Agbioscience Sector Review: Agricultural Equipment Technologies and Systems

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In 2013, the Central Indiana Corporate Partnership (CICP) Executive Committee approved the formation of the Indiana Food and Agriculture Innovation Initiative as a strategic initiative under the CICP parent organization. The entity was launched to focus on the growth and development of innovation in the food and agriculture industry (collectively referred to as the “agbiosciences”) within Indiana. Upon securing support from key state, university, and industry stakeholders for an initial period, the entity was re-named and re-branded as AgriNovus Indiana (AgriNovus) in November 2014 and launched as CICP’s fifth industry sector initiative.

AgriNovus capped its first year with the release of a "first-of-its-kind" report that examined the state of the agbiosciences and agricultural technology ecosystem in Indiana, providing its stakeholders and the public with a detailed examination of key food and agricultural innovation drivers in the State. Drafted by the Battelle Technology Partnership Practice (Battelle), this baseline analysis revealed the type and sources of research-based innovation in Indiana. Battelle identified four Innovation Sectors in which Indiana could leverage an existing industrial base along with private and university research to accelerate economic activity. These four Innovation Sectors include:

- Plant science and crop protection
- Animal health and nutrition products
- Value-added human food and nutrition products
- Agricultural equipment technologies and systems.

Each of these sectors has significant potential for future growth and economic development in Indiana, and will serve as guiding areas of collaborative and strategic opportunity for AgriNovus. The full report can be found at: http://agrinovusindiana.com/resources/

To gain a broader perspective on each sector, Battelle has performed additional research on each Innovation Sector. This white paper, "Agbioscience Sector Review: Agricultural Equipment Technologies and Systems", provides industry trends on the sector, including market statistics, emerging technologies, leading companies, research and regulatory issues. It is one of four white papers that form an "Agbioscience Innovation Sector Series" that will be used by AgriNovus in discussions with stakeholders to identify and develop strategic initiatives for the organization. AgriNovus is also pleased to make these four white papers available to the public at www.agrinovus.com.

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I. What Does This Sector Do?

Modern agricultural production is equipment and technology intensive. Large, midsize, and small companies are active in the U.S. in the design, engineering, and manufacturing of specialized agricultural production equipment and systems[1], while multiple major research universities are likewise engaged in R&D for production technologies (particularly within agricultural engineering departments at major Land-Grant Universities).

Agricultural equipment technologies and systems represent a highly diverse market, with distinctive products and technologies required for different crops, livestock, and materials handling. Individual farms need specialized equipment to handle field preparation, soil maintenance, planting, application of crop protection chemicals, irrigation, and harvesting. Similarly in livestock agriculture, specialized systems are needed for livestock feed handling, livestock watering, housing, and other applications, such as milking or egg handling. Materials handling and storage is also another major component of the farm equipment sector. Finally, because of the rugged construction and long service life of many farm machines, replacement parts represent a significant industry segment as well.

Major categories of agricultural equipment and systems for crops include:

- Tractors/mobile power
- Soil cultivation
- Planting
- Fertilizer and pest control
- Irrigation
- Harvesting
- Hay making/baling
- Produce sorting
- Grain dryers and blowers
- Loading and transportation

As discussed below, the primary global challenge of "how to increase agricultural production without pressing more land into agricultural use" is a key driver of innovation in agriculture. Striving to increase yield from every square foot of farmland, researchers and equipment producers are increasingly deploying new technologies to create a "precision agriculture" industry. Precision agriculture systems deploy highly precise global positioning systems, advanced sensors, and data analysis technologies to provide the tools and information farmers need to optimize and customize the timing, amount, and placement of seed, fertilizer, pesticides, irrigation, and other inputs – all towards the goal of producing maximum yield at the lowest cost. Precision agriculture is the next evolution in production systems, embracing an emerging set of technologies in sensing and data analytics to gather, track, and analyze agricultural data, usually in conjunction with other systems such as harvesting, planting, or field-inputs application machinery. Integrating multiple hardware and software technologies, precision agriculture includes not only traditional agricultural equipment manufacturers, but also includes companies engaged in information- or computer-oriented technologies, including agricultural decision support software, sensors and monitoring systems, GPS and mapping systems, predictive modeling technologies, and unmanned aerial surveillance (UAS) and imaging technologies.

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The Economist views precision agriculture as "the biggest change to agriculture in rich countries since genetically modified crops"[2] and Battelle concurs with that assessment. Precision agriculture is being empowered by advancements in "big data" analytics. Big Data involves an ongoing major paradigm shift in the processing and use of data. Rather than looking at data collected over time to assess what occurred in the past to make decisions—which is today's standard approach to using more high powered

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[1] Some 1,000 companies manufacture agricultural equipment in the United States, according to the U.S. Bureau of the Census, employing nearly 53,000 workers in 2006 (latest data available). U.S. manufacturers of agricultural equipment reported sales worth $19.8 billion in 2006, the latest year for which complete data is available, according to the Census' Annual Survey of Manufacturers. Source: U.S. International Trade Administration. Accessed online at http://www.trade.gov/static/doc_Assess_Ag_Equip.asp

[2] *Schumpeter*, "Digital Disruption on the Farm," The Economist, May 24, 2014.

analytics to analyze massive data sets stored in data warehouses—this new paradigm will be using real-time continuous processes for sensing, gathering, protecting, analyzing, and interpreting data that allows one to improve an outcome during an event based on real-time information from sensors, radio frequency identification, and other devices.[3] AgInformatics is a new term used to describe the study and practice of creating, storing, finding, manipulating, and sharing food and agricultural information and data along the entire value-chain.

A unifying characteristic is that all of the machinery, equipment, sensing and analytical systems being deployed are ultimately working towards one major goal—making agricultural production per unit of land as efficient as it can possibly be while minimizing the level of inputs required to achieve that optimal yield. It is an inherently transdisciplinary challenge requiring expertise in mechanical engineering, electrical and electronic engineering, signal processing, software engineering, and information technology, together with a range of agbioscience disciplines (plant science, soil science, agronomy, agricultural economics, animal science, etc.).

II. Primary Drivers of Growth

Improvement of agricultural production efficiency and yield are of intense importance to global well-being and progress. Agriculture is tasked with the global grand challenges of feeding a rapidly expanding worldwide population, enhancing and protecting human health, preserving the environment and global biodiversity, and providing inputs to a growing green industrial economy. Agriculture has to achieve the above goals by doing more with less, all the while working within a dynamic production environment with variability in both natural factors (such as weather and climate conditions, emergent pests and disease pressures) and socio-economic factors (such as commodity price fluctuations, changing consumer demands, evolving governmental regulations, and foreign competitive practices).

> Agriculture is a leading economic sector responsible for employing over two billion people globally. Within the United States, the agricultural sector is currently responsible for one in every 12 jobs.

A series of individual and interrelated factors are evident in driving opportunities and growth in the agriculture sector. Chief among these are discussed in Table 1.

Table 1: Factors Influencing Sector Growth

Factor	Implications for Growth and Development Opportunities
Population growth	Today, the global human population stands at 7.27 billion. In a decade's time (2024), the United Nations projects global population will pass the 8 billion mark, expanding to 9 billion by 2040 and 10 billion by 2062.[4] Thus, by 2062 there could be as many as 2.7 billion more people to feed on the planet (yet almost all quality agronomic land on Earth is already in production).
Wealth growth (expansion of disposable income and per capita consumption)	Increasing incomes, driven largely by global industrialization, are correlated with increasing demand for processed foods, packaged foods, high energy foods and meats. These "developed world" foods consume considerably more resources in their production than basic foodstuffs. Increasing food demand is therefore not only caused by rising population but also increasing per capita consumption. "People who are initially undernourished obtain access to more food calories, they first go through an expansion phase where diets contain more food—typically, grains, roots, tubers and pulses—and then

[3] See Davenport, Barth and Bean, "How "Big Data" is Different," MIT Sloan Management Review, July 30, 2012.
[4] Statistics accessed at http://www.worldometers.info/world-population/

	a substitution phase, where the latter are replaced by more energy-rich foods such as meat and those with a high concentration of vegetable oils and sugar. Typically the production of high-energy food requires more resources (for example, instead of grain being directly consumed by humans, it is used as animal feed for livestock production which is then consumed by humans."[5] It takes approximately 8kg of grain to generate 1kg of beef, 6kg for 1 kg of pork, and 2kg for 1 kg of chicken meat.[6]
Climate change	Agriculture contributes to global climate change (via deforestation, carbon dioxide emissions, and methane emissions), and agricultural production yields are directly impacted by changing climatic conditions likely to exacerbate extreme weather, droughts, and the geographical range of crop pests and diseases. Innovations are required to reduce the climate change exacerbation factors associated with agriculture and to adapt crops to changing biotic and abiotic stress factors associated with climate change.
Environmental protection	The vast majority of available cultivable land globally is already in production. Most of the unexploited land is either too steep, too wet, too dry, too cold[7] or too ecologically important for agriculture. In addition, poor farming practices in much of the developed world are degrading existing farmland – in terms of direct soil erosion, soil nutrient depletion, and soil salinity increases. The pressing of more marginal lands into agricultural production causes natural habitat losses and reductions in global biodiversity. (Scientific American reports 80,000 acres of tropical rainforest and 135 species of organisms lost daily). In addition, non-sustainable agricultural practices generate significant water pollution, aquifer depletion, and greenhouse gas emissions.
Resource use efficiencies	There is a need for crops that are able to produce the same yield or even enhanced yield with reduced application of inputs (i.e., water, light, fertilizer, and crop protection chemicals). Demand in this regard is driven by the related factors of needing to reduce the environmental impacts of agricultural chemicals, reduce to sustainable levels the use of scarce water resources, and provide solutions for resource poor developing world farmers who may be unable to afford modern agricultural chemicals. Water use efficiency is a particularly important goal. The UN FAO reports that 70 percent of freshwater resources are consumed by agriculture annually (whereas 19 percent is consumed in industrial processes, and just 11 percent is used for municipal consumption).[8] Freshwater withdrawals have tripled in the last 50 years, and current usage levels are unsustainable in much of the world.
Evolving and emerging diseases and pests	Because agriculture is an inherently biological production system, it is subject to the laws of nature that govern processes of organismal evolution and adaptation. Seed and crop protection solution providers are in a constant innovation race against the emergence of pests (e.g. insects, weeds, and pathogens) resistant to current chemicals and control strategies. It is anticipated that climate change will exacerbate pressures as it will likely shift the geographic range of a broad variety of crop pests.

