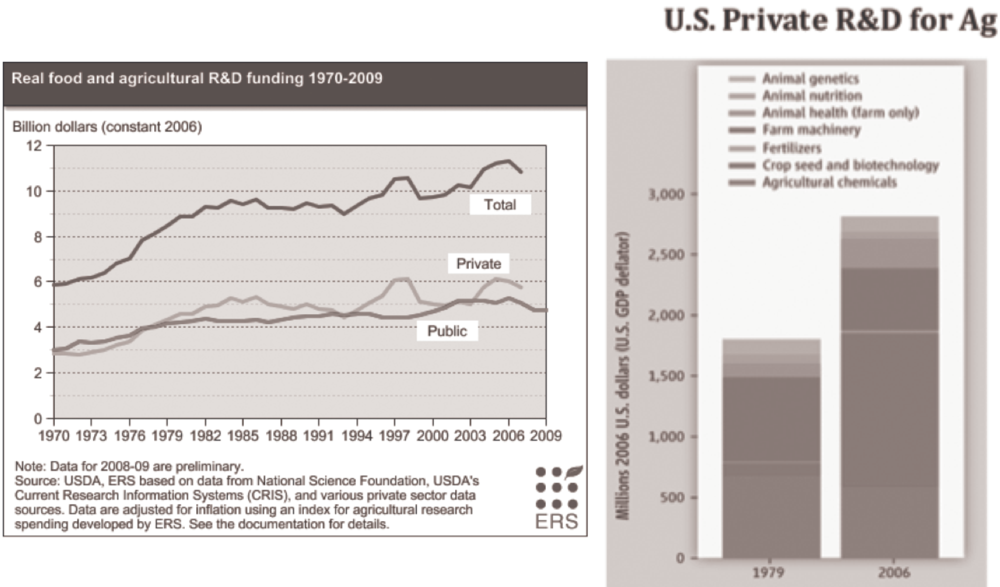


Figure 16. Trends in public and private AgTech R&D spending in the United States

The growth of private R&D spending on AgTech illustrates a simple and, on its face, obvious point: investing in AgTech offers solid opportunities for innovation and value creation. Corporations and private investors are largely rational in their decisionmaking, generally only investing capital when they have a high degree of confidence in a good return. When entrepreneurs and private industry develop business models that capture the value of needed AgTech innovations, they have a tremendous opportunity to achieve high returns. Indeed, this has happened with the development of biotechnology. The right-hand graphic in Figure 16 shows the dramatic increase in private R&D spending in crop seed and biotechnology between 1979 (shortly before the U.S. Supreme Court allowed for patenting of biotechnology traits) and 2006; this research spending occurred because of the opportunity to capture value from novel applications of genetic engineering.

Source: (above left) USDA, "Background: Agriculture Depends on Research and Technology Development," 2012; (above right) Fuglie et al., "The Contribution of Private Industry to Agricultural Innovation," Science 338, no. 6110 (2012).

Dubai, and Qatar are beginning to take notice of geographic centers with farming capabilities, including those in China, Brazil, and Chile.

Government policies, regulations, incentives, and penalties will play an important role in determining the AgTech sector's future. It either could result in growth spurts or constrain innovation and entrepreneurial activity in the sector, and investors will need to stay abreast of how these are impacting returns.

