Agbioscience Sector Review: Plant Science and Crop Protection

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I. What Does This Sector Do?

This sector includes organizations and companies engaged in crop improvement and crop protection via the application of plant science, biotechnology, chemistry, and other scientific disciplines. These companies engage in seed genetics and development, crop hybridization, and the development and production of agricultural chemicals (fertilizers, herbicides, pesticides). A key goal of businesses in this sector is to enhance the productivity of production agriculture through creating crops with higher yields, resistance to stress (such as drought or frost tolerance), and resistance to pests and plant diseases. Enhancements may be generated through traditional breeding/hybridization techniques and advanced genomics technologies. Innovators in this sector may also work to introduce crop varieties with enhanced functional characteristics (nutrition content, color, flavor, shape, downstream processability characteristics, etc.). Chemistry is also an important area of activity in this sector, with companies engaged in developing targeted crop protection chemicals, fertilizers, soil inoculants, and other chemical and biologic inputs to production.

II. Primary Drivers of Growth

Plant science and crop protection are of intense importance to global well-being and progress. Agriculture and related agricultural science and value-chain activities (agbioscience) are faced 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. Plant-based 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 pest and disease pressures) and socio-economic factors (such as commodity prices, consumer demands, changing 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 driving opportunities and growth in the plant science and crop protection 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.[1] 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 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

[1] Statistics accessed at http://www.worldometers.info/world-population/

	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."[2] 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.[3]
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[4] 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 (such as 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).[5] Freshwater withdrawals have tripled in the last 50 years, and current usage levels are unsustainable in much of the world.

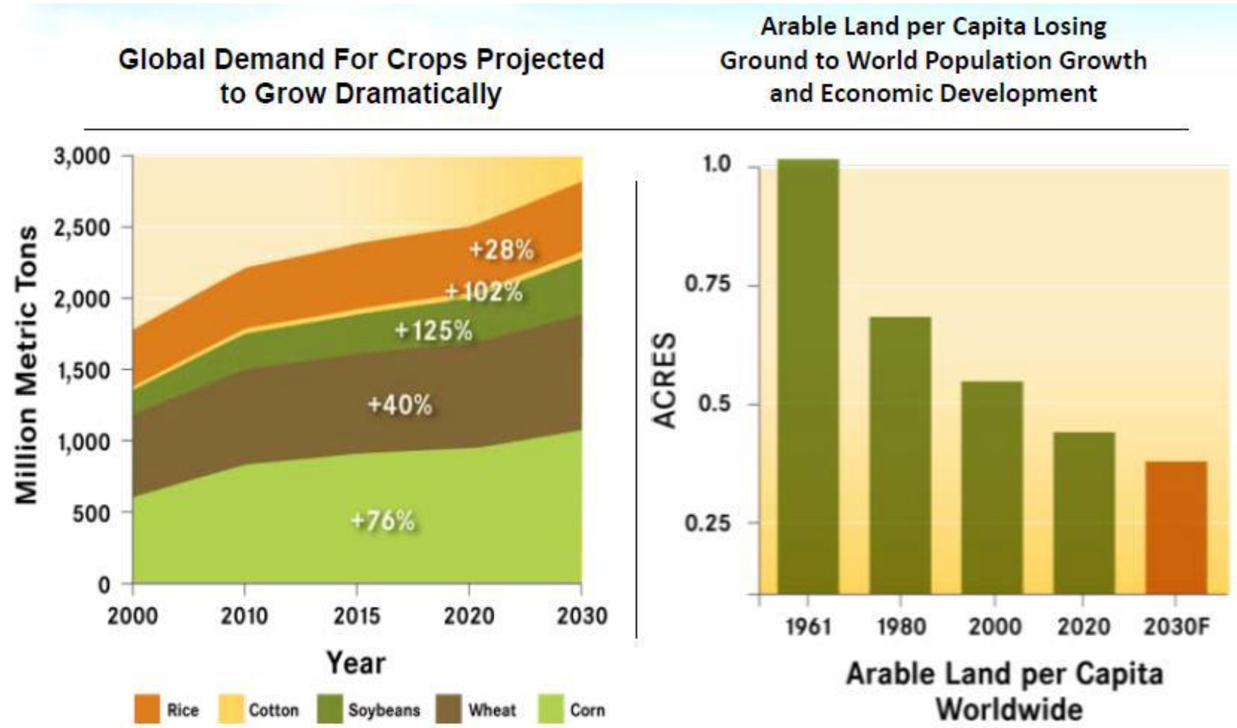
[2] H. Charles J. Godfray, et al. "The future of the global food system." Phil. Trans. R. Soc. B (2010) 365, 2769–2777.
[3] Jonathan Watts. "More wealth, more meat. How China's rise spells trouble." The Guardian, May 29, 2008.
[4] Human Appropriation of the World's Food Supply. http://www.globalchange.umich.edu/globalchange2/current/lectures/food_supply/food.htm
[5] United Nations Food and Agriculture Organization http://www.fao.org/nr/water/aquastat/water_use/index.stm

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.
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[6] 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.[7]
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.

[6] 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.
[7] World Resources Institute. 2013. "Creating a Sustainable Food Future."