[5] H. Charles J. Godfray, et al. "The future of the global food system." Phil. Trans. R. Soc. B (2010) 365, 2769–2777.

[6] Jonathan Watts. "More wealth, more meat. How China's rise spells trouble." The Guardian, May 29, 2008.

[7] Human Appropriation of the World's Food Supply.
http://www.globalchange.umich.edu/globalchange2/current/lectures/food_supply/food.htm

[8] United Nations Food and Agriculture Organization http://www.fao.org/nr/water/aquastat/water_use/index.stm

A need for healthier foods	Poor diets and unhealthy food choices by consumers lead to negative health outcomes: both in terms of malnutrition at one end of the spectrum and obesity at the other. Many in the developed world eat unbalanced diets, high in sugars and fats – diets that contain far more calories than are required to provide sustenance resulting in obesity and other health disorders (such as diabetes and cardiovascular disease). In the developing world, it is estimated that over 800 million people suffer from malnutrition, whereby their readily available food supply provides an insufficient nutrient profile for health. Both behavioral changes and technological solutions are required to combat the evident nutrition profile gap that exists across the globe. The development of "foods for health" – foods with robust nutrition characteristics associated with a healthy diet are needed, and in some instances this may require the development of staple crop plant-based foodstuffs with enhanced nutrient and vitamin content. Similarly, technologies that improve the taste, smell, and other sensory inputs during human consumption can also enhance utilization of more healthy foods.
Reduce food waste	Technologies and practices that would reduce food loss and waste could significantly increase food supplies and provide significant environmental and economic benefits. Currently loss and waste of food occurs along the entire post-harvest value chain. The UN FAO estimates that approximately 32 percent of food (by weight) is lost[9] or wasted in the current global food system. The World Resources Institute (WRI) estimates that this translates into 24 percent of all available food energy being lost or wasted overall. The WRI notes that cutting food waste and loss in half by 2050 could close 20 percent of the projected food gap.[10]
Changes in consumer behavior	The agbiosciences is driven, at the end of the day, by ever evolving human consumption patterns, which at times are in conflict with the other global challenges detailed above. Whether it is the desire for a local food movement (localvore movement) in towns across the nation, the anti-GMO sentiment that is particularly widespread across Europe but growing in the United States, the organic food movement that has been a market force since the 1970s but growing ever stronger, or the growing desire by many consumers to better understand how to impact their health through the food choices made, the bottom line is that how agricultural commodities are grown, processed, and manufactured into final food products will continue to be driven by the evolving nature of consumer preference.

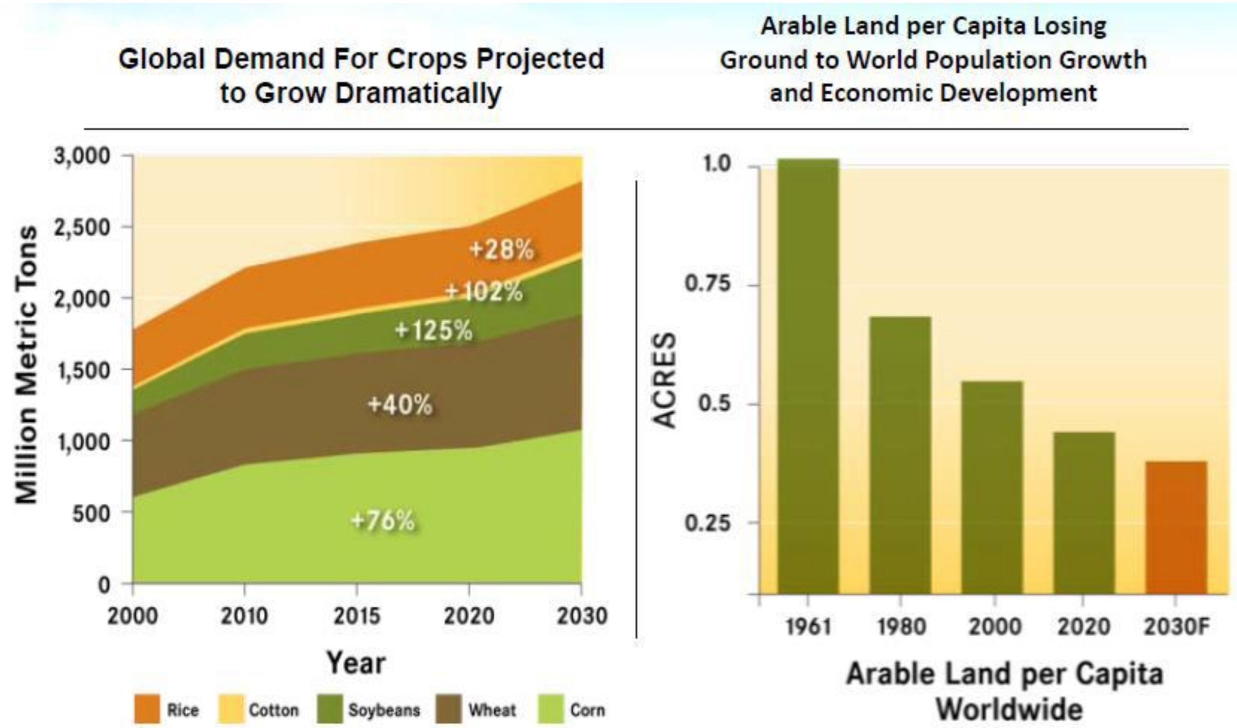
The scope of some of the challenge factors is well represented in the graphics illustrated in Figure 1, produced in a report by Suren Dutia for the Kaufmann Foundation.[11]

[9] Loss" refers to food that spills, spoils, incurs an abnormal reduction in quality such as bruising or wilting, or otherwise gets lost before it reaches the consumer. "Waste" refers to food that is of good quality and fit for consumption, but is not consumed because it is discarded after it reaches consumers—either before or after it spoils. Source: UN FAO.

[10] World Resources Institute. 2013. "Creating a Sustainable Food Future."

[11] Suren G. Dutia. "AgTech: Challenges and Opportunities for Sustainable Growth." Ewing Marion Kaufmann Foundation. April 2014.

Figure 1: Kaufmann Foundation Graphics on Expanding Crop Demand and Reducing Arable Land Per Capita



Many of the challenges and demand-side factors noted in Table 1 have a direct relationship to potential solutions that may be derived from innovation in agricultural equipment technologies and systems. Examples are discussed in Table 2.

Table 2: Potential Agricultural Equipment Technologies and Systems Solutions to Agbioscience-Related Challenges

Challenge	Potential Solutions
Population growth	Equipment for enhanced application of new and existing inputs to increase yield. Real-time field conditions analysis systems to monitor soil conditions, plant health and development, etc. to enhance and protect yield.
Wealth growth (expansion of per capita consumption)	High efficiency systems for livestock feeding and watering. Real-time systems for measuring livestock health and determining approaches to improve the health and nutrition of livestock.
Climate change	Precision application of water in drought or scarce-water resource conditions.
Environmental protection	Precision sensing of individual plant or soil-area input needs and prescription application of reduced but optimal amounts of chemicals. Precision application of water in drought or scarce-water resource conditions.
Resource use efficiencies	See above.
Evolving and emerging diseases and pests	Rapid field detection, and early warning, of pests and diseases in crops and soils. Prescription application of crop protection chemicals.
A need for healthier foods	Pathogen detection.
Reduce food waste	Development of harvesting systems to prevent bruising or other damage that may lead to spoilage or wastage of food products post-harvest.

The varied challenge factors and potential technological-solution categories outlined above combine to provide for a bright future for companies with significant R&D and new product innovation capabilities in these market spaces. Battelle has access to a broad library of proprietary market research resources, and some key data points evident in a review of market projections are highlighted in the next section.

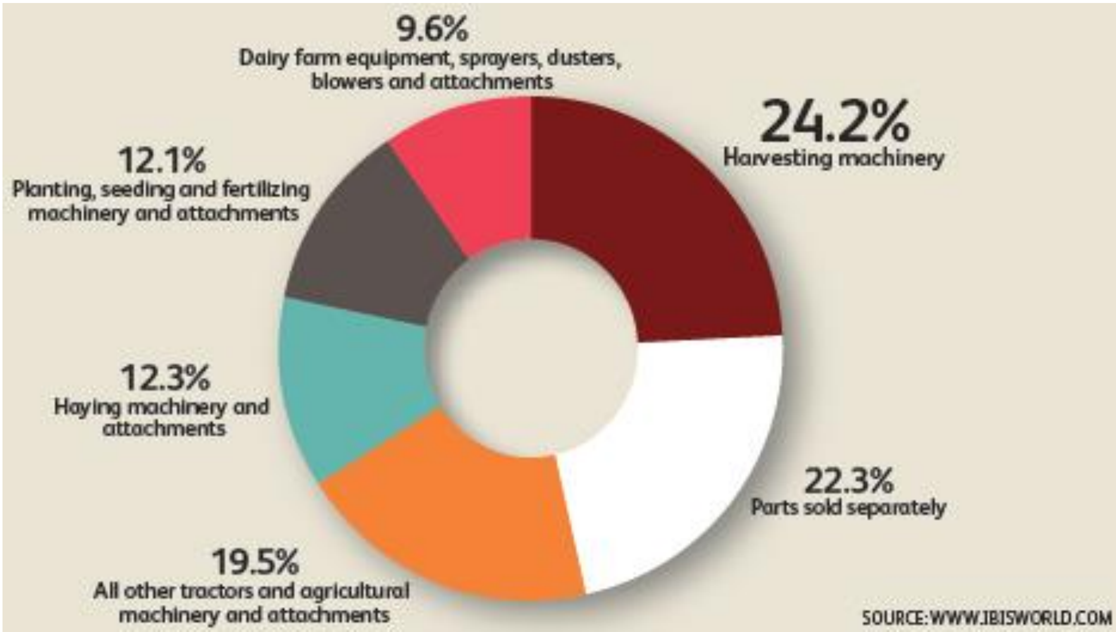
III. Market Statistics, Growth Trends and Projections

Recent market research concludes that the aggregated revenue of U.S. manufacturers of agricultural machinery totaled $41.6 billion in 2014, with exports totaling $11.8 billion. IBIS World projects annual growth in the sector from 2014 through 2019 to be 2.4 percent (a decrease over the previous annual growth rate for 2009-2014 which stood at 3.9 percent).[12] IBIS World notes there to be 1,138 businesses in the sector within the U.S. with a total employment of 17,211 personnel. Market researchers at the Freedonia Group are projecting that the global market for agricultural equipment will grow 6.9 percent annually through 2018 to reach $208 billion.