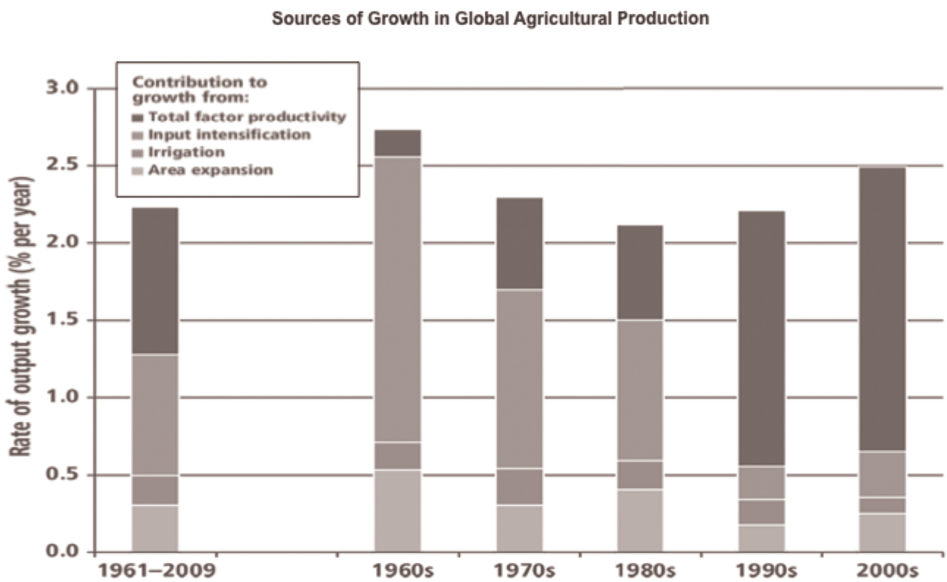


Figure 17. Relative contributions to growth in global agricultural production

Source: Fuglie et al., "Productivity Growth and Technology Capital in the Global Agricultural Economy," Productivity Growth in Agriculture, 2012.

We also want to highlight a potential trend where investors may have a more diverse set of return motivations. Economic returns still dominate, but goals relating to social consciousness and environmental returns also are on the rise. These types of returns always have existed and historically have received philanthropic and government support. However, new sources of capital are emerging that seek environmental and social returns or, at least, having these returns blended with economic returns, including social entrepreneurship innovations funded by socially conscious investors; declared socially conscious corporations; socially conscious innovator and corporation partnerships; consumers making purchasing choices based on environmental and social factors; crowdfunding; and others. As these trends gain momentum, there may be opportunities in the AgTech sector to translate shared social returns into individual economic returns.

Overall, we see the AgTech sector evolving through an increasing number of agriculture technology entrepreneurs connecting with angel, venture capital, corporate, philanthropic, government, and other investors to create an even more vibrant sector within the global economy. We foresee many "green" opportunities across the supply chain categories to suit the size and characteristics of different entrepreneurs and investor classes. The attributes of a potential investment opportunity and associated return on investment also will be key. As always, the most

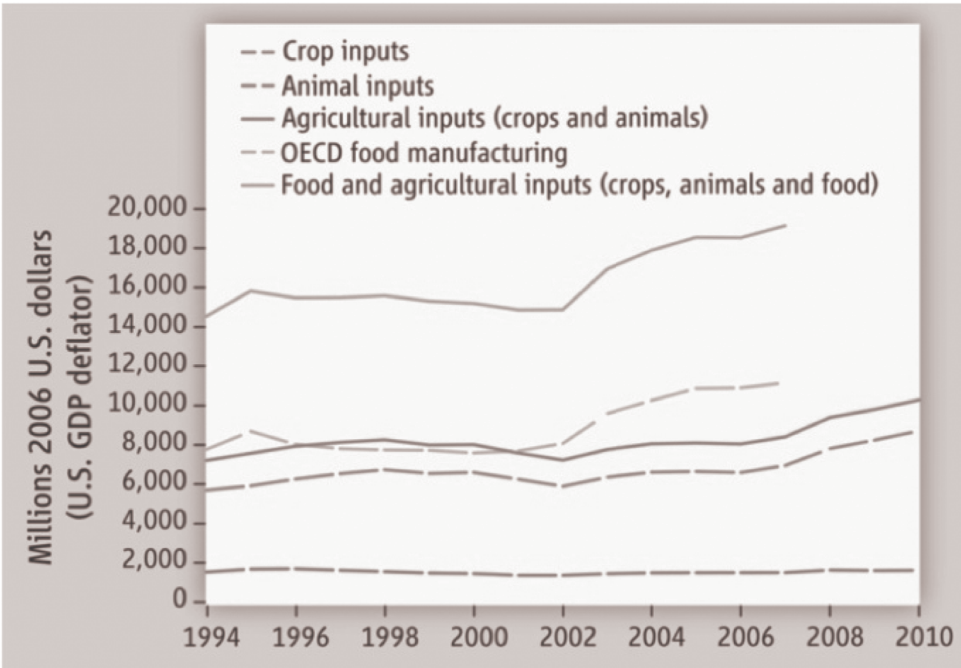


Figure 18. Global private investment in food and agriculture research

disruptive and quickly scalable breakthroughs will deliver the most handsome economic, social, or environmental returns. Investors and entrepreneurs will have many opportunities to collaborate, given the magnitude of the need and the return opportunities.