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.[8]

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



The challenges and demand-side factors noted in Table 1 each have a direct relationship to potential solutions that may be derived from innovation in plant science and/or crop protection solutions. Examples are discussed in Table 2.

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

Table 2: Potential Solutions to Agbioscience-Related Challenges

Challenge	Plant Science and Crop Protection Platform – Potential Solutions
Population growth	Development of crop varieties with increased inherent yield. Crop protection technologies to prevent yield reductions from biotic stress.
Wealth growth (expansion of per capita consumption)	Increased yield of feed grains to meet livestock nutrition demands. Development of enhanced staple foods with improved sensory characteristics and nutrition profile.
Climate change	Development of plants available to achieve high yields with reduced inputs. Development of cover crops and no-till practices to protect soils and promote carbon sequestration. Development of feed products with lower methane production during livestock digestion.
Environmental protection	Naturally degrading biological crop protection products. Plants with high use efficiency of soil nutrients and amendments. Precision sensing of individual plant input needs and prescription application of reduced amounts of chemicals.
Resource use efficiencies	Plants with high levels of drought tolerance and water use efficiency characteristics.
Evolving and emerging diseases and pests	New varieties of pest tolerant/pest resistance crops. Herbicide/pesticide tolerant crop varieties. Biological crop protection agents. New crop protection chemicals.
A need for healthier foods	Healthy food crops with enhanced sensory characteristics that increase demand. Crops with enhanced functional nutrition characteristics to offset micronutrient and other human diet deficiencies.
Reduce food waste	Development of crops resistant to post-harvest bruising, wilting, or other spoilage conditions that prevent their consumption.
Changes in consumer behavior	Development of organic pest control technologies (biologics). New crop variety development via traditional breeding and hybridization techniques (non GMO).

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

The global market for agricultural crops and crop protection technologies is obviously extremely large. The worldwide market for seed, for example, was estimated by BCC Research to have reached $36.7 billion in 2012, comprising $19.6 billion in conventional seed[9] and $17.1 billion in transgenic/GM seed.[10] Proprietary, commercially grown and sold seed comprises the largest component of the market (67 percent).

Transgenic seed represents the fastest growing component of the market. In 2001, transgenic seed represented just 20.6 percent of the market. By 2006, this grew to 34.1 percent, and in 2012 it represented fully 46.6 percent. BCC Research now places the 2014 market size for transgenic seed at $23.4 billion and projects it will reach $34.1 billion in 2019, representing a robust 7.8 percent CAGR between 2014 and 2019.[11]

Market research places the global crop protection chemicals market at $50.7 billion in 2013, and projects it growing to $69.6 billion by 2019 (a CAGR of 5.5 percent between 2014 and 2019). The largest segment of the market comprises herbicides, followed by fungicides and insecticides.

IV. Technologies and Emerging Opportunities

The sector will present opportunities and demands for innovation and new technology development across a range of sub-platforms. Chief among these are likely to be:

A. Tools and Technologies for Plant Science R&D

Description	The plant science research enterprise (contained in industry, academe, government laboratories, and independent non-profit institutes) is a consumer of new scientific instrumentation, tools, and technologies for facilitating inquiries into basic plant biology and applied plant science development activities (including lab, controlled environment, and field research).
Examples	Most of the new advancements in biological science R&D technologies have applicability to plant sciences. Modern systems for high-resolution imaging, real-time imaging, gene sequencing, crystallography, mass spectrometry, gene insertion, big data informatics, etc. are of direct relevance. A relatively recent perspectives paper in *The Plant Cell* by Ehrhardt and Frommer[12] is particularly current and helpful in thinking through technology and innovation needs for the plant science research community. They note the following categories of technology as being needed by plant scientists into the future: ▪ Gene replacement technology ▪ Artificial chromosomes and respective transformation technology ▪ Tissue-representative cell lines (as are available in animal and human research) ▪ Cyberinfrastructure and data handling systems ▪ Reverse genetics tools that can be efficiently applied to plants beyond models ▪ Plant phenomics: high throughput systems that mimic real world conditions

[9] Conventional seed are typically hybrid seeds produced by cross-pollination.
[10] BCC Research. "Seed treatment Technologies and Global Markets". Data sourced by BCC from the International Seed Federation and World Seed. BCC Research report number CHM072A.
[11] BCC Research. 2014. Agricultural Biotechnology: Emerging Technologies and Global Markets. BCC Research report number BIO100B.
[12] David W. Ehrhardt and Wolf B. Frommer. "Perspective: New Technologies for 21st Century Plant Science." The Plant Cell, Vol. 24: 374–394, February 2012.