The IBIS World report divides the U.S. agricultural equipment manufacturing sector into six segments as illustrated in Figure 2.

[12] IBIS World. "Tractors & Agricultural Machinery Manufacturing in the U.S." June 2014.

Figure 2: IBIS World Market Research. Segmentation of the U.S. Agricultural Equipment Manufacturing Sector (2014)

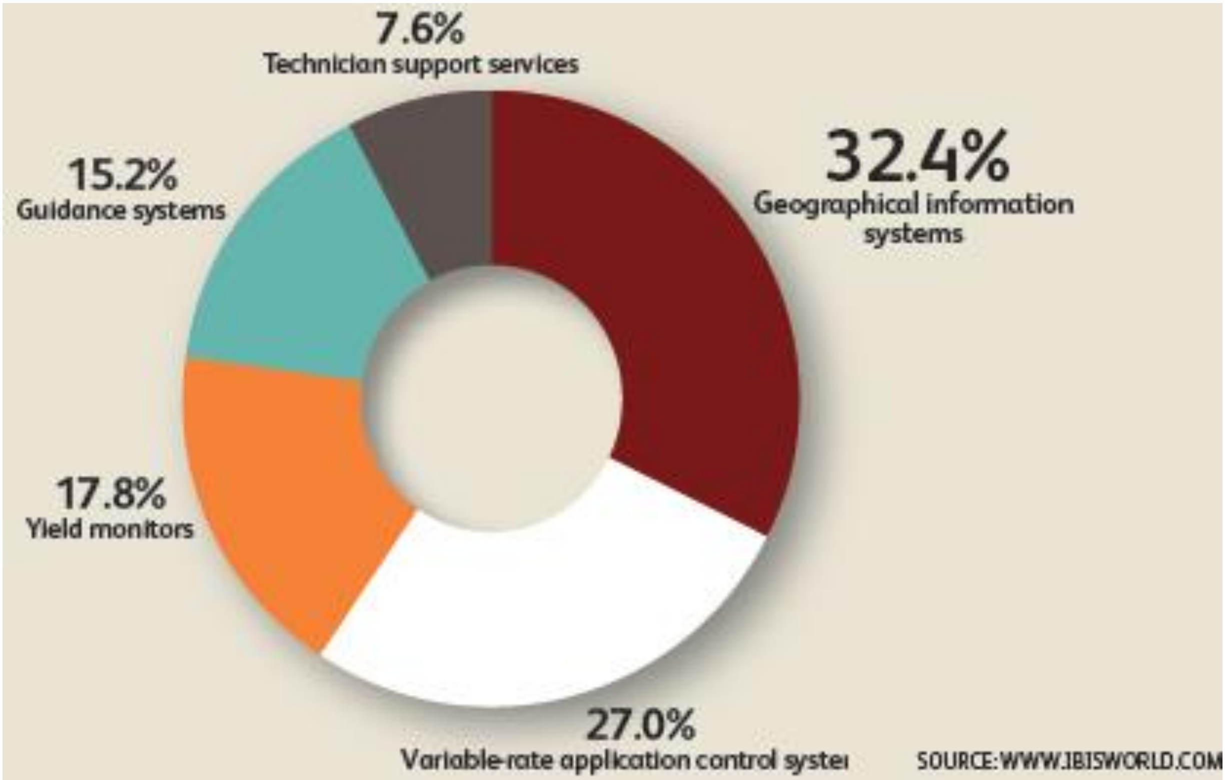


The emerging precision agriculture technology segment is obviously smaller in total market size – representing a sub-segment of the overall agriculture equipment marketplace. IBIS World research specific to precision agriculture systems and services in 2014 places the sector as having overall revenues of $1.5 billion in the U.S. (3.6 percent of total U.S. agricultural equipment revenues). The emerging nature of the sector, however, is evident in growth statistics and projections which show the sector grew at an annual growth rate of 5.3 percent during 2009 through 2014, projected to increase to an annual rate of 6.6 percent from 2014 through 2019 (2.8 times the rate of growth projected for the overall domestic agricultural equipment sector).[13]

The precision agriculture sector lends itself, more so than the overall agricultural equipment sector, to entrepreneurial business development. Like other high-tech and information technology intensive sectors, precision agriculture systems provide a market for small companies to introduce innovations. This characteristic of the sector is evidenced by data indicating there to be 1,446 businesses operating in this sector in 2014 (a number larger than the number of businesses in the agricultural equipment manufacturing sector overall). Trimble Navigation Limited is identified as having the largest market share in the sector (22 percent) followed by Deere & Company at 12.9 percent. Segmentation of product and service categories in the precision agriculture space in the U.S. is illustrated in Figure 3.

[13] IBIS World. "Precision Agriculture Systems & Services in the U.S." May 2014.

Figure 3: IBIS World Market Research. Segmentation of the U.S. Precision Agriculture Systems and Services Sector (2014)



There are a range of views on the future growth of precision agriculture. The current market for precision agriculture in the U.S. is probably fairly estimated to be in excess of $1.5 billion. Some market researchers view it as a very fast moving market with expected compound annual growth of over 13 percent from 2013 to 2018, while others view the market growing at a more modest pace of under 7 percent.[14] Even under the less optimistic forecasts, the market for precision agriculture in the U.S. is expected to reach close to $2 billion by 2018, employing over 5,000 workers.

The key uncertainties for future growth are how much precision agriculture will penetrate the market beyond the largest agribusinesses, and whether smaller farmers will be slow to adopt the technologies involved (and possibly reluctant to have precision agriculture companies have access to data about their farms). There are also uncertainties regarding whether smaller farmers will be able to afford the investment in precision agriculture if there are lower prices for crops or farmers are unable to access financing. It is also expected that the pace of new product introductions will be critical and will depend upon new regulations for the commercial use of unmanned aerial systems as well as continued technological advancements in global positioning systems, remote sensing, automated piloting, and modeling and simulation technologies.

Overall, it is likely that the advanced technology, highly-innovative, and emerging precision agriculture equipment and systems market will offer most opportunities for new entrants within the overall agricultural equipment and machinery marketplace. As IBIS World points out:

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[14] Market intelligence is drawn from several reports including: IBISWorld, Precision Agriculture Systems and Services in the U.S., May 2014; Focus Investment Banking, Precision Agriculture: Special Market Report, Winter 2014; and news releases from MarketsandMarkets, Precision Farming Market: Global Forecast and Analysis 2013-2018.

The Tractors and Agricultural Machinery Manufacturing industry exhibits a moderate level of competition. There are more than 1,000 companies in the industry, but the top four generate about half of all revenue. A high level of research and development expenditures, large economies of scale, extensive dealer networks and long-standing reputations make it difficult for new players to compete with the major operators.

Thus, it may be concluded that the traditional agricultural equipment market is quite challenging for new market entrants (although there are some expanding spaces as noted in the next section), and that the emerging precision agriculture systems and technologies marketplace represents a more open opportunity for new market entrants.

IV. Technologies and Emerging Opportunities

The agricultural equipment technologies and systems sector presents opportunities and demands for innovation and new technology development across a range of sub-platforms. Chief among these, in Battelle's opinion, are likely to be:

- Harvesting equipment
- Precision agricultural sensing, monitoring, and decision support systems
- Precision application systems for agricultural inputs (variable rate systems)
- Agricultural biosecurity equipment and technologies
- Livestock production equipment and technologies.

A. Harvesting Equipment

Description

While major row crops have long-benefited from efficient harvesting equipment, many specialty and smaller niche crops do not yet have efficient and affordable mechanized solutions. These crops typically have to rely on manual field-labor for harvesting, but such reliance is proving an increasing challenge as immigration concerns negatively impact migratory labor access.

As noted in one report:

The hand harvesting of fruit and vegetable crops in the United States is a labor-intensive operation that accounts for about 50 percent of total production costs. The number of crops and percentage of crop acreage that are mechanically harvested today have increased somewhat since the late 1970s. Most of these crops are used for processing. However, at least 20 to 25 percent of the U.S. vegetable acreage and 40 to 45 percent of the U.S. fruit acreage is totally dependent on hand harvesting. The crops represent about 30 percent of the U.S. fruit, nut, and vegetable acreage and have an annual farm-gate value of over $13 billion. Declining labor availability and increasing labor costs are reducing U.S. growers' competitiveness with foreign suppliers. Harvest mechanization and improved production technologies show promise for keeping U.S. growers in business.[15]

The situation has not changed significantly for the better since the report was written in late 2000 – rather, access to short-term migratory labor has tightened.

[15] Yoav Sarig, James Thompson, Galen Brown. "Alternatives to Immigrant Labor? The Status of Fruits and Vegetables Harvest Mechanization in the United States." December 2000. Center for Immigration Studies.

	In addition the emergence of the industrial bioeconomy, with its associated move towards the production of woody perennial biomass crops, likewise generates demand for the development of alternative and new harvesting systems. In a different vein, the expanding ability to produce vaccines, medical proteins, or other high-value biomedical-oriented products in plants will likely encourage the development of highly specialized harvesting equipment. In part the necessity will be driven by a need to avoid long-term exposure of workers to active biopharmaceutical compounds. The risk of such exposure, and the need for mechanized solutions, is demonstrated by cases of acute nicotine poisoning that has occurred in laborers harvesting green tobacco.
Examples	Harvesting equipment for cost-effectively mechanizing the harvesting of fruits, vegetables, nuts and other niche food crops. Equipment has to meet the requirement of harvesting the product without causing bruising or other damage that may lead to food waste. Specialized harvesting equipment for emerging biomass crops. Specialized harvesting equipment for biopharming and the growth of other specialty chemical compounds in plants that could pose health risks if manually harvested. Systems for precision measurement and tracking of spatial variability in yield during harvesting (for connection into precision farming system technologies described below).