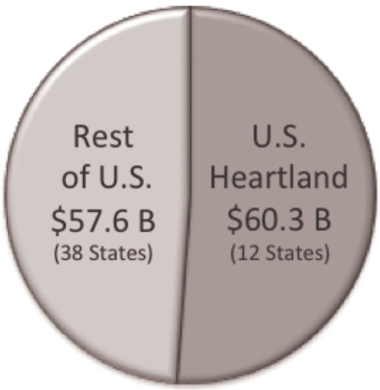
THE OPPORTUNITY FOR AGTECH IN THE U.S. HEARTLAND: AN EXAMPLE OF REGIONAL ASSETS AND EXPERTISE TO DRIVE INNOVATION

While the evergreen revolution is a global challenge and AgTech is broadly applicable across North America, the AgTech innovation required to achieve sustainable increases in productivity will happen through research and entrepreneurial networks at a regional scale. We believe that the American heartland is one of the regions especially well suited for the challenge of developing a robust innovation ecosystem in AgTech. The American heartland already has the research and innovation hubs needed to develop the new AgTech products and processes, and is beginning to develop the entrepreneurial hubs needed to grow these innovations to scale. But it will need to do more if it hopes to be the center of the emerging AgTech revolution and capture the value of the resulting products and processes.

Total U.S. Net Farm Income was $117.9 B in 2011

Agricultural Sectors Crop, Vegetable, Forestry and Livestock Production

U.S. Net Farm Income = $117.9 B



U.S. Department of Agriculture; Economic Research Service 2013

Heartland Net Farm Income = $60.3 B; 51.2% of Total

State	x $1,000	
Iowa	$10,813,218	9.2%
Nebraska	$7,456,742	6.3%
Illinois	$6,099,710	5.2%
Minnesota	$5,784,631	4.9%
Kansas	$5,191,219	4.4%
South Dakota	$4,619,874	3.9%
Ohio	$3,886,437	3.3%
Indiana	$3,803,890	3.2%
Wisconsin	$3,802,732	3.2%
Michigan	$3,347,852	2.8%
Missouri	$3,333,185	2.8%
North Dakota	$2,171,118	1.8%
Heartland	**$60,310,607**	**51.2%**
Rest of U.S.	$57,597,050	48.8%
TOTAL US	$117,907,650	100.0%

Figure 19. Contribution of the heartland to U.S. net farm income

As a group, the 12 states listed in Figure 19 generated $60.3 billion in net farm income in 2011, or 51.2 percent of all U.S. net farm income. The heartland produces 85 percent of U.S. corn, 85 percent of U.S. soybeans, 70 percent of U.S. pork, 45 percent of U.S. eggs, 33 percent of U.S. milk, and 30 percent of U.S. beef. This high quantity of production makes the heartland important in global commodity markets, as heartland corn and soy comprise 27.2 percent and 29.75 percent of global production, respectively.

Source: U.S. Department of Agriculture, Economic Research Service, 2013.

Defining the U.S. Heartland

For our purposes, we define the U.S. heartland as the collection of Midwestern states that generate the highest concentration of agriculture-related economic value in the United States. Commonly referred to as America's heartland, or the Midwest, this region consists of 12 states in the north-central U.S.: Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, and Wisconsin. The area has some of the richest farming land in the world, and has come to be known as the nation's "breadbasket."

