THE NORTH CAROLINA PLANT SCIENCES INITIATIVE:

AN ECONOMIC FEASIBILITY STUDY

Prepared for the State of North Carolina

Prepared by the Partnership of
North Carolina State University,
College of Agriculture and Life Sciences and
North Carolina Department of Agriculture &
Consumer Services

Date: December 2014

NC STATE UNIVERSITY
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January 1, 2015

Please find attached to this letter a report entitled *The North Carolina Plant Sciences Initiative: An Economic Feasibility Study* in response to Section 13.1 of 2014 NC Legislation:

> *PLANT SCIENCES RESEARCH AND INNOVATION INITIATIVE – SECTION 13.1*
>
> *(a) The funds appropriated by this act to the Department of Agriculture and Consumer Services for the Plant Sciences Research initiative shall be used by the Commissioner to develop jointly with the College of Agriculture and Life Sciences at North Carolina State University and other stakeholders a formal proposal and economic needs assessment for establishment of a public/private partnership between the University, other academic institutions, private companies in the agribusiness and bioscience sectors, the Department, and other State regulatory agencies for the following amounts and purposes: (i) the sum of three hundred fifty thousand dollars ($350,000) for a partnership to be known as the "Plant Sciences Research and Innovation Initiative" and (ii) the sum of two hundred fifty thousand dollars ($250,000) for a partnership to be known as the "Food Processing Initiative."*
>
> *(b) The Department and North Carolina State University shall jointly submit a copy of the proposal and report on the results of the economic needs assessment to the Chairs of the House of Representatives Appropriations Subcommittee on Natural and Economic Resources, the Chairs of the Senate Appropriations Committee on Natural and Economic Resources, the Agriculture and Forestry Awareness Study Commission, and the Fiscal Research Division by January 1, 2015.*

This report specifically addresses the economic feasibility study for section 13.1, part (a) (i) related to "Plant Sciences" and was completed in partnership with the NC Department of Agriculture and Consumer Services, and, the College of Agriculture and Life Sciences at North Carolina State University. The economic analysis, evaluations and recommendations provided in this report have been provided after extensive external stakeholder input and food/agricultural data for North Carolina, and beyond.

It is our hope that this report provides meaningful information for North Carolina to grow its number one industry – Agriculture – to even higher levels. Questions and suggestions related to this report can be directed to either one of us or to the project lead: Dr. Steve Lommel, Associate Dean for Research, NC State University College of Agriculture and Life Sciences at slommel@ncsu.edu or 919-515-2717

Sincerely,

Steven W. Troxler, Commissioner
North Carolina Department of Agriculture
and Consumer Services

Richard H. Linton, Ph.D., Dean
NC State University
College of Agriculture and Life Sciences

Abstract

North Carolina has a significant opportunity to be the global hub for advanced plant sciences research and for the application of that research to expanding agricultural productivity. Given the strong and growing demand for agricultural products into the foreseeable future, driven by expanding populations and global wealth, agriculture and agbioscience represent a significant economic growth driver.

North Carolina currently has a compelling case to make with regards to its global position within plant sciences, driven by several distinctive assets: a diverse agronomic environment suited to the development and commercialization of multiple crops; a world-class cluster of multinational agbioscience corporations; an expanding base of entrepreneurial business enterprises in the sector; and NC State University (which ranks 6th in the nation in agricultural research volume). While the state's case for plant science-based economic development is highly compelling, there is a rather stark gap evident in the lack of modern physical infrastructure for plant science advancement at NC State (which has not seen a new building in the College of Agriculture and Life Sciences since the 1950s). This gap in world-class academic plant-science infrastructure is well recognized by key agriculture, business and economic stakeholders in North Carolina who have identified both a need and urgent opportunity to develop a major new interdisciplinary plant science building on the NC State Centennial Campus. Independent evaluation of the potential development of the NC State Plant Sciences Initiative (PSI), and the proposed Plant Science Building (PSB), has found unprecedented levels of support for the initiative from agricultural commodity groups, the NC Farm Bureau, leading NC-based multinational agbioscience companies, the North Carolina Department of Agriculture and Consumer Services, and other key stakeholder groups. The initiative is seen as a "must do" program, one that will serve as a critical step in enhancing public/private partnerships and completing an extremely robust ecosystem for agbioscience- and plant-science based economic growth.