B. Precision Agricultural Sensing, Monitoring, and Decision Support Systems

Description	"Precision agriculture technologies provide the information and systems that allow a farmer to optimize and customize the timing, amount, and placement of inputs (seed, fertilizer, pesticides, irrigation, etc.) for any given section of a field. This allows the farmer to produce the maximum yield from the entire field at the lowest possible cost."[16] Several different types of technologies are converging to realize the full promise of precision agriculture: • High precision location-fixing technologies using GPS and correctional augmentation technologies such as Wide Area Augmentation System (WAAS) technology and Real Time Kinematic (RTK) technology. Combined with mapping software and tied into steering systems, this technology can guide equipment and the application of agricultural inputs down to the centimeter level of precision. • Real-time sensing technologies providing rapid sensing of field conditions (such as soil moisture content, soil chemistry, etc.), physiological condition of crops and individual plants, and the presence of emergent weeds, pathogens, or other pests. • Big data analytics involving the collection of large volumes of temporal, spatial, and sensor-based data will provide a significant analytical challenge. Sophisticated data analysis algorithms and decision support software systems will be needed to guide precision actions in real-time. • Variable rate application systems. Current applicators of irrigation water and agricultural inputs such as fertilizer, growth stimulant biologics and crop protection chemicals typically distribute the input at a fixed rate. The real

[16] Eric Oganesoff and Reid Howard. "Precision Agriculture: M&A, Investments, and Start-ups on the Rise." FOCUS Investment Banking, LLC.

	promise of precision agriculture is realized when the technologies noted above are combined with applicators that are able to vary their rate of input application based on sensor-data and decision support software. • Potential wireless technologies connecting agricultural equipment to online/cloud decision support systems, specialist analytical services, weather data, etc.
Examples	Field-research phenotyping systems for evaluating plant physiology, gene expression and other factors important in plant variety development. Sensors for detecting soil conditions and soil chemistry, physiological and growth status of individual plants, presence of pests (ideally at a very early emergent stage). Software systems for decision making based on sensor-inputs that also provide positional guidance of equipment and variable rate control of inputs applicators. Guidance systems and precision autosteer systems to centimeter levels of precision. Unmanned aerial and terrestrial remote sensing systems and sensor platforms. Imagery collection from aerial and satellite platforms, including multi-spectral imaging. Variable rate agricultural input applicators for seed, crop protection chemicals, biologics, fertilizer, manure spreading, irrigation water, etc. In-cab/on-equipment control interface and real-time decision support information for operators. Mixed-fleet controls and systems are also an emphasis area with the goal of developing portable systems that can work across the broad variety of equipment types and brands present on farms. Cloud and remote services for data storage, current and historic data analytics and decision support, and data sharing.

C. Agricultural Biosecurity Equipment and Technologies

Description	Farmers and agricultural technologists have always had to cope with an “unsecure” operating environment in which crops and livestock are at risk from natural biotic and abiotic threats. Indeed, the agricultural production sector is unique among industries in having such significant naturally occurring dynamic external threats to productivity. Today, the threat spectrum for farmers has expanded to include the malicious and deliberate introduction of pathogens, toxins, and invasive species by individual or organized actors, together with accidental introduction of similar threats. For the most part, the major agricultural biosecurity events that have occurred in recent years have been accidental in causation. Accidental human-assisted transfer of invasive pests and pathogens is the most pervasive threat, with international travel and trade able to relocate organisms from one global location to another quite rapidly. The cost of outbreaks associated with disease or pest transfer can be extremely large. As noted by Waage and Mumford[17]: • An outbreak of classic swine fever in 1997 cost The Netherlands approximately $5 billion. • The foot and mouth disease (FMD) outbreak in 2001 cost the UK approximately £7 billion.

[17] J. K. Waage and J. D. Mumford. “Agricultural Biosecurity.” Phil. Trans. R. Soc. B (2008) 363, 863–876. Published online 30 August 2007

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The appearance of bovine spongiform encephalopathy (BSE) in Canada and the USA in 2003 is estimated to have cost each of those countries $3–4 billion in lost trade revenue
In recent years, particularly worrying introductions of exotic crop pathogens have occurred on four crops: wheat, rice, maize and potatoes that constitute 50 percent of the world’s food supply.

In addition to accidental introduction, there also exists, as noted above, the threat of deliberate acts of bioterror designed to disrupt a national or regional food supply.
Tools and technologies for combating these threats are largely similar whether for accidental or deliberate events.

Preventive screening of imported agriculturally derived products and biological materials.
Early-stage detection of contaminants or invasive species by diagnostic tests or field observation.
Development of livestock vaccines.
Post-detection interventions in terms of livestock therapeutics or livestock/crop eradication (culling), or application of crop protection chemicals.

A niche area of work related to prevention and detection of deliberate acts at the farm level is the development of anti-tampering technologies for agricultural equipment.
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<td>Examples</td>
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Primarily, technologies that may be applied in the biosecurity space are also those partially covered in the other Indiana platforms pertaining to animal health and plant sciences/crop protection. The main implications for the agricultural equipment marketplace would be for the development of surveillance systems, rapid diagnostic sensors placed on agricultural equipment, and anti-tampering equipment.
Overall, agricultural biosecurity needs will increase the demand for the following primary types of products and technologies:

Diagnostics and rapid diagnostic kits for livestock and plant pathogen detection
Livestock vaccines
Livestock therapeutics (antibiotics, antivirals, etc.) and other countermeasures (such as disinfectants)
Biocontainment technologies and facilities for the study and evaluation of pests, pathogens and invasive species and associated control technologies
Decision support technologies for optimizing strategic response to outbreaks or other biosecurity events and for measuring impacts
Security controls and anti-tampering systems for agricultural equipment.

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D. Livestock Production Equipment and Technologies

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<tr><td>Description</td><td>As noted by Philip Thornton[18]:

Several assessments agree that increases in the demand for livestock products, driven largely by human population growth, income growth and urbanization, will continue for the next three decades at least. Globally, increases in livestock productivity in the recent past have been driven mostly by animal science and technology, and scientific and technological developments in breeding, nutrition and animal health will continue to contribute to increasing potential production and further efficiency and genetic gains.

The increasing demand for livestock products will drive not only the genetic improvement of livestock species and the development of enhanced livestock nutrition products, it will also likely impact the development of equipment used in livestock production. While the developing world is still (largely) pastoral based, using grazing for livestock production, the developed world is more oriented towards intensive confined-animal production systems. Intensive livestock operations require specialized livestock housing facilities, climate control/air handling systems, waste management systems, automated feed systems, health monitoring systems, milking systems, etc. for efficient operation. Each of these areas provide opportunities for new technology and product introductions.

Several issues associated with intensive livestock production require technological solutions. Key areas in need of solutions include:
Carbon/greenhouse gas emissions reduction from livestock operations globally, and, more generally, reduction in emissions associated with localized air quality
Waste management and waste utilization systems
Livestock housing (especially in response to rising ethical concerns and challenges)
Biosecurity for control of disease in closely confined animal stocks.</td></tr>
<tr><td>Examples</td><td>Automated feed handling and watering systems
Cost-effective alternative housing for ethical treatment of animals
Waste management and utilization technologies
Emissions reduction and management systems
Biosecurity monitoring equipment.</td></tr>
</table>

E. Another Critical Need

Finding solutions to the global food challenge, and associated challenges for agriculture, is not dependent on scientific progress alone. While a robust scientific R&D infrastructure is a precursor to progress, other important factors also influence development potential and the development environment. Socio-cultural and political considerations, in particular, are an area of challenge that cannot be ignored. Multiple states have experienced significant lobbying and ballot measures aimed at curtailing confined animal agriculture operations driven by animal rights advocates, while environmentalists and dwellers of urban fringes interfacing with agricultural usages voice strong opinions on air quality, water quality, and other factors influenced by intensive animal agriculture practices. A critical need is helping to ensure that the political and regulatory framework in the U.S. and within individual states (and in crucial international markets) follows scientific rational methods. The global challenges for which agriculture promises solutions cannot

[18] Philip Thornton. "Livestock production: recent trends, future prospects." Phil. Trans. R. Soc. B (2010) 365, 2853–2867.

be met if unnecessary barriers, often rooted in unfounded fears and misinformation surrounding advanced life science technologies or environmental impacts, are allowed to proliferate unchallenged. Legislation around issues such as transgenics and GMO's or livestock housing and animal welfare can have significant impacts on industry economics and viability.

Ultimately, the success of Indiana's efforts to build upon the existing agbioscience cluster in the state will depend not only on the R&D that takes place in Indiana (or the acquisition of external innovations by Indiana companies), but also upon attention being paid to the additional factors that influence the growth of science-based and technology-based innovation ecosystems. The State of Indiana and AgriNovus will need to help ensure that Indiana maintains solid levels of performance on the key factors for agbioscience cluster development noted by Battelle in Table 3.