Heartland Assets for AgTech

The heartland is one of the world's most fertile crop production areas, with abundant soil and a climate that currently is amenable to producing large amounts of food. In 2006, a study by the Potsdam Institute for Climate Impact Research sim-

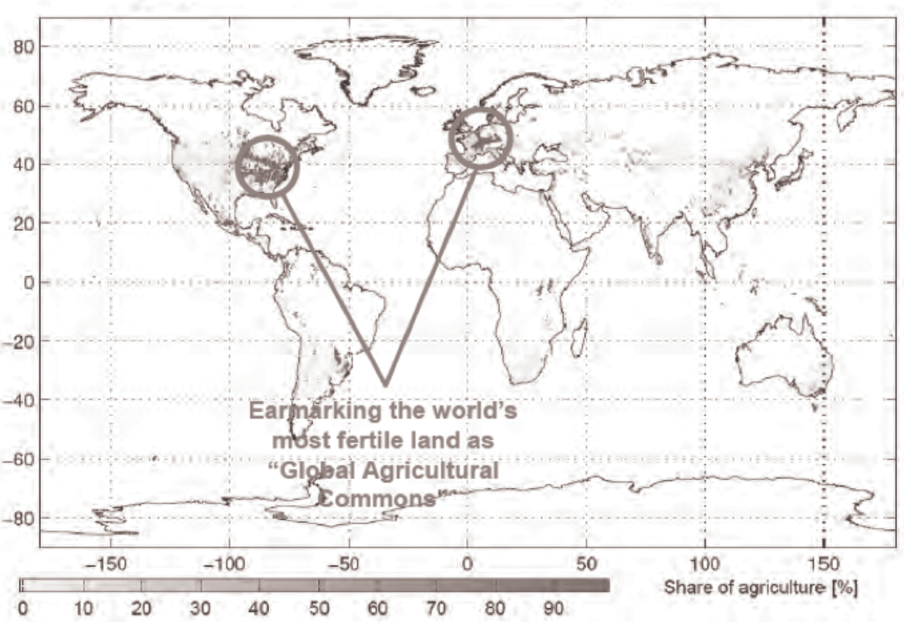


Figure 20. Simulation of globally optimized agricultural production

Source: Kahn & Zaks, "Investing in Agriculture: Far-Reaching Challenge, Significant Opportunity," Deutsche Bank Group, 2009.

ulated what optimal global agricultural production would look based solely on climate, soil, and water constraints, without any regard to existing ag infrastructure. The results of this simulation, displayed in Figure 20, below, show that the U.S. heartland and central Europe are the two most fertile areas in the world. Thus, the heartland's unique geography explains its high concentration of farms of the United States, as shown in Figure 21.

The heartland also has unique advantages in its transportation and processing infrastructure. Goods can be moved by rail, truck, or barge, and transportation networks are concentrated within the region (see Figure 22). Farm products can be shipped from any coast, reaching the Pacific Ocean by rail, the Gulf of Mexico via the Mississippi River, and the Atlantic Ocean via the Gulf of Mexico. Value-added products, such as ethanol or biofuels, can be processed directly in the heartland, due to its concentration of processing facilities, as shown in Figure 23.

Potsdam Institute's Simulation of Globally Optimized Agriculture Production

In addition, the heartland has a strong concentration of human capital and research infrastructure focused on AgTech, including land grant public universities and prestigious research institutions. The land grant universities provide a unique network of cutting-edge basic science platforms, which are catalyst of