Why is the proposed Plant Sciences Building required?

- NC State has antiquated plant science infrastructure.
- The big challenges in agbioscience require multi-disciplinary approaches, and NC State lacks this space for plant sciences.
- NC's leading agbioscience industry cluster wants space on campus for collaborative industry/university R&D projects.
- There is a need for space to incubate new businesses from plant science innovations and new technology development.
- Specialized space is needed for cross-disciplinary training of students to produce the workforce that a growing industry in NC will require.
- A signature space investment will help attract the very best and brightest in plant sciences to NC State.
- Recommended focus areas for research in the PSB will result in innovations that will enhance agricultural production in NC and its associated economic impacts.

Conservative employment impact estimates of the PSI over the next decade indicate that it could, by itself, generate an additional 2,365 jobs in North Carolina by 2024. Starting in 2018 (allowing for PSB construction time), economic output in North Carolina would increase significantly, growing to $366 million annually by 2024. Battelle's projections show economic output directly attributable to the PSI, between 2018 and 2024, growing by $1.4 billion. As noted, by 2024 the output of the North Carolina economy, just for that year, would be $366 million higher than otherwise projected if the PSI were not built (and, again, that is being conservative). Put another way, just six months of increased economic output in one year (2024)

would be equivalent to the entire $180 million PSB cost. Clearly, these conservative impact results provide a strong justification for the Initiative.

As noted in this report, the PSI and PSB will serve to build upon and reinforce North Carolina's strong momentum in life sciences and biotechnology development, while at the same time developing innovations and technologies that will enhance the economic success of North Carolina's farms and the value-added industry chain that depends on high-productivity agriculture. It is important to note that the Plant Science Initiative comprises a critical element in development of a fully-integrated food production value-chain in North Carolina — and will be a key contributor to further significant economic impact benefits through synergies with the proposed Food Manufacturing Initiative (discussed in a separate report) and the existing NC State Plants for Human Health Institute.

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Executive Summary

Introduction

As a leading economic sector, agriculture is responsible for employing over 2 billion people globally providing for the economic well-being of countless families in both the developed and developing world. Closer to home, the agricultural sector is currently responsible for one in every 12 U.S. jobs. In North Carolina, agriculture and its value-chain represents the largest industry in the state.

The current and future importance of agriculture to global well-being and progress is hard to overstate. Agriculture and its related agricultural science and value-chain activities (agbioscience) are faced with the awesome responsibility of feeding a rapidly expanding global population, enhancing and protecting human health, preserving the environment and global biodiversity, and providing inputs to a growing green industrial economy. When examining the diverse geographic nature of agriculture, the scope of challenges addressed, and its critically important role in supporting global and local economic systems, agriculture is as important today, and into the foreseeable future, as it has ever been. Because of this, the opportunities for agbioscience-based economic development are substantial.

Agbioscience as a Signature Development Opportunity for North Carolina

North Carolina has an extremely compelling case to make for agbioscience-based economic development, especially in plant sciences. It is currently one of a limited number of global locations that:

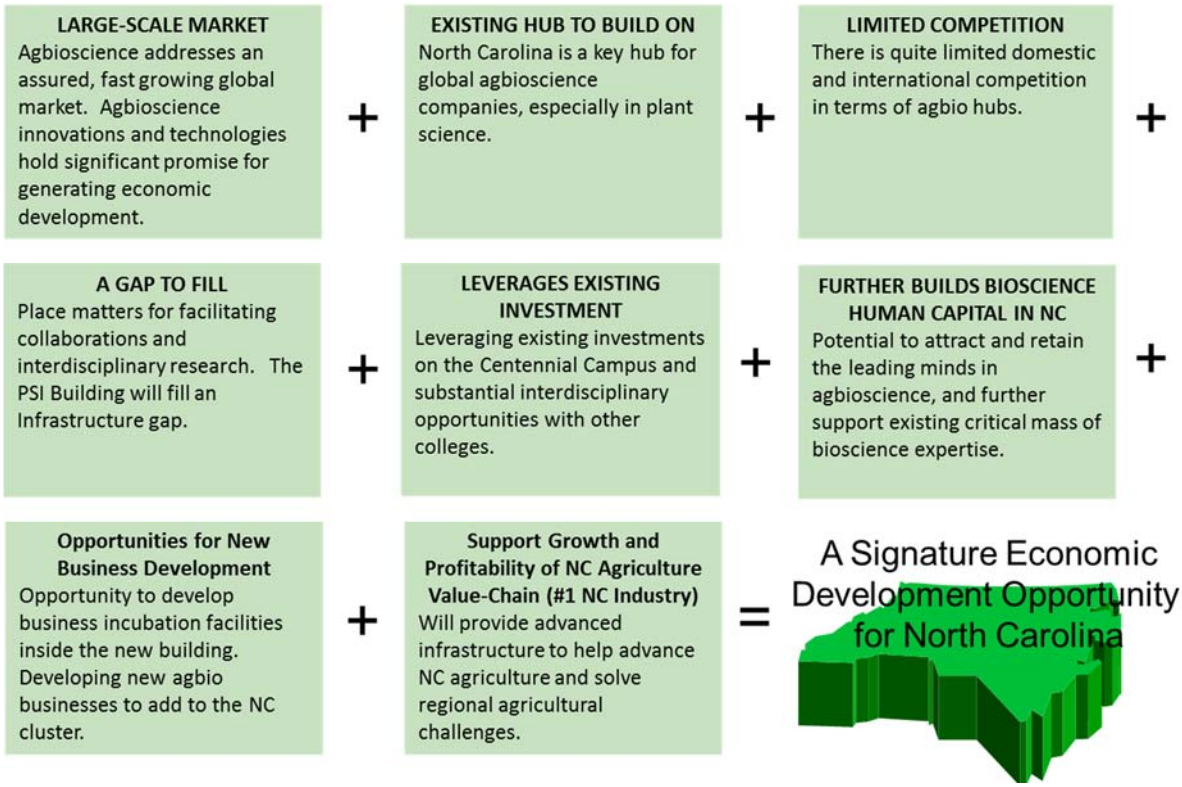
- Enjoys a strong, recognizable cluster of major agbioscience multinational operations, including major R&D operations of these companies.
- Is experiencing growth in agbioscience start-up business enterprises.
- Is home to a top ranked land-grant university, NC State University, in terms of total agbioscience research funding.
- Has a diverse agronomic environment suited to the growth and development of multiple crops.
- Maintains an overall policy and regulatory framework that is still generally favorable to agbiotech and the introduction of associated innovations.
- Has developed the infrastructure, business support services and workforce development programs required to underpin the growth of advanced biotechnology industry.
- Provides a quality of life and location conducive to the attraction of the skilled human capital required for advanced agbioscience jobs.

Because of these favorable characteristics there is an opportunity for North Carolina in agbioscience that is perhaps matched by only a handful of other places globally. There is an open window of opportunity for the state to invest in building upon the strong foundation already present in North Carolina to become the core global hub for plant-based agbioscience R&D and associated business growth. The Battelle Technology Partnership Practice (TPP) performs science- and technology-based economic development (TBED) projects across the world and has directed the evaluation and design of TBED programs in most U.S. states but in no location so far has Battelle TPP seen such a promising convergence of assets poised to take advantage of large-scale expanding markets as North Carolina has in plant science and associated agbioscience.

Recognizing the opportunity to cement North Carolina as the leading global location for advanced plant sciences, NC State University has proposed to develop a Plant Sciences Initiative with an

associated Plant Sciences Building on the Centennial Campus that would be unequalled in U.S. academe and serve as a powerful hub for plant science innovations to reinforce North Carolina agriculture, spur innovative research collaborations with North Carolina's major base of agbioscience corporations, and form a state-of-the-art education center for producing the plant scientists of the future. As can be seen in Figure ES-1, such a development is a solid fit into an equation of agbioscience-based economic development in North Carolina.

Figure ES-1: The Plant Sciences Equation: Leveraging Unique Advantages for NC Economic Development



NC State University: An Asset to Build Upon

NC State is particularly well positioned to take on a major plant sciences initiative. The University is ranked in the elite Carnegie Classification of "very high research activity" institutions, and as one of the nation's premier land-grant universities. A key component of NC State's research, education and extension activity has always been focused in agricultural sciences and associated disciplines. In a nation where agricultural research occurs in all 50 states, NC State's performance in research is distinctive, placing the University in a strong position of 6th in overall agricultural sciences R&D expenditures.