Table 3: Characteristics for Successful Agbioscience Geographic Hubs

Success Element	Description
Presence of major multi-national agbioscience corporations (especially R&D operations of these companies)	The presence of major existing agricultural equipment manufacturers and systems developers is certainly beneficial to hub development. The presence of major agricultural equipment manufacturers, or key supply-chain vendors, greatly enhances hub prospects.
Presence of major academic or independent research institutes with a robust program of agbioscience R&D and world-class infrastructure	In the U.S., academic agbioscience and agricultural engineering R&D is heavily concentrated in major Land-grant Universities and a few specialized independent R&D institutes. It is notable that rather than being a focus of most research universities, agriculture tends to be a more specialized undertaking concentrated in less than 50 major institutions with a long standing tradition of agricultural research and extension activity. A similar pattern of concentration in a comparatively compact number of leading institutions is seen globally. In the U.S., the presence of a leading Land-grant University with substantial agricultural research and agricultural engineering R&D activity is a significant advantage in hub development.
Presence of government agbioscience R&D institutes	Because of the importance of agriculture, and the proportion of national land mass dedicated to it, national governments have tended to be active participants in agbioscience research. In the U.S. this is a clear focus of the U.S. Department of Agriculture (USDA) and its Agricultural Research Service. The USDA maintains multiple intensive research sites across the nation, and the presence of USDA labs is an advantage for these locations.
Diverse agronomic production environment	All other things being equal, a state or nation with a more diverse agronomic, climate, and soils environment will have an advantage in research and development across a diversity of crops and livestock species (and potentially an advantage in R&D relating to equipment for application in the production of specific plant and livestock species). In particular, those locations that possess a significant number of established experiment stations and research farms distributed across a variety of environments have an advantageous position for R&D and the demonstration of new technologies.

Engaged and collaborative stakeholder groups	Technology-based economic development is enhanced by having collaborative environments in which academic, industry, government, and other key stakeholder groups cooperate and communicate with one another. Those locations that have organizational structures in place to facilitate collaborative engagement have an advantage.
A business environment conducive to entrepreneurial business development	Frontier areas of agbioscience (such as microbiomics, advanced phenotyping, precision agriculture, advanced big data analytics, etc.) present significant opportunities for new business development around the commercialization of innovations. While R&D can lead to innovations anywhere, it requires a special environment to support the establishment and growth of new business ventures. Those locations that are skilled in technology transfer, intellectual property management, entrepreneurial business management, business incubation services and early-stage capital access have a distinct advantage.
Presence of a science-based regulatory and policy environment that is predictable over the long-term	In an industry such as agriculture, where the process of advancing R&D innovations to a commercialized product can take a cycle as long as a decade, it is imperative that industry sees a stable and predictable regulatory and policy framework within which it can operate. Unpredictable, ad hoc regulation changes can greatly hamper industry success, likewise industry needs to be able to trust that policies and regulations will be science-based and not rooted in unrelated political agendas or loose public opinions. Europe, in particular, has created a regulatory environment viewed as unfavorable to agricultural biotechnology, hampering their hub growth. For precision agriculture, areas to watch will include potential FAA regulations surrounding UAV applications in agriculture and other industries, and environmental policies that reflect concerns over air, water, and soil quality associated with agronomic practices.
The presence of a robust education and workforce development pipeline meeting the needs of R&D and industry sectors.	Agbioscience, agricultural engineering, and associated equipment manufacturing represent high-tech, knowledge-based sectors that run on the skills and capabilities of a well-educated workforce. Industry requires PhD trained scientists, skilled technicians, engineers, and lab and field workers able to work in a dynamic multi-disciplinary science and engineering environment. Locations with an existing base of workers already employed in agricultural equipment R&D and production are at an advantage because knowledge-workers tend to be attracted to locations where clusters of peers exist (providing multiple job opportunities without the need for relocation). Similarly, robust academic programs are required to maintain the workforce pipeline and to support continuing education.

The rewards for getting the economic development equation right for agbioscience growth are likely to be significant. If a state or region achieves a robust position as a major global hub in the agbioscience sector, it may expect to achieve economic development and job growth via:

- Attraction of significant external funds to support research and development, thereby creating high paying science and technology R&D jobs.
- Attraction of existing agbioscience and associated manufacturing industry to the region to undertake R&D and production activities.
- Further growth of existing regional agbioscience and agricultural equipment technologies and systems industries.
- Growth of new entrepreneurial businesses commercializing R&D outputs.

- Transfer of technologies to regional industry and agricultural sectors that enhance productivity or provide new products and services for sale.
- R&D-based solutions to challenges hampering sector growth and development.

V. Major Companies Operating in this Sector

As noted previously, the traditional agricultural equipment sector is estimated to contain over 1,100 individual businesses in the U.S., while the fast growing precision agriculture services and systems sector adds more than 1,400 businesses to this mix. While a base of over 2,500 businesses certainly implies diversity in the competitive marketplace, it should be noted that in the traditional agricultural equipment space, more than half of all industry revenues are consolidated within the top three companies (Deere & Company, CNH Industrial, and AGCO Corporation). As noted by IBIS World: "A high level of research and development expenditures, large economies of scale, extensive dealer networks and long-standing reputations make it difficult for new players to compete with the major operators."[19] In this regard, the agricultural equipment market is quite similar to the crop seed and agricultural chemicals market, where a handful of very large multinational corporations hold the majority of market share. Table 4 lists many of the major and midsize companies engaged in the agricultural equipment sector worldwide.

Table 4: Major Companies in the Agricultural Equipment Sector

Large Companies	HQ Location	Main Products
Deere & Company	Illinois, USA	Tractors, combines, etc. Highly diversified in most major equipment.
CNH Industrial NV	UK (but owned by FIAT Italy)	New Holland, Case and Steyr brands. Tractors, balers, combines. Highly diversified in most major equipment.
AGCO Corporation	Georgia, USA	Tractors, combines and other agricultural Equipment. Key brands are Massey Ferguson, Fend, Laverdat and Challenger.
Claas	Germany	Tractors, balers, harvesters.
Kubota	Japan	Tractors, mowers, spreaders and hay tools
JCB	Georgia, USA (World HQ UK)	Tractors and agricultural loaders
Midsize Companies	**HQ Location**	**Main products**
Alamo Group Inc.	Texas, USA	Mowing equipment
Bauer GmbH	Austria	Irrigation equipment
Belarus (Minsk Tractor Works)	Belarus	Tractors and agricultural machinery
Bentall Rowlands	UK	Storage, handling and processing equipment
Chafer Machinery	UK	Crop sprayers
Collinson	UK	Silos and livestock feeding systems
Daeyang Machinery Company	Korea	Loaders and composters
SAME DEUTZ-FAHR	Italy	Primarily tractors. DEUTZ-FAHR, SAME. Lamborghini Trattori, Hurlimann and Gregoire brands
EB Equipment	UK	Bulk storage and livestock feeding systems
Equipment Technologies	Indiana, USA	Apache brand precision guided sprayers
Fimaks	Turkey	Tractor attachments (choppers, feeders, manure spreaders, rakes, baling equipment)

[19] IBIS World. "Tractors & Agricultural Machinery Manufacturing in the U.S." June 2014.

Hoopers Engineering	Australia	Graders, rakers, cultivators and other farm implements
Hi Spec	Ireland	Manure spreaders, feeding systems, vacuum tankers
Horsch LLC	North Dakota, USA	Soil cultivation and seeding equipment
Knight Farm Machinery	UK	Sprayers and cultivators
Kongskilde	Denmark	Diet mixers, mowers, forage harvesters, rakes
Koylu Agriculture Machines	Turkey	Cultivators, mowers, rakes, threshers, sprayers and spreaders
Krone	Germany	Forage harvesting equipment
Kuhn S.A.	France	Ploughs, spreaders, shredders, sprayers, hay mowers and balers, wrappers and seeding equipment
Kverneland Group	Norway	Soil cultivation equipment, seeding equipment, spreaders, sprayers, forage equipment and feeding equipment. Also includes the Vicon brand.
Lely Holding	The Netherlands	Livestock equipment (housing, feeding, milking), and forage harvesting
Lindsay Corporation	Nebraska, USA	Irrigation equipment
Mascar	Italy	Harvesters, sowing equipment, balers and baler wrappers
McCormick/Argo	Italy	Landini and McCormick tractor brands
Merlo	UK	Telescopic handlers
George Moate	UK	Tillers, toppers and soil cultivation equipment
Spray Innovations Inc.	Kansas, USA	Sprayers for crops and livestock
Sunco	Nebraska, USA	Soil cultivation equipment
Swaraj	India	Tractors, combines and implements
Taurus Agricola	Argentina	Machines for feeding livestock
Teagle Machinery	UK	Mowers, spreaders, soil cultivation equipment.
Valmar Airflo Inc.	Canada	Seeders, fertilizer applicators, spreaders
Valtra	Finland	Tractors
West Agricultural Equipment	UK	Diet feeders, spreaders
Zetor	Czech Republic	Tractors, mowers

Source: Battelle research

The precision agriculture sector is, in many ways, more diverse than the general equipment sector—primarily because it includes participation not just by traditional agricultural equipment manufacturers (such as AGCO and Deere & Company), but also significant participation by the big seed and crop chemical agbioscience companies (e.g. Monsanto, DuPont), and software and information technology companies. Chief among the public companies active in the space are those listed in Table 5.

Table 5: Public Companies in the Precision Agriculture Sector

Public Company	HQ Location	Precision Agriculture Products
AGCO	Georgia, USA	Integration of precision systems onto own key tractor, combine and other equipment brands (Massey Ferguson, Fend, Laverdat and Challenger).
AgJunction Inc.	Kansas, USA	Outback Guidance, Satloc, AJ Cloud Services
Agrium Inc.	Alberta, Canada	Seeds, herbicides, fungicides, insecticides and seed care chemicals
Buhler Industries	Manitoba, Canada	Versatile and farm King brands. Tractors and agricultural machinery
Deere & Company	Illinois, USA	Tractors, harvesters and sprayers with section control and variable rate application. Guidance control and software systems
DuPont Inc.	Delaware, USA	Pioneer brand. Agronomy software solutions for field management.
Lindsay Corporation	Nebraska, USA	Irrigation equipment under Zimmatic brand. Variable rate irrigation and management software
IBM Research	New York, USA	IBM Research builds models and simulations to predict future conditions for producers.
Monsanto	Missouri, USA	FieldScripts Software for variable rate planting
MTS Systems	Minnesota, USA	GPS guidance sensors and hardware for precision agriculture
Raven Industries, Inc.	South Dakota, USA	Field computers, GPS and autosteer hardware, control systems and hardware for planting and harvesting
Topcon Corporation	Japan	Guidance systems, application control systems, field data collectors, GPS receivers and field management software
Trimble Navigation Ltd.	California, USA	Crop health sensors (Green Seeker brand), GPS, automated steering, precision applicators, irrigation systems
Yara International ASA	Norway	Water sensors, precision irrigation systems

Source: Focus bankers

Focus Bankers have identified 87 private companies active in the precision agriculture space. While this is no doubt only a partial list, it does show the types of market entrants (mostly quite small) who are developing technologies and systems for agricultural applications. Battelle has also added to the companies listed in Table 6 known Indiana firms in this segment.