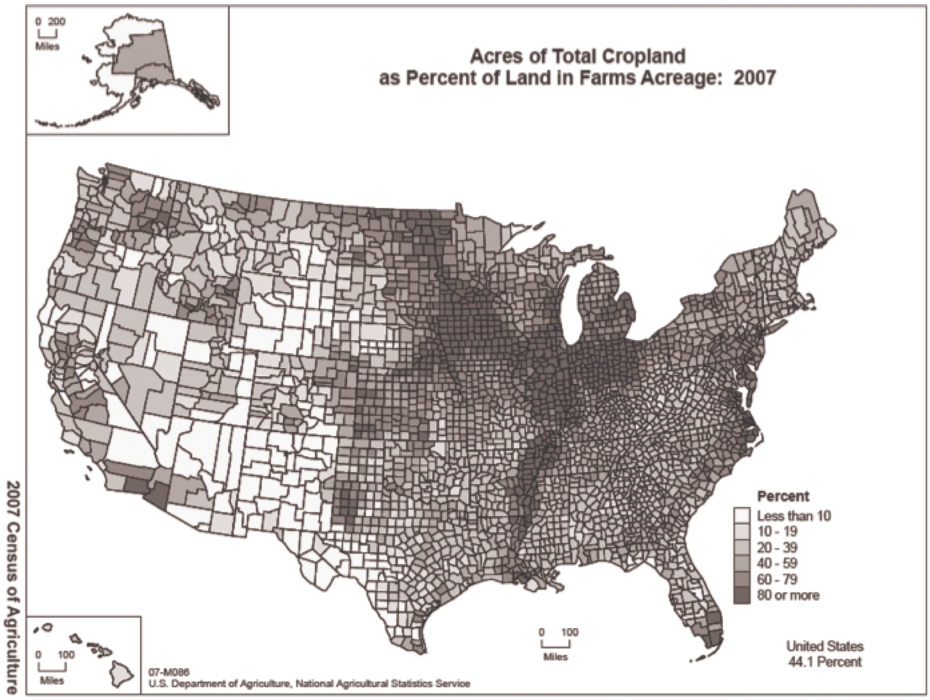


Figure 21. Freight tonnage on highways, railroads, and inland waterways, 2007

Source: U.S. Department of Agriculture, National Agricultural Statistics Service.

innovation, knowledge transfer, entrepreneur development, and a well-trained workforce.

An Opportunity for the Heartland: Building AgTech Entrepreneur Support Systems

It seems only natural that the heartland would serve as the epicenter for the development of a comprehensive innovation ecosystem and entrepreneurial economy around the emerging AgTech sector. However, several factors are holding back such a collaborative effort. First, the heartland does not have a strong regional identity, with various states claiming sole ownership of the "Midwestern" identity. This leads to competition between states and a narrow vision, only looking within a state's borders for beneficial economic opportunities and preventing larger interstate projects. The heartland also has resisted letting go of its current economic practices, having experienced a very prosperous 20th century after the rise of organized labor and American superiority in global agriculture. While globalization has upended this established economic model, Americans in the heartland often are hesitant to let go of the recipe that led to success in the past. Finally, the open culture of investing in innovation that exists in places like San Francisco or Boston does not exist in much of the Midwest, which maintains a more stable and sometimes hierarchical social order.