	▪ Tools for genomic engineering ▪ Four-dimensional imaging at the super-resolution level ▪ Multimodal imaging ▪ Crystal structure of all (plant membrane) proteins ▪ Diagnostics of plant health ▪ Diagnostics of plant pathogens ▪ Methods to manipulate gene and protein function with high resolution in space and time and in combination (cellular and sub-cellular scales) ▪ Biosensors for plant hormones and signaling intermediates ▪ Biosensors for all key metabolites ▪ Tools to take cell-level biology and physiology to the environment ▪ Methods to image cell wall organization and molecular rearrangements ▪ Precise small molecule inhibitors for all proteins ▪ Tools for rapid increase or decrease in protein activity/amount ▪ Field-scale imaging to measure plant performance over time from individuals in a population ▪ Remote (satellite or airplane) sensing of photosynthetic efficiency, nutritional status, and water status ▪ Methods for imaging deep in tissues or in the soil ▪ A virtual plant to test hypotheses ▪ Genetic vehicles for transferring complex traits or even complete pathways to new contexts for plants

In recent interviews conducted by Battelle with major plant science multi-national corporations, several needs were repeatedly expressed for facilitation of applied research and product development:

- The need for field phenotyping/physiological metrics measurement;
- The need for real-time imaging and analysis of plant gene expression, including in below-soil regions; and,
- Solutions to the analysis and interpretation of the massive volumes of data likely to be generated through field phenotyping, genomic analysis, remote sensing, etc.

Another excellent high-level overview of key R&D themes/needs moving forward in plant science has been provided by the American Society of Plant Biologists, whose “decadal vision” for plant science sets goals for four major advancement themes (see Table 3).[13]

[13] American Society of Plant Biologists. “Unleashing a decade of Innovation in Plant Sciences: A Vision for 2015-2025.”

Table 3: American Society of Plant Biologists: Key Plant Sciences Development Themes for the next Decade 2-15-2025

Theme	Description of Needs
Increase the ability to predict plant traits from plant genomes in diverse environments	This requires programs that will: 1) link genome to performance during environmental change and biotic interactions by establishing the interconnections among a plant's genes, their myriad cellular products and functions, and the ways these determine agronomically important plant traits; 2) expand plant phenotyping capabilities, in particular drawing upon advances in computation and robotics; 3) define how plant species have naturally adapted to stressful or extreme environments, specifying biological mechanisms that can be harnessed for agriculture; 4) understand the dynamics of plant communication, from the intracellular to the interorganismal scale, and 5) establish a comprehensive plant attribute database that integrates genetic, molecular, and chemical data with developmental, architectural, field performance, and environmental parameters.
Assemble plant traits in different ways to solve problems	Introduce traits via breeding strategies or the virtually unlimited possibilities of synthetic biology. This requires combinations of breeding, biology, and engineering and computation talent. Plus there is a need for large scale genetic, genomic and biochemical characterization of wild or heritage germplasm related to crop species.
Discover, catalog, and utilize plant-derived chemicals	Plant scientists have only scratched the surface of cataloging plant-derived chemicals and their biological purposes. The Society's recommendations are to: 1) determine the chemical composition and biosynthetic pathways in 20,000 ecologically and medicinally important species to understand the synthesis and biological purpose of plant-derived chemicals, and 2) utilize plant chemistry for application in human health, agriculture and manufacturing.
Enhance the ability to find answers in a torrent of data	For plant biology to become a reliably predictive science, data analysis must undergo a paradigm shift. Defining the complex relationships that underlie plant behavior will require: 1) Integrating data through the perfection of statistical models, application of machine learning, and validation of functional predictions from models, and 2) facilitating data storage, retrieval and analysis through incentivizing, enabling, and training scientists to develop or test hypotheses through intensive data analysis before conducting wet lab or field experiments

Moving beyond the more early stage and basic questions and opportunities outlined above, there are major categories of applied R&D and new product development that represent core thrusts for academic, industry and government R&D. Chief among these R&D focus areas are:

B. Crops with Resistance to Abiotic Stress

Description	Typical abiotic stress factors negatively impacting crop yield include drought, flooding, extreme temperatures (cold or heat), high winds, and increasing soil salinity. While estimates vary, a notable study found that abiotic stress causes the most crop loss of any other factor and that most major crops are reduced in their yield by more than 50 percent from their potential yield.[14] R&D can lead to the development of crop varieties with resistance to single or multiple abiotic stressors, providing a potential pathway to significantly enhanced yield and to the option of expanding the environment within which a crop may be grown. Climate change, leading to an unpredictable increase in potential weather extremes, is a particular concern for plant scientists and seed companies working towards crops with abiotic stress resistance.
Examples	Drought tolerant crops Cold hardy crop varieties Crops adapted to growth in soils with elevated salinity Crops resistant to flood conditions. A key emerging technology space for advancing crops with resistance to both abiotic and biotic stress is in genomics tools, "including next-generation sequencing and microarrays, which are permitting marker-assisted breeding, which typically yields faster results compared with traditional breeding practices. Once a desirable trait has been identified, newer genomics tools such as genome editing, RNA interference and synthetic biology come into play to make changes to the plant's genome."[15]

C. Crops with Resistance to Pests (Biotic Stress)

Description	Biotic stress is plant stress induced by other organisms (pests), typically in the form or plant pathogens (bacteria, viruses, fungi), weeds and parasitic plants, insects, and wildlife, such as birds. Preventing and controlling the impact and spread of pests is a key ongoing challenge for the agbiosciences. Globally, an average of 35 percent of crop yields are lost to pre-harvest pests.[16] Approaches taken to pest management through crop improvement include the breeding or engineering of plants with inherent resistance traits to disease, and/or insertion of traits into crops making them resistant to the application of herbicides that broadly control weeds or other pest control products.
Examples	Insertion of single, or stacked traits, for disease resistance Insertion of single, or stacked traits, for insect resistance or repulsion Insertion of single, or stacked traits, for herbicide or other chemical tolerance

[14] Wang, W., Vinocur, B. and Altman, A. "Plant responses to drought, salinity and extreme temperatures towards genetic engineering for stress tolerance." Planta 218: 1-14, 2007.
[15] BCC Research. 2014. Agricultural Biotechnology: Emerging Technologies and Global Markets. BC C Research report number BIO100B.
[16] Dehne HW, Oerke E, Schonbeck F, Weber A (2004). Crop production and crop protection: Estimated losses in major food and cash crops. Elsevier: Amsterdam.