Table 6: Private Companies in the Precision Agriculture Sector

Private Company	HQ Location	Precision Agriculture Products
Ag Integrated	Pennsylvania, USA	Cloud based systems
Ag Leader	Iowa, USA	Cloud data, guidance, yield monitors, variable rate controls
AgData	Australia	Agribusiness management software
AgNav	Ontario, Canada	Remote sensing, spraying systems
AgNition	Ontario, Canada	Mobile field scouting systems
AgriApps	South Africa	Agricultural equipment software
AgriData	North Dakota, USA	Software for aerial imaging and applications management
Agri-Vision	Missouri, USA	Inventory management software
AgSense	South Dakota, USA	Software for field data, irrigation management, flow monitoring

Private Company	HQ Location	Precision Agriculture Products
AgSmarts	Tennessee, USA	Field management software, crop management software ad irrigation software
AgSquared	New York, USA	Field planning and management software
AgSync	Indiana, USA	Software systems, site scouting applications for aerial and terrestrial applications
AgTerra Technologies	Wyoming, USA	Field management software and data loggers
AgXcel LLC	Nebraska, USA	Hardware for precision seen and fertilizer application
Ally Precision Industries	South Dakota, USA	Touch screen systems and field management software
Amazone Gmbh	Germany	Hardware systems for soil cultivation, spreading and planting
Arvus	Brazil	Variable rate application software and hardware
AquaSpy	Indiana, USA	Multi-sensor soil moisture probes
Baron Brothers International	Georgia, USA	Variable rate spreaders, software
Bestway Inc.	Kansas, USA	Automatic boom height control systems
Blue River Technologies	California, USA	Automated weed control
Bullseye Precision Farming	Australia	Precision fertilizer applicators
Claas	Germany	Automation and guidance systems on their tractors, combines, etc.
Crop Ventures Inc.	Nebraska, USA	Field management software
Cropio	New York, USA	Field management and vegetation control software
CropMetrics	Nebraska, USA	Field management software
CropTrak	Arizona, USA	Field management software
Decisive Farming	Alberta, Canada	Field management software
DICKEY-john Corporation	Alabama, USA	Sensors and auto steering systems
Digi-Star LLC	Wisconsin, USA	Weighing systems for grain
DN2K, LLC	Colorado, USA	Cloud software for field management
Dycam	California, USA	Sensors and image acquisition systems
E4 Crop Intelligence	Iowa, USA	Yield analytics software, fertilizer and seed prescription
Echelon	Saskatchewan, Canada	Field management software
eLEAF	Netherlands	Remote sensing and analysis software
ESRI	California, USA	GIS mapping software systems
Fairmade Management Systems	UK	Crop management software
Fairport Farm Software	Australia	Field management and asset management software
Farm Works	Indiana, USA	Field management software, cloud data
Farmeron	California, USA	Dairy farm management software
FarmLogs	Michigan, USA	Field management software
Farmscan	Australia	Spray and variable rate controllers, sensors and imaging equipment
Hardi North America	Iowa, USA	Sprayers and variable rate controllers
Headsight Inc.	Indiana, USA	Height and row control systems
Hiniker Company	Minnesota, USA	Cultivators, sprayers, controllers, shredders
Holland Scientific	Nebraska, USA	Geographic data loggers and sensors
Hortau Inc.	Quebec, Canada	Wireless field monitoring and weather systems
iCropTalk	Arizona, USA	Field management software
iLinc	Georgia, USA	Data acquisition and storage software

Private Company	HQ Location	Precision Agriculture Products
Intelligent Agricultural Solutions	North Dakota, USA	Wireless sensing and reporting of blockages in agricultural equipment
Juniper Systems	Utah, USA	Handheld field data collection hardware
Kinze	Iowa. USA	Variable rate planters
Land 'O Lakes, Inc.	Minnesota, USA	Variable rate application software
Libera Systems	North Dakota, USA	Variable rate mapping software
Loup Electronics	Nebraska, USA	Yield and drill monitors – hardware and sensors
MapShots Inc.	Georgia, USA	Soil fertility software, variable rate irrigation and seeding management software
MDA Information Systems	Maryland, USA	Weather forecasting software and predictive modeling
Meteo-Logic	Israel	Weather forecasting software
Micro Trak Systems	Minnesota, USA	Rate and flow control for seeding. Row monitors, controls and speed sensors
Mueller Electronics Inc.	Illinois, USA	Field navigation systems and displays for sprayers, tractors, trailers, etc.
MyFarms	Indiana, USA	Field and farm management software and systems
MyWay RTK	Illinois, USA	Autosteer RTK corrections systems
Netafim	California, USA	Wireless crop monitoring systems
Norac	Saskatchewan, Canada	Spray height control systems
Novariant Inc.	California, USA	Autosteer systems and farm management software
Nozzleworks Inc.	Washington, USA	Variable rate nozzle control systems
OmniStar	Texas, USA	Satellite guidance solutions and networks
OnFarm	California, USA	Decision management software and asset management software
Optima Concept	France	Electronic regulators and controls
Reichhardt Electronics Innovations Inc.	North Dakota, USA	Steering and RTK guidance systems
SBG Precision Farming	Netherlands	RTK and GPS guidance systems
ScoutPro Inc.	Iowa, USA	Corn and Soy Bean application software
Siga Farm Software	Quebec, Canada	Agricultural management software suites
Simplot AgriBusiness	Idaho, USA	Field management software and sensors
Sitewinder	Alberta, Canada	GPS guidance systems
Smart! Fertilizer Management	Israel	Fertilizer management software
SoilIQ	California, USA	Sensors and wireless smartphone-based soil management devices
Sol-Chip	Israel	Wireless sensors for soils and plants
Solum	California, USA	Soil and field management software
Spensa	Indiana, USA	Precision pest management tools
Spraytest Controls Inc.	Saskatchewan, Canada	Remote boom controls
SST Development Group	Oklahoma, USA	Agricultural management software suites
TeeJet technologies	Illinois, USA	Guidance systems and displays, autosteer systems
Tenacious Systems	New York, USA	Farm management software
The Daugherty Companies Inc.	Indiana, USA	Electronic monitors, controls and wiring systems for agricultural equipment
T-L Irrigation Company	Nebraska, USA	Precision drip irrigation systems and controls
Tru Count	Iowa, USA	Clutches for variable rate control applications

Private Company	HQ Location	Precision Agriculture Products
Veris Technologies Inc.	Kansas, USA	Soil analysis hardware and sensors
Weather Trends International	Pennsylvania, USA	Weather forecasting systems and predictive modeling software
ZedX, Inc.	Pennsylvania, USA	Irrigation management software and weather data systems.

Source: Focus Bankers

Multiple companies within the fast growing Unmanned Aerial Vehicle (UAV) segment are active in the development, testing, and production of agricultural UAV applications and technologies. Companies identified in this space are listed in Table 7.

Table 7: Unmanned Aerial Vehicle (UAV) and Unmanned Aerial Systems (UAS) Companies Active in Agricultural Applications

UAV and Associated Systems Company	HQ Location	Precision Agriculture Products
3D Robotics	California, USA	UAV image acquisition systems and analysis
AeroDreams	Argentina	UAV image acquisition systems
AgEagle	Kansas, USA	UAV image acquisition systems
Airwave	California, USA	UAV autopilot systems
Altavian Inc.	Florida, USA	UAV image acquisition systems
AutoCopter	North Carolina, USA	Multispectral image acquisition
Boeing	Illinois, USA	UAV systems
Bosh Global Services	Virginia, USA	UAV image acquisition systems and analysis
CropCam	Manitoba, Canada	UAV image acquisition systems
DroneDeploy	California, USA	UAV guidance systems
Hawkeye UAV	New Zealand	UAV image acquisition systems
Hypersight	Indiana, USA	UAV systems
IDETEC	Chile	UAV image acquisition systems
ISIS Geomatics	Alberta, Canada	UAV and satellite image and remote sensing acquisition systems
Microdrones GmbH	Germany	UAV image acquisition systems
MosaicMill Ltd.	Finland	UAV software and hardware
n-Link Corporation	Oregon, USA	UAV data collection systems
Precision Drone	Indiana, USA	UAV systems, image acquisition and analysis
Precision Hawk	Ontario, Canada	UAV image acquisition systems and analysis
senseFly SA	Switzerland	UAV image acquisition systems and analysis
Sky Hawk	Pennsylvania, USA	UAV image acquisition systems
Trigger Composites	Poland	UAV image acquisition systems
Volt Aerial Robotics	Missouri, USA	UAV image acquisition systems

Source: Focus bankers

The presence of a significant volume of small entrepreneurial business enterprises operating in the precision agriculture space bodes well for technology-based economic development potential. While still in the relatively early stages of market growth, there have already been some significant acquisitions by major corporations of precision agriculture and associated technology companies. Some notable examples include:

- Climate Corporation, purchased by Monsanto for $1.1 billion
- Precision Planting Inc., purchased by Monsanto for more than $200 million
- AgJunction, Inc. purchased by Hemispheres GPS for more than $10 million
- Geosys, acquired by Land 'O Lakes

- Rainwave LLC, Hydro-engineering Solutions LLC, Farm Works Software, and Nitech Solutions acquired by Trimble Navigation
- Spratronics acquired by Nozzleworks Inc.
- RDS technologies acquired by Digi-Star LLC
- Ezee-On acquired by Buhler Industries
- Ranchview acquired by Raven Industries.

The introduction of precision agriculture technologies requires the development and introduction of education programs for farmers and farm workers on the selection, implementation, and use of these technologies. Primary sources of information and education include:

- Land-grant Universities and their agricultural extension services
- Community college programs
- Independent crop/farming consultants
- Agricultural equipment dealers
- Agricultural equipment and precision agriculture systems producers.