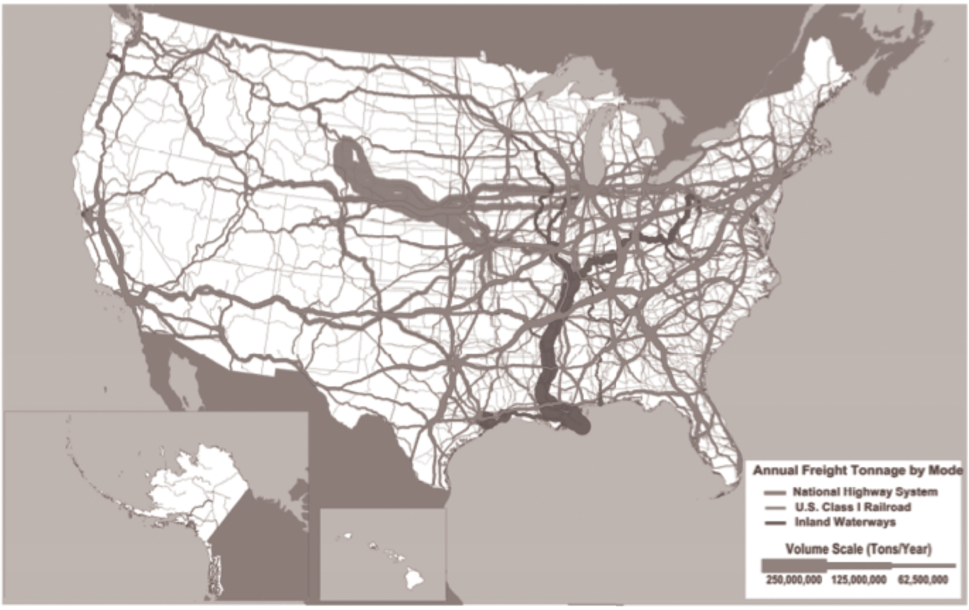


Figure 22. Annual U.S. freight tonnage by mode

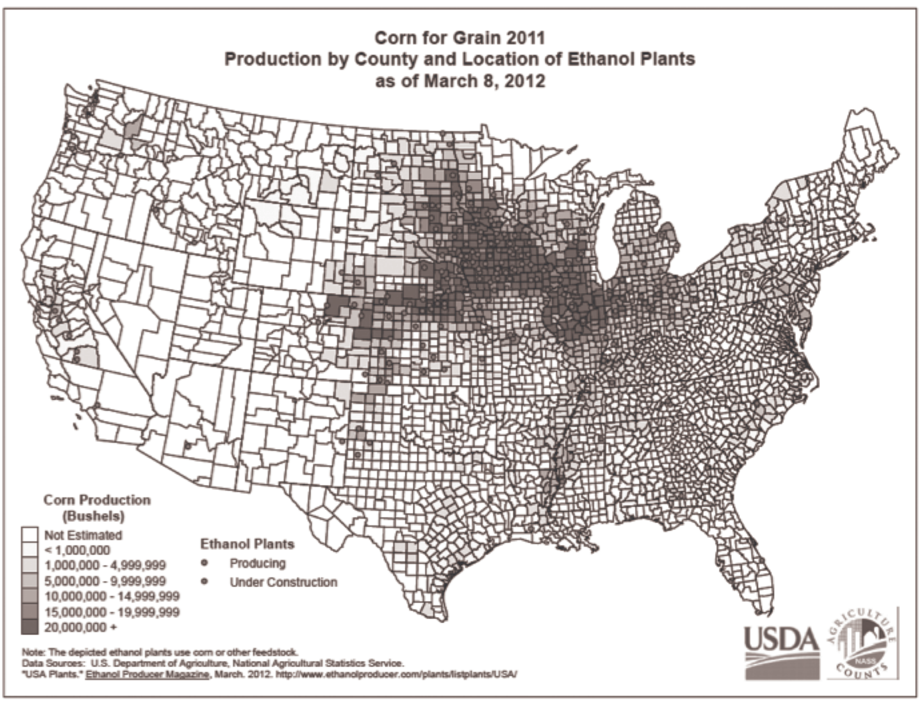


Figure 23. Location of ethanol processing plants in the United States

Source: "Production by County and Location of Ethanol Plants," USDA, 2012.

Figure 24. Institutions of higher education in the heartland contributing to AgTech innovation ecosystem

These cultural dynamics can be a huge obstacle to building successful innovation ecosystems and entrepreneurial economies, but Midwestern cities already are starting to have some success. Two of the most hopeful places for entrepreneurial activity in the AgTech sector are the St. Louis and Kansas City, Missouri, metropolitan areas. St. Louis has invested in institutions like the Danforth Center and BRDG Park, and the combination of its universities and the large AgTech research company, Monsanto, have helped it develop a fairly robust economy around innovations in the plant sciences. Kansas City has focused on animal health, and traditionally has had expertise in the areas of livestock and animal sciences. While Kansas City itself does not have any animal health research centers, the larger region incorporates top-tier veterinary schools at the University of Missouri, the University of Kansas, and Kansas State University. Both cities now are in the early stages of developing more comprehensive entrepreneurial support systems for their respective focus areas.

Some of the world's leading agribusiness, chemical, and farming companies are located in the heartland: Dow Chemicals, an American multinational chemical corporation headquartered in Midland, Michigan; Monsanto, the world's largest seed comp agricultural biotechnology corporation headquartered in Creve Coeur, Missouri; Deere & Company, commonly known by its brand name, John Deere, one of the world's largest manufacturers of agricultural machinery, based in

Moline, Illinois; the Archer Daniels Midland Company, an American global food-processing and commodities-trading corporation, headquartered in Decatur, Illinois; Cargill, an international producer and marketer of food, agricultural, and industrial products and services, based in Minneapolis; And Procter & Gamble, a multinational consumer goods company headquartered in Cincinnati. These are just a few of the leaders in the agricultural and food spaces, and with their combined forces, they can make a real difference in the amalgamation of clean energy, sustainable agricultural practices and productivity, and advances in new technology. These large players have the potential to create the right ecosystem and inspire new startups in their communities.