D. Seed Treatments

Description	The seed treatment technology space includes a variety of products used by commercial seed companies and growers for coating seed in order to safeguard seed and improve crops by controlling the population of seed-borne and soilborne pathogens.
Examples	Seed treatment technologies for crop protection are primarily focused in the following areas: ▪ Insecticides ▪ Fungicides ▪ Herbicides protection coatings (restricting herbicides from penetrating seeds) ▪ Nematocides In addition, seat treatments may also be applied for plant growth stimulation. These products would primarily comprise: ▪ Plant growth regulators ▪ Micronutrients Seed treatment application technologies include: ▪ Seed dressing (typically a one-layer coating leaving the seed shape unchanged) ▪ Coating/encrusting (used on uneven shaped seeds, smoothing the shape and generating uniformity) ▪ Film coating (again smoothing the seed using a spray application) ▪ Seed pelleting (significantly increasing the size of the seed into a spherical pellet – used on uneven seed and very small seeds to improve automated handling/planting)

E. Biological (Biotechnological) Crop Protection Agents and Plant Growth Enhancers

Description	According to BCC Research, "Agricultural biologicals, or microbials, are primarily compounds that come from microorganisms that can be applied to fields to achieve natural control of insects, pests, to protect soil or to improve productivity. Biologicals include those products that are derived from naturally occurring microorganisms, plant extracts, or organic materials." Battelle notes that there are additional biological agents of use, such as the application of beneficial nematodes for pest control. In addition to the goal of increasing or protecting yield, another key goal of biological agents is to provide an alternative, more environmentally benign tool versus traditional agrichemicals (which may be associated with pollution and negative environmental impacts). BCC Research notes that "biologicals are in a growth stage, and are filling a growing market need for environmentally friendly pest control. In addition, many large agricultural companies view the market for biostimulants as a growth opportunity because they represent a new product category that complements existing businesses." Another area to consider in relation to biologics is what Battelle terms "agri-symbiotics." This focuses on advancing scientific understanding of the beneficial biological interactions between plants and other organisms (especially microbes, but

	also including fungi and invertebrates), and application of knowledge of such symbioses to technologies for advancing agricultural yield. This is a highly interdisciplinary field of inquiry requiring engagement of expertise in bacteriology, virology, mycology, basic-microbiology, biochemistry, molecular biology and genomics, metagenomics and microbiomics, epigenomics, evolutionary and developmental biology, to name just some of the varied fields that can be engaged.
Examples	Two main categories include biopesticides (protect crops) and biostimulants (enhance crops). ▪ Biopesticide products include bioherbicides, biofungicides and bioinsecticides. Microorganisms, including bacteria, fungi, protozoa, viruses and yeast, are the main technologies for biopesticides. Biochemicals, including botanical extracts, fatty acids and semi-chemicals, are also used for biopesticide applications. Biopesticides provide farmers with a different mode of action than that offered by conventional chemical pesticides. This provides better protection against pesticide-resistant weeds. ▪ Biostimulant technologies include adjuvants, plant growth regulators and inoculants. Biostimulants are applied by farmers as a supplement to fertilizers and/or pesticides to create better plant health."

F. Precision Sensing and Prescription Agricultural Inputs Application Systems

Description	Precision and prescription agriculture uses precise positioning and sensor technologies, in combination with data analytics, to evaluate crop development and the conditions within the production environment. This may be accomplished in real-time to guide actions including the specific dosage of inputs to enhance yield. This technology space is mentioned here in the Plant Science and Crop Protection White paper because plant science knowledge will be directly relevant to the development of biological sensors for monitoring plant health, rapidly diagnosing plant diseases or the presence of pests, and monitoring the physiology of plants in response to stress and agronomic inputs.
Examples	Sensors and probes for the measurement of plant physiology. Analytical support systems for decision making on inputs application based on plant field condition.

It should be noted that advancement is going to be needed through an "all of the above" approach if the grand challenge of meeting expanding global food and feed demands is to be met. Experience over the past decade shows that the growth trajectory being achieved from single technologies or approaches (such as selective breeding, plant transgenics, etc.) is insufficient to meet demand projections. Meeting the challenge will likely require integrated systems approaches that combine advanced breeding and plant transformation techniques, novel biological and chemical crop protection agents, soil amendment and fertility enhancement technologies, precision sensing and inputs application, and enhanced harvesting and post-harvest preservation technologies. Recognition of this by major agbioscience multinationals is readily apparent in their acquisitions of a diverse base of ag-tech companies, and is overtly expressed within company websites and in annual reports.