In Indiana, Ivy Tech's Lafayette Campus offers an Associates of Applied Science in Agriculture with a focus area in Precision Agriculture (60 credit hours). Five courses (15 credit hours) provide students with hands-on emersion in precision agriculture technology. Students also take courses in agriculture business, sales, and agronomy in the degree program that will prepare them for any number of agriculture technology-related career opportunities.

VI. Major Research Institutions and Initiatives Focused in this Sector

Agricultural equipment technologies and systems design and engineering occurs across a variety of different organizational types. Academic institutions perform basic and applied research, and in the U.S., they are also proactive developers of novel technologies and equipment, particularly via agricultural engineering departments at Land-grant Universities. Institutions like Purdue University that have robust agriculture, engineering, and computer science/data analytics programs are particularly well positioned to be active in the type of multi-disciplinary R&D activity designed to produce integrated systems solutions in applications such as precision agriculture.

U.S. News ranks Purdue University as the #1 graduate school in the nation for Agricultural and Biological Engineering.

While there are also freestanding independent non-profit institutes engaged in agbioscience research, including major players such as the Samuel Roberts Noble Foundation and the Donald Danforth Plant Science Center in the U.S., these institutes tend to be more focused on biotechnology, crop research and development, crop protection and agronomy – and they are only engaged to a fairly limited degree in equipment programs. Similarly, while the Federal government is also an important performer of agricultural research through the USDA ARS (Agricultural Research Service), there is fairly limited USDA direct research on equipment. The USDA ARS does have a location in Columbia, Missouri with an interdisciplinary team of engineers and soil scientists conducting research in the field of precision agriculture.

In the agricultural equipment technologies and systems market, it is industry that is the key performer of R&D—just as it is in any sector with large-scale commercial markets. Industry research takes place in the large agricultural equipment multi-nationals, and in mid-size and smaller entrepreneurial business ventures as shown in the previous report section.

A. Universities

As noted in a 2011 report by Battelle:[20]

> *Helping to drive scientific discovery, innovation and the deployment of new technologies and innovations to enhance industry productivity is a uniquely American system developed by visionaries in the late 1800's—the Land-grant University. "Land-grant University" is the term used to identify a public university in each state that was originally established as a land-grant college of agriculture pursuant to the Morrill Act of 1862. In most states (including all of the North Central states) the original agricultural colleges grew over time into full-fledged comprehensive public universities by adding other colleges (e.g., arts and sciences, medicine, law, etc.). Today these universities stand among the world's premier research and extension education institutions.*

While almost all the Land-grant Universities will maintain focus areas in agricultural engineering and associated disciplines to some degree, several stand out for a significant emphasis in this area. The *U.S. News* ranking of best graduate schools for Agricultural and Biological Engineering ranks the following universities as the top 10, and notably they are all major Land-grant Universities:

- #1 Purdue University
- #2 (tie) Texas A&M University
- #2 (tie) University of Illinois – Urbana Champaign
- #4 (tie) Cornell University
- #4 (tie) Iowa State University
- #4 (tie) University of Florida
- #7 University of California – Davis
- #8 Virginia Tech
- #9 University of Nebraska – Lincoln
- #10 North Carolina State University

Purdue University's faculty demonstrate several concentration areas in relation to agricultural engineering. Chief among these are: ecological and ecosystems engineering (including soils, water, waste management, etc.); biomass processing and bioprocessing for fuels and industrial applications; fluid power systems; and sensors and precision agriculture.

Texas A&M has demonstrable strengths in sensors, and its precision agriculture applications work centers on the Biological Engineering and Sensor Technologies Lab. The University also has a particular focus on engineering solutions to environmental challenges, including those associated with agriculture (with program emphasis areas in soil and water engineering and air quality). There is also a small research cluster in bioenergy and biobased industrial products research and engineering of systems for this market.

At the **University of Illinois,** the Department of Agricultural and Biological Engineering sustains an active research program focused on off-road equipment R&D. The program area at the University works in R&D for design, manufacturing, testing, and operation of agricultural and construction equipment. Faculty research in this field focuses on areas relating to agricultural automation, remote sensing, and engineering solutions for biomass feedstock production. The University's Illinois Laboratory for Agricultural Remote Sensing (ILARS) conducts applied research, and work with industry and government agencies, to develop precision and site-specific tools for the agriculture sector and for natural resources management. Research conducted by ILARS ranges from on-farm production applications to large-scale

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[20] Simon Tripp and Deborah Cummings. 2011. "Power and Promise: Agbioscience in the North Central United States." Battelle Memorial Institute, Technology Partnership Practice.

agribusiness uses, such as regional yield estimations. The laboratory is interdisciplinary, "staffed with experts in the fields of crop science, agriculture engineering, extension, agriculture economics, geographic information systems, and remote sensing."[21]

Iowa State University claims to be ranked first in research and development spending among the nation's agricultural and biosystems engineering departments at public universities. These investments totaled over $9 million in FY13. Iowa State has notable concentrations of work in: advanced machinery engineering and manufacturing systems; animal production systems engineering (including integrated crop and livestock production systems), instrumentation for agricultural and biosystems engineering, and in biomass processing for industrial applications. Iowa State also has a Mechatronics Research Lab and an additional research focus on precision agriculture. Graduate courses include precision farming systems and electronic systems integration for agricultural machinery and production systems.

The **University of Florida** is one of the more active universities in terms of having extensive programs focused on the design, development, and improvement of agricultural production equipment. Research areas that are notable in this regard include work on: alternative machinery for field operations; agrochemical application technology; agricultural robotics and mechatronics; precision agriculture and sensor development (including sensors for variable rate applications); machine vision and image processing, and remote sensing of plant stress. Florida also has an active research focus in information technologies, software systems and data analytics for farm management. There is also significant work in post-harvest materials handling equipment and processes. The diverse nature of the types of agricultural products produced in Florida, including multiple niche crops, likely leads to the University having demand for its services in agricultural processing equipment R&D—whereas in states where there is more homogeneous monocropping of corn, soybeans, or wheat, the large agricultural equipment vendors have a large part of the equipment R&D space covered.

Similar to the University of Florida, the **University of California Davis** maintains a long-standing, active program in machine systems research focused on agricultural production machinery. As UC Davis notes, the University has:

> *[a] long history of success in developing machine systems for fruit, nut, vegetable, and field crops. Tractors, implements, and harvesting machines have been studied, improved, or developed from basic concepts. Harvesters for processing tomatoes, wine grapes, cantaloupes, dates, fresh market tomatoes, asparagus, prunes, peaches, and raisins were firsts for the department. The emphasis placed on this endeavor reflects the important status of California as a producer of a wide range of horticultural commodities. The state is a major producer of rice, other grain and seed crops, sugar beets, and hay. Out of a list of 126 major and minor fruit, nut, and vegetable crops grown in the US, nearly 60% are represented in California. In fact, California is the leading producer of 47 and the second leading producer of 17 of these US grown commodities.*

UC Davis notes that many smaller companies in California produce specialty equipment but are unable to finance major research programs, and so the Biological and Agricultural Engineering department devotes its attention to meeting machine research needs not met by large-scale manufacturers. The UC Davis commitment to work in agricultural equipment engineering benefits from the 1998 opening of the Joe A. Heidrick, Sr. Western Center for Agricultural Equipment—an 18,000 sq. ft. building accommodating teaching, research, and extension activities focused on agricultural field equipment for the western U.S. The integration of precision agricultural hardware and software solutions is also an emphasis area for UC Davis.

The **University of Nebraska** is notable for its emphasis on agricultural machinery design, development, and testing. All three of the core research thrust areas identified by the University of Nebraska

[21] http://abe-research.illinois.edu/remote-sensing/index.html

Department of Agricultural Engineering are pragmatically focused on important issues in production agriculture, with these foci including:

- **Machine Design Engineering.** Working to invent, design, or improve the machines used by agriculture.
- **Soil and Water Resources Engineering.** Developing irrigation systems, methods to control erosion, and practices for pollution prevention.
- **Test Engineering.** Working to evaluate the functional performance of machines and equipment through study of test procedure standards, measurements, and data acquisition.

In this latter area, the University of Nebraska is notable for being home to the Nebraska Tractor Test Laboratory which is "the officially designated tractor testing station for the United States and tests tractors according to the Organization for Economic Co-operation and Development (OECD) codes. Tractors are tested in the country of manufacture. Twenty-nine countries adhere to the tractor test codes (including non-OECD members: China, India, the Russian Federation, and Serbia) with active tractor test stations in approximately 25 of those countries."[22]

It should be noted that across the U.S., the research performed at Land-grant Universities produces a substantial base of new intellectual property (IP) every year. This IP is typically available for licensing (rather than being directly commercialized by the university or start-up companies – although that certainly does occur), and should be monitored for opportunities to in-license technology for commercialization in Indiana.

Battelle also notes the emergence of a small, but noticeable, trend among Land-grant Universities to reorganize their traditional structures to better facilitate interdisciplinary agbioscience and technology-development research. Cornell University, for example, recently reorganized to create the School of Integrative Plant Sciences and North Carolina State University's College of Agriculture and Life Sciences plans a similar reorganization. In addition, some universities are developing interdisciplinary campus-wide strategic initiatives targeting global grand challenges. Both The Ohio State University and the University of Minnesota have identified food and agriculture as key interdisciplinary thrusts.

B. University-based and State-based Agbioscience Economic Development Initiatives

Just as Indiana has recognized the large-scale economic development opportunities associated with agbioscience (embodied in the formation, for example, of AgriNovus), so too have other states and regions within the U.S. Other initiatives around the country represent competition, but they may also represent an opportunity for networking and collaborations. Some notable initiatives focused on agriculture and related industries are evident in:

- **Minnesota.** The State of Minnesota, the Minnesota Agricultural Utilization and Research Initiative (AURI), and the University of Minnesota collaborated in undertaking a detailed assessment of agbioscience core competencies and, like Indiana, identification of priority platforms for further development (based both on core competencies and an identified line-of-sight to major market opportunities).
- **North Carolina.** The State of North Carolina funded the North Carolina Department of Agriculture and North Carolina State University to assess the economic feasibility of a major $180 million investment in a new Plant Science Initiative and interdisciplinary plant science research building to be located on the Centennial Campus of NC State. As with Minnesota, the North Carolina strategy incorporated core competency analysis and platform identification.
- **Iowa.** The State of Iowa has maintained a decade-long emphasis on building its "BioEconomy" focusing on leveraging R&D and agricultural commodities to build a major bio-based chemicals and biofuels products industry. The advancement of plant sciences towards Bioeconomy and food

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[22] http://tractortestlab.unl.edu/

and feed applications has been facilitated by the formation of the Plant Sciences Institute at Iowa State University and investment in pilot plant facilities.