The strength of NC State and the College of Agriculture and Life Sciences (CALS) in plant sciences research and associated agbioscience disciplines is important because without a strong R&D foundation within universities and research institutions, it is difficult for any state to initiate or sustain major cluster-based economic development. In agbioscience it is clear that land-grant universities are particularly important contributors to basic and applied research. In North Carolina, the base of basic and applied R&D capability within NC State, and in smaller niche areas within other universities, is considerably extended by the intensive R&D operations of leading global agbioscience corporations, including Syngenta, BASF, Bayer CropScience, Novozymes, and Monsanto, together with an emerging base of new agbioscience companies.

Battelle's economic analysis of North Carolina shows that the commercial agbioscience industry is a strong contributor to science- and technology-based economic development in the state. In the agricultural and plant-related R&D sector, for example, North Carolina employs almost 1,700 people and is highly specialized compared to the nation having a location quotient of 3.85 (equivalent to having 2.85 times more people employed in the sector than would be expected given national averages). Over the past decade this sector has nearly doubled its employment base in North Carolina (growing by 98% since 2001) and even added jobs despite the recession. The state is similarly a leader in the highly technical agricultural chemicals sector, with almost 2,400 personnel and a location quotient of 2.23. Across plant science-related technological and agricultural sectors the state of North Carolina demonstrates very high productivity levels as measured by value-added per worker (operating at 540% of normative national levels driven especially by strong performance in tobacco, ag chemicals, bioprocessing, fruit and vegetable production, nursery and floriculture and cotton production. Because of high productivity, the overall plant science sector in North Carolina pays almost $5,000 per year more in average wages to workers than the national average for this sector.

Because of North Carolina's robust cluster of advanced agbioscience companies, and the research conducted at NC State University, the state stands out as a significant national contributor to innovation and patent generation in agricultural and plant science arenas. One of the state's primary areas for local patenting activity is in identification and production of new plant varieties. Innovations in this category, as well as the biocide/pesticide category, stem from both NC State and the industry base in the state. Between 2009 and 2014 Battelle identified 684 awarded patents in plant science with North Carolina inventors, plus an additional 424 patents have been assigned to North Carolina-located patent holders from other sources. North Carolina is both producing, and acquiring, advanced plant science technologies to commercialize and grow the sector.

As can be seen from these statistics, and the key factors highlighted in Figure ES-1, North Carolina has a compelling case to make as a global agbioscience leader. It is not, however, a perfect case. The key gap in the North Carolina offering pertains to the quality of physical building infrastructure at NC State University for advanced agbioscience research and the fact that industry currently views the institution as "good" but not "great" in many areas. This is because of infrastructure deficiencies, gaps in faculty expertise and unfilled faculty positions. There is also a lack of understanding within industry of the full scope of the faculty at NC State, and the highly relevant skills they have for advancing modern plant science.

Locations that have tended to become the leading growth poles in technologies have shared the characteristic of having a world-class university presence in that technology field with close industry connectivity think Stanford and Silicon Valley, MIT and Harvard in Boston, Cambridge University and the British biotech cluster. As science and technology becomes more complex, the requirements for educated workers more critical, and open-innovation more central to technology industry strategies the presence of a world-class university, with world class infrastructure, to support an industry cluster becomes more and more important. North Carolina has proven that industry growth can be attracted by quality research universities with Research Triangle Park standing as a testament to the vision of marketing a region based on the presence of three anchoring world-class research universities. **The one part of the equation that is quite obviously lacking is high-quality advanced agbioscience academic building infrastructure, especially in terms of space to accommodate the interdisciplinary teams that are so important to advancing discovery and innovation across complex challenges.**

A Need to Invest to Realize Full Development Potential

For NC State there is a need for agbioscience investment on three primary fronts:

- **Most pressing is a need for improvement in physical infrastructure to advance clusters of expertise and interdisciplinary science** and to better connect capabilities with regional agbioscience industry.