While a large component of plant science is focused on production agriculture for food, it is not the only application area. Plants are also a key source of fiber, industrial bulk and specialty chemicals, and medicinal ingredients. Here the intersection of plant science with other disciplines (especially chemistry and chemical engineering) comes into play, a fit to the strength of a university such as Purdue with robust capabilities in both agbioscience and engineering. This is also an area of industry where the connectivity between agbioscience companies (e.g. Dow AgroSciences) and chemical companies (e.g. Dow Chemical) generates R&D and product development synergies.

G. Plants as Production Systems for Value-Added Chemicals

Description	Plants represent sophisticated chemical production organisms that may be engineered to produce substances that, in addition to nutrition applications for food and feed, may also be used for applications as diverse as vaccine production, biopharmaceutical production, or the production of industrial chemicals. The Midwest region of the U.S. already has a relatively well developed industry base in the use of plant chemicals and biomass as inputs to industrial products. The traditional pulp and paper industry has long been a converter of forestry output, but row crop production is also utilized for production of biofuels (e.g. ethanol and biodiesel), specialty chemicals and bioplastics. Beyond bulk chemical production, plants are increasingly being seen as production vehicles for very high value products such as vaccines, biopharmaceutical proteins, and other advanced phytochemical use applications. The emergence of synthetic biology holds significant potential for growth in this technology-space, as does plant transgenics.
Examples	Plant primary and secondary metabolites are used in the production of industrial chemicals and materials and biopharmaceuticals. There is long-standing use of such chemicals as oils, lubricants, drugs, anesthetics, waxes, fragrances, flavors, rubber, etc. Researchers at Iowa State and Berkeley[17] note that: “with modern biomanufacturing, common crop species can be genetically engineered to synthesize and deliver a broad range of unique biomolecules needed for medical or industrial use. In theory, production of almost any kind of biomolecule could be engineered into plant hosts--including nucleic acids, carbohydrates, oils, and secondary metabolites such as vitamins. However, today most R&D is focused on expressing just a handful of valuable proteins, mostly antibodies, vaccines, enzymes, and other pharmaceutical proteins.” Some key target technology growth areas include, but are not limited to: • Biopharmaceuticals • Vaccines • Nutraceuticals • Cosmetics • Biodegradable polymers • Liquid fuels • Advanced textiles and materials • Industrial enzyme production • Medical materials (e.g. elastin, collagen).

[17] Gregory Gaff and GinaCarolo Moschini. 2004. Pharmaceuticals and Industrial Products in Crops: Economic Prospects and Impacts on Agriculture. Iowa Ag Review. Fall 2004, Vol. 10 No. 4.

H. Another Critical Need

Science and technology-based solutions to the global food security challenge, and realizing the opportunities for economic development from plant-science and crop protection innovations, unfortunately does not only depend upon scientific progress. While a robust scientific R&D infrastructure is a precursor to progress, other important factors also influence development potential. Currently, a notable barrier to plant-science innovations is the length of time required to move from basic discovery to an on-the-market approved product – with the introduction of new crop varieties (especially those with transgenic constructs) requiring up to a decade to navigate the process. A critical need is assuring that the political and regulatory framework in the U.S. and within individual states (and indeed in crucial international markets) follows scientific rational methods. The global challenges for which agriculture promises solutions cannot be met if unnecessary barriers, often rooted in unfounded fears and misinformation surrounding advanced life science technologies, are allowed to proliferate.

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 4.

Table 4: Characteristics for Successful Plant Science, Crop Protection and Agbioscience Geographic Hubs

Success Element	Description
Presence of major multi-national agbioscience corporations (especially R&D operations of these companies)	The seed and crop protection technology sectors are highly consolidated with a large component of global R&D and production concentrated in relatively few multinational corporate leaders (including, for example, Monsanto, Syngenta, Dow AgroSciences, BASF, Bayer CropScience, KWS, DuPont and Limagrain). The presence of one or more of these agbioscience corporate leaders 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 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, agbioscience 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 agbioscience being concentrated 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 agbioscience 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. 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 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 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 agbioscience, 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. Some additional areas of concern also include the emerging challenges associated with a patchwork of local and state GMO food labeling requirements, and potential expansion of food manufacturers and retailers removing GMO ingredients from products not because of science-based information but because of consumer attitudes and associated pressures.
The presence of a robust education and workforce development pipeline meeting the needs of R&D and industry sectors	Agbioscience is a high-tech, knowledge-based sector that is driven by the skills and capabilities of a well-educated workforce. Industry requires PhD trained scientists, skilled technicians, and lab and field workers able to work in a dynamic multi-disciplinary science environment. Places with an existing base of workers already employed in agbioscience 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:

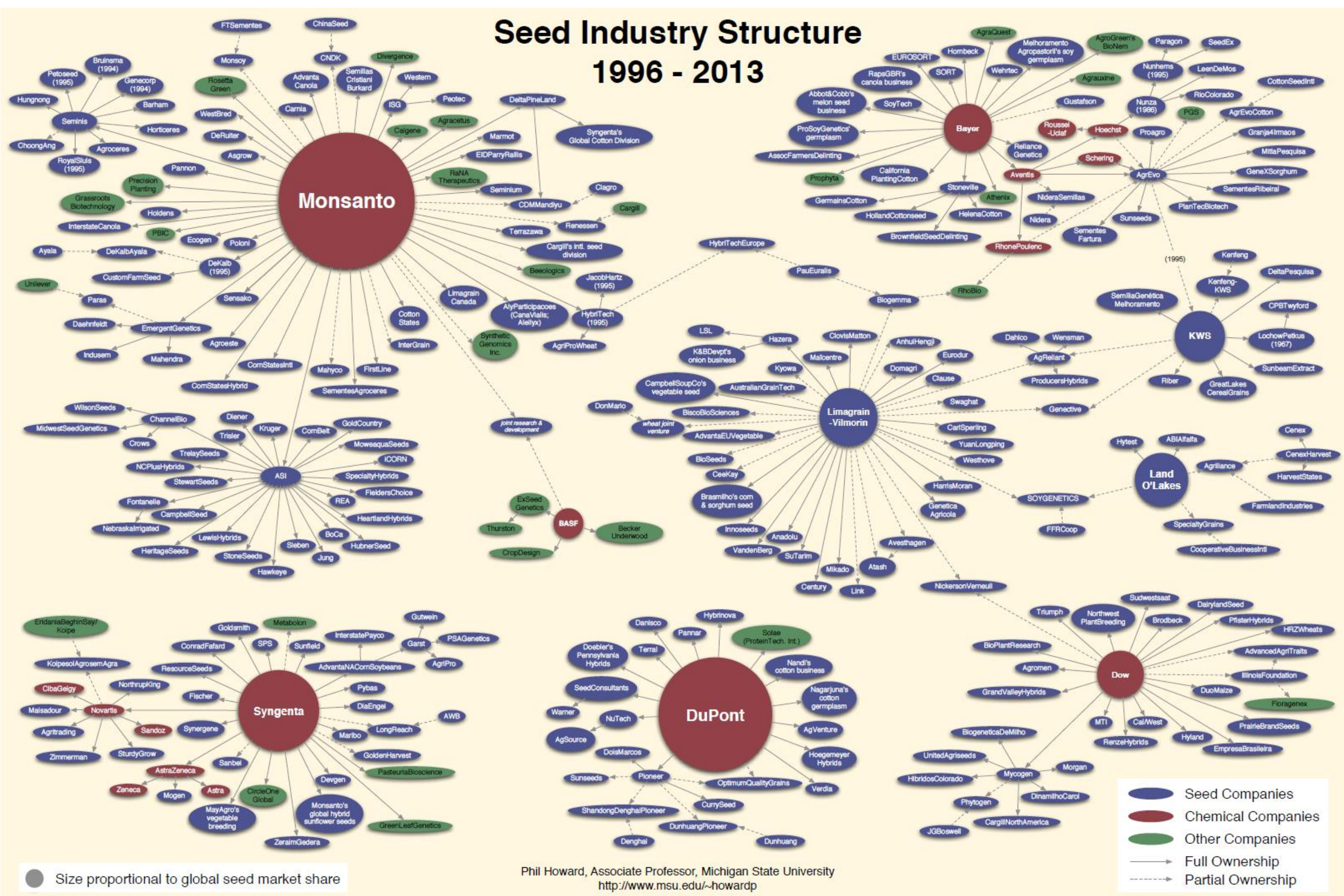
- Attraction of significant external funds to support research and development, thereby creating high paying science and technology R&D jobs.
- Attraction of existing agbioscience industry to the region to undertake R&D and production activities.

- Further growth of existing regional agbioscience 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

While there exists a considerable number of brands of crop seeds available for use by agricultural producers, the reality is that consolidation and acquisition activities within the industry means that a very large proportion of the global plant science industry is controlled by a few large-scale multinational corporations. Figure 2, produced by Phil Howard at Michigan State University does an especially good job of illustrating this characteristic of the industry.

Figure 2: Illustration of Major Seed Industry Corporate Connectivity. Graphic produced by Phil Howard, Associate Professor, Michigan State University[18]



[18] Phil Howard, Associate Professor, Michigan State University. http://www.msu.edu/~howardp

The agbioscience industry is quite similar to the biopharmaceuticals industry in this regard. A particular positive attribute of the model from a new business development standpoint is that a successful entrepreneurial venture can see a fairly well-established “exit strategy” in that there is a healthy base of well-capitalized multinationals with which to form strategic alliances, joint ventures, or acquisition.

Indiana has the advantage of being home to one of the major multinationals, Dow AgroSciences, and also in close proximity to industry giant Monsanto located within the Midwest region.

The extent of dominance by a few very large companies in the proprietary seed and biotech seed marketplace is illustrated by the following data identified by BCC Research:[19]

Table 5: Leading Seed Companies

Company	Global HQ	Estimated Percent of Seed Market	Estimated Percent of Biotech Seed market
Monsanto	Missouri, USA	22.8	45.6
DuPont	Delaware, USA	18.1	29.0
Syngenta	Switzerland	7.1	11.3
Dow Chemical	Michigan, USA	3.6	5.8
BASF	Germany	<3.0	<5.0
Bayer Crop Science	Germany	<3.0	<5.0
Vilmorin	France	4.2	---
KWS	Germany	3.3	---
SUM		**≤ 65.1%**	**≤ 100%**

Several important plant science companies operate from a base in Indiana, including of course Dow AgroSciences, and also Beck’s Hybrids and AgReliant Genetics (part of KWS of Germany and Groupe Limagrain of France). AgReliant especially focuses on corn and has developed hybrids with higher yields, improved feed value, and utilization of traits to achieve resistance to insects, drought, and diseases. Beck’s Hybrids is the largest family-owned seed company in the United States, and a leading supplier of high performance corn, soybeans, wheat, and alfalfa (and other forages). Dow AgroSciences is among the leading plant science companies globally, employing more than 8,000 people worldwide, and having 2013 global sales totaling $7.1 billion. As might be anticipated, given Dow AgroSciences size, the company has a broad range of products including (but not limited to) seeds and traits, insecticides, herbicides, fungicides, fumigants, nitrogen stabilizers, and oils.