Other states have identified agricultural science capabilities and opportunities into statewide bioscience development strategies (strategies that examined not only agbioscience, but also biomedical and industrial life science opportunities). Such strategies have been undertaken in many states, with recent examples including Ohio, Colorado, Mississippi, Oklahoma, and Nebraska.

It should be noted that, while other states are emphasizing agricultural technology-based economic development, there is no location in the U.S. or globally that has cemented itself as the go-to hub of agricultural equipment engineering in general, nor in the fast growth area of precision agriculture technologies. In the latter technology arena there is an open opportunity for locations to emphasize the development of interdisciplinary connections and industry/university research collaborations to advance hub development for precision agriculture. There are certainly locations with a significant volume of start-up business activity in precision agriculture, but a formal collaborative economic development program focused on development of the cluster has not been identified.

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C. Freestanding Agbioscience Institutes

Two independent non-profit agricultural research institutes are particularly notable for the size and scope of their agbioscience research activities – the Noble Foundation and the Donald Danforth Plant Science Center. The most long-standing of these is the Samuel Roberts Noble Foundation, located in Ardmore Oklahoma. Founded in 1945, the Noble Foundation now employs over 360 personnel and conducts direct operations, including assisting farmers and ranchers, and conducting plant science research and agricultural programs to enhance agricultural productivity regionally, nationally, and internationally.

The Donald Danforth Plant Sciences Center is located in St. Louis, Missouri. The Danforth Center employs 200 individuals from more than 20 countries. Twenty scientific teams conduct basic research focused on improving agricultural productivity and preserving natural resources by reducing the need for pesticides and fertilizers, increasing the nutritional content of crops, and improving resistance to drought, pests, and disease.

Neither of these two major independent agbioscience research institutions has a large-scale focus on agricultural equipment engineering or precision agriculture systems R&D.

D. Key International Agbioscience Hubs

With agriculture being a worldwide industry of great importance to both developed and developing nations, it should come as no surprise that, in addition to the U.S., there are notable hubs of agricultural science research activity located around the world. Some key examples include:

- **The United Kingdom.** The UK has an extensive history of work in agriculture and a significant network of major agbioscience research institutes. Internationally recognized centers for agbioscience research in the UK include, for example, the James Hutton Institute, John Innes Center, Rothamstead Research and Moredun. The UK also has a significant agricultural equipment manufacturing sector.
- **Continental Europe.** Multiple hubs of agricultural science and crop protection research and industrial activity are notable in the Netherlands, Denmark, Germany, Switzerland and France. In Germany, the Cluster of Excellence on Plant Sciences (CEPLAS) is working to coordinate the work of multiple research university partners to advance plant science discoveries. While multiple European universities have strengths in agbioscience, Wageningen University (located in the

Netherlands) particularly gets noted for its excellence in conversations with industry and international academics. Some of the top 30 ranked institutions in agricultural sciences are located in Europe, including Wageningen, Ghent, Copenhagen, Helsinki, Zurich and the Swedish University of Agricultural Sciences. Several major agricultural equipment brands are based in Europe, and notable centers for R&D and production of agricultural equipment exist in Germany, Italy, France, the Netherlands, Denmark, Norway and Finland.

- **Oceania.** Both Australia and New Zealand have notable clusters of excellence in agbioscience. In Australia notable clusters of activity are particularly evident in Adelaide and Melbourne, but other regional initiatives are building momentum (with Sydney, for example, in the planning stages for a science park with an emphasis in this area). In New Zealand, AgResearch New Zealand is a well-recognized program of excellence and most New Zealand Universities have concentrated areas of expertise in agbioscience given the importance of agricultural exports to the New Zealand economy.
- **China.** The Chinese Academy of Sciences is the publisher of records for a large volume of agbioscience research publications. Some notable assets are: the Shanghai Institute of Plant Physiology and Ecology; the National Center for Gene Research (rice, bamboo and miscanthus); the Shanghai Chensan Plant Science research Center, and the Shanghai Institute for Biological Sciences.

Specific to agricultural engineering and precision agriculture, some notable international locations and centers include:

- **India:** The Central Institute of Agricultural Engineering located in Bhopal, primarily focuses on the development of low-cost equipment solutions for developing world farmers for soil cultivation, sowing and planting, harvesting and post-harvest processing. Much of this work is focused on implements for use by small-holders using animal-drawn power (e.g. oxen).
- **United Kingdom:** Harper Adams University operates the UK National Centre for Precision Farming. The centre promotes and evaluates the use of technology as a vital aspect of precision agriculture, building upon the university's reputation as an innovator in the field of engineering. Its work in the area of robotics in crop scouting and dairy production, for example, is claimed to be already well-known in the agri-food sector. It has also developed automatic steering systems.
- **Australia:** The University of Sydney Precision Agriculture Laboratory was established at the beginning of 2012 to operate within the University of Sydney's Centre for Carbon, Water and Food. The lab is the descendant of the Australian Centre for Precision Agriculture (ACPA) which was established in 1995. The mission of the ACPA was to provide excellent precision agriculture science and training, leading agricultural industries towards incorporating practical, sustainable precision agricultural management techniques
- **New Zealand:** The NZ Center for Precision Agriculture is located at Massey University. Research is focused on GIS, GPS and remote sensing, animal tracking systems, variable rate technology for fertilizer application, and sensors and precision systems for pasture yield evaluation.
- **China:** The Chinese Academy of Agricultural Mechanization Sciences (CAMS) is a state run organization focused on agricultural equipment for China and further improving the manufacturing base for agricultural equipment in the country. It is part of the long-standing China Academy of Machinery Science and Technology (CAM).
- **Brazil:** In Brazil the Research Network in Precision Agriculture represents the main coordinating entity for precision agricultural development and implementation into Brazilian agriculture. It represents a network arrangement composed of 214 researchers, 19 research centers, 15 experimental fields comprising different Brazilian ecosystems and 12 crops.

VII. Conclusion

Agricultural equipment technologies and systems represent strong economic growth propositions for Indiana. By helping to address major global grand challenges (including enhancing food yields, assuring food security, improving environmental protection, and resource use efficiencies), modern agricultural equipment technologies and systems interface with large-scale and significantly growing global markets.

Indiana is already well-positioned to take advantage of growth potential in this economic sector. With multiple Indiana companies, such as Equipment Technologies, AgSync, AquaSpy, Farm Works, Headsight, MyFarms, and Spensa, active in the space, this is an existing cluster industry to build upon. It is further reinforced by the strong agriculture and engineering R&D programs at Purdue University and relevant engineering and technology programs at other Indiana universities.

The sector provides promise for Indiana along several economic development pathways. R&D within industry and academic institutions hold promise for the development of new commercial innovations, and the growing global demand for agbioscience solutions suggests that growth in Indiana companies in the sector is to be anticipated. Purdue's emphasis on agricultural science research and engineering will help attract further extramural funding into Indiana from outside sources, and forms the backbone for the education and training of the skilled scientists and technicians needed for the sector to expand. It is also the case that R&D and associated innovations in Indiana agricultural technologies will not only provide opportunities for exportable products, technologies, and services, but also provide solutions needed by Indiana farmers to improve yields and enhance farm profitability across the state.

AgriNovus, by convening key stakeholders in plant science and crop protection across Indiana, will play a critically important role in facilitating the industry/university and public/private partnerships that can help further advance the sector in the State. This is especially important given the interdisciplinary and systems-integration nature of precision agriculture which needs diverse capabilities across various engineering disciplines, agricultural science disciplines, computer science and information processing. Through encouraging dialog and teamwork between key actors in the field within Indiana, and assuring Indiana government and economic developers pay attention to sustaining a healthy ecosystem for agricultural equipment technologies and systems innovations in the State, AgriNovus can help assure a robust platform for growth.

VIII. Suggested Further Reading

David Schimmelpfennig and Robert Ebel. *"On the Doorstep of the Information Age: Recent Adoption of Precision Agriculture."* U.S. Department of Agriculture, Economic Research Service .Economic Information Bulletin Number 80. August 2011

IBIS World. *"Tractors & Agricultural Machinery Manufacturing in the U.S."* June 2014

IBIS World. *"Precision Agriculture Systems & Services in the U.S."* May 2014.

Oganesoff and Reid Howard. *"Precision Agriculture: M&A, Investments, and Start-ups on the Rise."* FOCUS Investment Banking, LLC.

J. K. Waage and J. D. Mumford. *"Agricultural Biosecurity."* Phil. Trans. R. Soc. B (2008) 363, 863–876. Published online 30 August 2007

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H. Charles J. Godfray, et al. *"The future of the global food system."* Phil. Trans. R. Soc. B (2010) 365, 2769–2777
http://rstb.royalsocietypublishing.org/content/royptb/365/1554/2769.full.pdf

Simon Tripp and Deborah Cummings. 2011. *"Power and Promise: Agbioscience in the North Central United States."* Battelle Memorial Institute, Technology Partnership Practice.

Online Resources:

For general news and information on the industrial precision agriculture sector a useful resource is: http://www.precisionag.com/

A general resource is the International Society of Precision Agriculture at: https://www.ispag.org/ICPA

A good general overview and description of precision agriculture is provided by the NASA Earth Observatory website at: http://earthobservatory.nasa.gov/Features/PrecisionFarming/

Oklahoma State University maintains a website with links to external information resources on key precision agriculture technology areas. The website is:
http://www.agmachinery.okstate.edu/PrecisionAgTech