- **Also required is investment in faculty and graduate student positions directed towards filling gaps in current capabilities** and assuring that NC State achieves the global leadership position in the final platforms determined as interdisciplinary thrusts for the Initiative.

- **Further investment in seed funding will also be needed to facilitate interdisciplinary team formation** and to provide the start-up funds that may then be leveraged to attract significant extramural funding. This would build upon the existing Research Innovation Seed Fund Program at NC State.

St. Louis, one of the other leading global agbioscience hubs, sees North Carolina as formidable competition to their vision to be the global leader in agbioscience (see sidebar). However, St. Louis has invested in world-class independent research institute/academic facilities (the Donald Danforth Plant Science Center), to advance agbiosciences research and collaborations with industry, whereas North Carolina has not…yet.

NC State has advanced a concept for filling the gap for developing, on the Centennial Campus, a $180 million advanced interdisciplinary Plant Sciences Building (PSB). The stated vision for the building is "to create the premier plant sciences infrastructure in the U.S." As envisioned, the Plant Sciences Building would be a world-class facility that will:

- *Foster the spirit of multi-disciplinary research to solve global challenges*
- *Create unique partnerships among universities, industry and government*
- *Maximize efficiencies for integrating our core missions of research, teaching, and outreach programs*
- *Be the premier destination for plant sciences in the world*
- *Allow NC to have a unique competitive advantage locally to globally*
- *Leverage our unique assets to create the Silicon Valley of Plant Sciences.*

> "We (St. Louis) are a hub… but we're not the only hub. A true hub goes all the way down the value-chain starting with seed and then through agriculture, agricultural product processing, distribution and food manufacturing. If you look at some of the other hubs like Research Triangle Park in North Carolina, they are very much a hub for seed companies and other technologies. And they're a very formidable hub, but it is a little less integrated than St. Louis, and it's less of an innovation culture."
>
> James Carrington, President
> Donald Danforth Plant Science Center

With a total building area of 190,000 sq. ft. the envisioned Plant Sciences Building will provide space for the faculty offices and research labs of up to 65 faculty. It will accommodate the faculty and their associated research teams (post-docs, students and staff) together with core scientific infrastructure required to support several major interdisciplinary research thrusts. It is also anticipated that the PSB will contain business incubation and company co-location space. Battelle concurs with NC State that this building is a critically important component in realizing the state's potential for agbioscience and plant science leadership.

While the United States has had a long-standing record of excellence in agbiosciences, firmly rooted around the major land-grant universities, it is an area of academic research that has seen relatively little investment in state-of-the-art research infrastructure. As noted in a recent report by Pardee, Alston and Chan-Kang[1] the "U.S. public agricultural research infrastructure is antiquated", and this situation is certainly the case at NC State where the last major new building investment in CALS, as noted by Dean Richard Linton, occurred in the 1950s. Whereas in biomedical sciences the quality of facilities seen on leading university campuses is at a level seen in industry, the same is not true in agbiosciences where industry has built state-of-the art laboratories and automated greenhouses, while academic agbioscience space investments have languished. Industry leaders in North Carolina, interviewed by Battelle, noted the lack of modern infrastructure and facilities at NC State in CALS in comparison to the University's investment in state-of-the-art buildings for engineering and other disciplines at the Centennial Campus. The comparison of the modern agbioscience facilities available to agbiotech company researchers at RTP, compared to current infrastructure within CALS is stark.

This general lack of investment in U.S. academic agbioscience facilities, of course represents an opportunity for North Carolina to gain significant visibility and attention by developing the proposed PSI building on the NC State Centennial Campus. Other than the non-profit Donald Danforth Plant Science Center in St. Louis, the proposed PSI building would stand without peer among U.S. academic institutions serving to show the commitment of NC to the sector, and a powerful attractor for academic research talent and industry collaborators. Several of the major agbioscience companies interviewed by Battelle noted that, were the PSB to be developed as envisioned, they would likely station research teams and post-docs in the building, sponsor joint research programs with the university, and potentially support the endowment of faculty positions. Commodity groups in North Carolina are similarly supportive of the need to invest in advanced scientific infrastructure to keep NC State generating the innovations and practices that sustain yield improvements in North Carolina agriculture. Again, in Battelle's experience, the expressed support by external stakeholders to seeing the new building developed at NC State is unprecedented.