Within the growing agricultural biotechnology sphere, which includes companies engaged in plant transformation (and biotech seed) and in biologics for crop protection and biostimulant technologies, BCC Research has identified key players as including:

[19] BCC Research. 2014. Agricultural Biotechnology: Emerging Technologies and Global Markets. BCC Research report number BIO100B.

Table 6: Biotech Trait Specialty Companies

Company	HQ Location	Product Focus
Arcadia	California, USA	Nitrogen use efficiency, salt tolerant crops, water use efficient crops, produce shelf life.
Biocentury Transgene	China	Transgenic, insect-resistant cotton.
Ceres	California, USA	Sweet sorghum and biomass sorghum. Other energy crops (switchgrass, miscanthus)
Evogene	Israel	Abiotic and biotic stress tolerance, water and nitrogen use efficiency in major crops (corn, soybean, cotton, canola, rice and wheat)
Hexima	Australia	Insect and fungal pest resistance traits. Gene delivery technology.
KeyGene	The Netherlands	Trait R&D – biotic and abiotic stress tolerance, herbicide tolerance and reproductive traits
Mendel Biotechnology	California, USA	Recently purchased by Koch-Agronomic Services. Transcription factor-based tech for manipulating plant traits.
Performance Plants	Ontario, Canada	Drought and heat tolerance. Water use efficiency. Trait stacking.
Venganza	North Carolina, USA	Gene silencing and RNA interference. For pest resistance. Work in tobacco, soybean and potato.

Table 7: Seed Treatment Companies

Company	HQ Location	Product Focus
Bayer	Germany	Global leader in seed treatments. Protection against nematodes, as well as seed and seedling diseases, increasing crop vigor, stands and yields
Syngenta	Switzerland	Seedcare brand. Pest protection, e.g. fungi, nematodes. Multiple major crops.
BASF	Germany	Disease and pest control treatments. Multiple major crops.
Nufarm	Australia	Disease and pest control treatments
Venganza	North Carolina, USA	Gene silencing and RNA interference.

Table 8 Companies in Agricultural Biologics

Major Company	HQ Location	Product Focus
BASF Agricultural Solutions	Germany	Biological control products, biological plant health and growth regulator products. Acquired Becker Underwood.
Bayer CropScience	Germany	Live micro-organisms for biological crop protection. Horticultural and field crop protection solutions.
Monsanto	Missouri, USA	RNA interference.
Syngenta	Switzerland	Bacterial control of nematodes. Fruits and vegetables concentration.
Small Companies	HQ Location	Product Focus
Actagro	California, USA	Plant metabolism stimulants. Fungicides
Adaptive Symbiotic Technologies	Washington, USA	Symbiotic fungi promoting stress tolerance
Advanced Biological Marketing	Ohio, USA	Biostimulants for root health using fungi strains
Agricen	Texas, USA	Biostimulants encouraging fertilizer uptake.
Agrinos AS	Norway	Biostimulants for nutrient fixation
BrettYoung	Manitoba, Canada	Biologics for soybean and corn yield enhancement
Bug AGentis Biologicos	Brazil	Wasps that control pests
Certis USA	Maryland, USA	Biopesticides
Eden Research	UK	Technologies for increasing shelf life of biological agents. Terpenes-based technologies.
Kip Cullers Co. Brasil	Brazil	Biostimulants
Marrone Bio Innovations	California, USA	Biopesticides for row crops using micro-organisms and plant extracts.
New Leaf Symbiotics	Missouri, USA	Bacteria-based biological stimulants. Focus on pink pigmented facultative methylotrophs plant bacteria.
Novozymes BioAg	Denmark	Biostimulants and biopesticides. Microbial-based biofertility, biocontrol, and bioyield enhancer products
Stroller USA	Texas, USA	Hormone supporting biostimulants
Valent Biosciences	Illinois, USA	Biopesticides and biostimulants

VI. Major Research Institutions and Initiatives Focused in this Sector

Agbioscience, plant science, and crop protection R&D 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 specialized crops and germplasm and, via the land-grant universities, operate proactive extension systems to disseminate technologies and best practices. 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. The Federal Government in the United States is also an important performer of agricultural research through the U.S. Department of Agriculture's ARS (Agricultural Research Service) which has a series of research stations and programs across the nation, often operated in close collaboration with major land-grant universities. Industry, of course, is a key performer of R&D – just as it is in any sector with large-scale commercial markets. Industry research takes place in the large commercial seed and agricultural chemical multi-nationals, and in midsize and smaller entrepreneurial business ventures.