Many of the developing nations look up to the U.S. heartland in terms of advances in farming technologies and mechanization of their agriculture sectors. AgTech entrepreneurs and innovators can get a head start by incubating in close proximity to these advanced companies. Similar to the technology prowess of Silicon Valley, the financial leadership of New York, or the entertainment hub of Los Angeles, America's heartland has the right ingredients to be a powerhouse in the agriculture technology space.

RECOMMENDATIONS

We conclude this paper with five major recommendations:

- Educate and promote the opportunities provided by AgTech.
- Build and support regional AgTech innovation support systems with "agripreneur" champions.
- Enable the transition to new technology around the theme of "Green and Lean Efficiency."
- Engage nonpartisan groups.
- Develop human capital to meet the needs of tomorrow.

1. Educate and promote the need and opportunity for AgTech and sustainable agriculture.

For entrepreneurs to build AgTech companies, for investors to direct capital to AgTech ventures, and for public officials to promote AgTech development through public policy, they first must know that AgTech exists. They must learn about the major challenges of meeting rising global demand for ag products while staying within the planetary boundaries. And they must realize how the United States, and in particular the heartland, can play a hugely constructive role in moving AgTech forward.

2. Build and support regional AgTech entrepreneur support systems with "agripreneur" champions.

Two sets of factors will be needed to create an AgTech entrepreneur friendly culture. The first factors needed are social relationships and a collaborative culture, which we believe to be the most essential elements in building an effective entrepreneur support system. The support system should be led by an AgTech entrepreneur champion. This person must serve selflessly for the benefit of the whole, contributing countless hours toward building a system that will help others succeed. The champion must have deep expertise in the area of entrepreneurial activity, but must be willing to set aside his or her ego and let others take credit. Such a champion will create a collaborative, grassroots entrepreneurial culture. As this culture matures, deal quality and volume will grow naturally, creating a scalable culture with many investment opportunities. For AgTech, such a champion must be an "agripreneur," someone completely immersed in the agriculture system across the complete value chain and with deep entrepreneurial experience in agricultural innovation.

Regional agripreneur champions should be consciously and regularly (at least quarterly) connected across regions. The purpose should be to enhance the overall network, and the goal to share ideas about how individual regions are developing and supporting entrepreneurs. As the collective support systems gain momentum, entrepreneurial activity and needed innovations will blossom. Thus, agripreneurs will attract and develop more agripreneurs.

The second set of factors that needs to be created relates to economic development items. These include infrastructure and capital formation. Some of these assets already exist in the same regions and more will be needed as the AgTech entrepreneur culture grows and scales. Economic development investments usually are made regionally and should be guided by direct feedback from agripreneurs.

"Agripreneur" champions particularly are needed in the heartland, where the culture of entrepreneurship and collaboration is not as strong as on the coasts. There already are many AgTech startups in the heartland: in the Cultivian dataset, 305 companies out of the 800 full companies represented in the database were headquartered in the heartland, and 200 were located in the "corn belt" subregion (Iowa, Illinois, Indiana, Missouri, and Ohio).

3. Enable the transition to new technology around the theme of "Green and Lean Efficiency."

The term "Green Revolution" was coined in 1968 to indicate revolutionary improvements in crop yield in several Asian countries. Many of these improvements came at the cost of adverse environmental effects in areas subjected to intensive farming. However, where population pressure is high, there is no option except to produce more food. Productivity must increase, but in ways that are environmentally safe, economically viable, and socially sustainable. This has been christened the evergreen revolution.

We are shifting from scale-driven efficiency to "green and lean" efficiency. After 60 years of chemical control, farming now is entering an era of responsible, transparent, and ecological control, driven in part by consumer demand. AgTech is at the cusp of a new revolution in which innovations in seeds, nutrition, protec-