A. Land Grant 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.*

Within the national system of land grant universities, Purdue University stands among the premiere providers of agbioscience research. In 2013, the combined research expenditures of Purdue's College of Agriculture, Experiment Station and Extension research system totaled over $120 million. The basic through applied agbioscience research continuum at Purdue is supported by a robust base of specialized resources and infrastructure, with basic and applied research facilities in West Lafayette supported by 14,697 acres of Purdue University agricultural land distributed across the state to facilitate research and field trial activity (including 11 experiment stations), and Purdue Extension reaching all 92 Indiana counties in provision of research-based education.

Several key Purdue resources were highlighted in the recent Battelle report on agbioscience opportunities in Indiana, with some notable focus areas relating to plant science being:

- **Center for Molecular Agriculture:** Investments in fundamental research that allow Purdue to develop the technology to customize plants to meet emerging needs both locally and across the globe.
- **Plant Genome Engineering Facility:** A genome engineering lab bridging the gap between identification of valuable genes and their commercialization.
- **Automated Field Phenotyping Laboratory:** Investment in new technology to facilitate billions of field measurements for detailed assessment of important traits such as canopy development, leaf area index, height, photosynthetic activity, etc., that are important for both research and commercialization.
- **Plant Commercialization Incubator Facility:** For field trials and testing leading to licensing and commercialization in the plant sciences or related areas to move new innovations to market.

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

- **The Plant Science Research and Education Pipeline:** Under this program, the University has committed more than $20 million focused towards building and sustaining Purdue's position among the world leaders in understanding the most basic elements of plant biology, translating those discoveries to commercially important crops, assessing the performance of these new developments in the field, and moving these improved plants and products through to commercialization.

While almost all the land grant universities will maintain focus areas in plant science and crop protection to some degree, several stand out for a significant emphasis in this area. Notable examples, defined by having a high volume of publishing in plant science and associated disciplines between 2009 and 2014, include:

- Cornell University (New York) and the Boyce Thompson Institute for Plant Research
- Michigan State University
- North Carolina State University (with the largest number of plant breeding faculty among any U.S. institution)
- The University of California, Davis with an emphasis on collaborative interdisciplinarity research and plant reproductive biology and the Seed Biotechnology Center
- Iowa State University and the Plant Sciences Institute
- University of Georgia.

Depending on the individual area of crop protection or plant sciences under consideration, there is great variability in terms of which universities are the most formidable competitors in each area. For example, emphasis in a specific crop will highlight certain universities (typically those for which that crop is a key production commodity in that state – such as wheat in Kansas and soybeans in Ohio). Similarly, niche areas in entomology, parasitology, invasive weed species, mycorrhizae, drought tolerance, etc. will show variability depending on where the top faculty in that individual specialty are located.

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 notes the emergence of a small, but noticeable, trend among land-grant universities to reorganize their traditional structures to better facilitate interdisciplinary agbioscience and plant science research. Cornell University 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 competing initiatives 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 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, Iowa, and Nebraska.

C. Freestanding Agbioscience Institutes

Two independent, non-profit plant science institutes are particularly notable for the size and scope of their plant science research activities – the Samuel Roberts 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. Principal activities of the Noble Foundation focused on plant science and crop improvement are contained in:

- The Plant Biology Division, which conducts basic biochemical, genetic and genomic plant research for the purpose of improving crop productivity and value, and enhancing animal and human health
- The Forage Improvement Division, which translates basic plant science research into tangible plant varieties.

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.

D. Key International Plant Science 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 plant science and crop protection activity located around the world. Some key examples include:

- **The United Kingdom.** The UK has an extensive history of work in plant sciences and a significant network of major agbioscience research institutes. Internationally recognized centers for research in the UK include, for example, the James Hutton Institute, John Innes Center and Rothamstead Research.
- **Continental Europe.** Multiple hubs of plant 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 plant science, 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.

- **Oceania.** Both Australia and New Zealand have notable clusters of excellence in agbioscience and plant sciences. 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 plant science 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.

VII. Conclusion

Plant science and crop protection represents a strong economic growth proposition for Indiana. Addressing major global grand challenges (including enhancing food yields, assuring food security, improving environmental protection, and resource use efficiencies), plant science and crop protection interfaces with large-scale and significantly growing global markets.

Indiana is already well-positioned to take advantage of growth potential in this economic sector. With 19 Indiana businesses focused on plant science and crop protection activities, employing over 3,100 workers in the state, this is an existing cluster industry to build upon. It is further reinforced by a robust base of plant science and crop protection R&D at Purdue University, which is furthering its already significant concentration in this sector through the Plant Science Research and Education Pipeline initiative.

The sector provides promise for Indiana along several economic development pathways. R&D within industry and academic institutions holds 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 plant science and crop protection research will help attract further extramural funding into Indiana from outside sources, and forms the backbone for the education and training of the skilled plant scientists needed for the sector to expand. It is also the case that R&D and associated innovations in Indiana plant science crop protection 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. Through encouraging dialog and teamwork between Indiana's key actors in the plant science and crop protection field, and assuring Indiana government officials and economic developers pay attention to sustaining a healthy ecosystem for agbioscience, AgriNovus can help ensure a robust platform for plant science and crop protection growth.

VIII. Suggested Further Reading

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