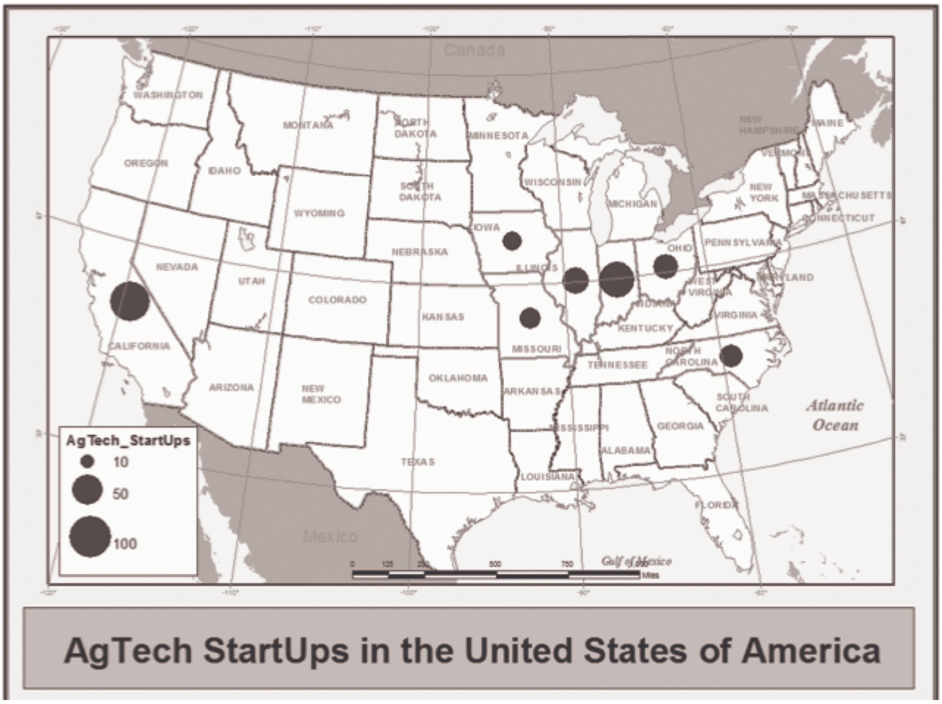


Figure 25. Map showing the number of AgTech startups per state in the Cultivian dataset

Figure 25 displays the number of AgTech startups in each state, which shows that, overall, AgTech entrepreneurial activity is higher in the heartland than in any other U.S. geographic region. The challenge is that most of this activity appears to be separate or confined by state boundaries. Agripreneur champions will unite the independent startup efforts of AgTech ventures into a movement, and hopefully someday will develop a "Silicon Valley of AgTech" in the American heartland.

tion, and agronomics are merging. Experts have pointed to similarities with the IT field, in which leading players have embraced convergence and interdependence in Internet search, cloud storage, smartphones, tablets, and PCs, and still carve out their own space to effectively compete. AgTech must go through a similar revolution, wherein players will unite to implement state-of-the-art developments in crop nutrition, crop protection, biotechnology, and agronomics, leading to integrated agricultural productivity.

4. Engage nonpartisan groups.

Independent, nonpartisan organizations have the unique ability to bring like-minded people and those with divergent views to the table. Having these organizations take up the cause will help further the common goal of providing nutritious food to a growing population in an environmentally sustainable way. They can be instrumental in providing connectivity to implement agri-tech best practices to farming communities worldwide by fostering networks in which knowledge is shared across communities.

5. Develop human capital to meet the needs of tomorrow.

The solutions that may be available to address the expected food and water shortages likely will require expertise in the development and application of information technology. This expertise currently is not broadly available within the agricultural community and needs to be developed through the whole continuum of our existing learning institutions, including high schools, trade schools, community colleges, and higher education institutions.

CONCLUSION

The task of sustainably increasing global food production is one of the monumental challenges of our time. The framework of an evergreen revolution is helpful in reminding us that, while technology has worked to produce more food in the past, we now must produce more food while also eliminating agriculture's negative environmental impact. A successful evergreen revolution will require many actors, but in particular it will require entrepreneurs who are passionate about promoting innovation and investment in AgTech.

In short, our overall objectives should be to:

- Increase awareness so that more entrepreneurs and investors can seize this opportunity while helping meet this most basic societal need
- Foster vital communities of AgTech activity across the world that are focused on the "Lean and Green" theme, based on the unique assets and core competency of each region
- Enable strong networks across communities so that ideas and solutions can flow seamlessly for the benefit of all
- Develop strong educational pillars so that talent and skills are up to par to the challenge at hand

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