The Need for an Interdisciplinary Approach, and Space to Facilitate it.

There is growing recognition of the benefits associated with interdisciplinary science and team science in addressing major scientific and technological challenges. Indeed there is growing acknowledgement that modern grand challenges, and some of the biggest questions in science, demand solutions that are beyond the capabilities of any single discipline. The facilitation of interdisciplinary teams of faculty is thus key to advancing progress and innovation in a complex area such as agriculture. **Recent research shows that the construction of an interdisciplinary building to house interdisciplinary activity is key to developing an interdisciplinary culture** communicating commitment to interdisciplinarity efforts in a way that words or policies alone cannot. Harris and Holley conclude that there is a "need for collaborative teams to be housed in a single structure regardless of existing organizational structures. Physical proximity is a key element in creating an environment of communication and open exchange of ideas".[2]

Having state-of-the-art scientific research infrastructure and instrumentation available to interdisciplinary teams of scientists is likely to be beneficial to NC State's traditional land-grant university role in supporting NC agricultural producers, in addition to providing distinctive capabilities to advance research discoveries and collaborations with North Carolina's leading cluster of global agbioscience corporations and entrepreneurial agbioscience businesses. A number of key issues facing agricultural producers (such as the expanding challenge of herbicide

[1] Philip G. Pardey, Julian M. Alston, and Conie Chan-Kang. April 2013. "Public Food and Agricultural Research in the United States: The Rise and Decline of Public Investments, and Policies for Renewal." AGree, Food & Ag Policy.
[2] Michael Harris and Karri Holley. "Constructing the Interdisciplinary Ivory Tower." Society for College and University Planning, 2008.

resistant weeds, emerging diseases and pests, etc.) lend themselves to multidisciplinary solutions engaging expertise in plant pathology, entomology, crop science, soil science, horticulture, engineering, economics, etc. to develop integrated approaches to challenge management. Modern economic development is not just about creating new jobs, it is also concerned with maintaining existing jobs and industry competitiveness in the face of relentless domestic and international competition. The new PSB, and the platforms suggested as key thematic areas for NC State (see below), hold significant promise for the rapid deployment of cross-disciplinary teams to address emerging issues for North Carolina agricultural producers. The overarching theme of increasing agricultural yield factors directly into supporting North Carolina farmers and the agricultural-value chain in the state in addition to directly connecting to the agbioscience industry cluster.

Suggested Development Platforms for the PSI/PSB to Advance in North Carolina

Some choices have to be made in order to develop an initiative that:

- **Is focused enough** to have a critical mass of world-class interdisciplinary expertise brought to bear to make significant progress on a relatively compact number of important basic and applied agbioscience questions
- **Advances the study of selected frontier areas of plant science** as identified by major external bodies (such as those identified in the decadal vision established by the American Society of Plant Biologists)
- **Presents a potential pathway towards the development of commercial technologies** and products that would be a fit to established and emerging clusters of corporate agbioscience capabilities in North Carolina yet, includes major work at the pre-competitive level allowing multiple corporate stakeholders to participate collaboratively
- **Makes significant progress in developing innovations and solutions relevant to the grand challenge of advancing global food security**
- AND, ideally, shows promise for **translation into potential applications in North Carolina agricultural production.**

Generating Job Growth for North Carolina

It should be noted that across the U.S. agricultural output has increased substantially in recent decades while employment in agricultural production has continued to decline. Overall this leads to the conclusion that while agricultural productivity will continue to grow, the primary production sector (farming) is unlikely to be a source of major job growth in individual U.S. states, including North Carolina. This is supported in the economic analysis performed by Battelle and reported herein.

The real promise for significant growth in high-paying jobs is contained within the advanced agbioscience sector the sector developing and producing the advanced technology-based inputs that farming will need to achieve global food security.

North Carolina has the opportunity to leverage its existing base of advanced agbioscience companies, in combination with a major investment in academic plant science (through the proposed Plant Sciences Initiative), and its diverse agronomic environment (for R&D field support) to become THE global leader in advanced agbioscience industry. While clichéd, the opportunity is real to make North Carolina the Silicon Valley of agbioscience.

NC State is already, as the 1862 land-grant university for the state, a provider of diverse R&D and extension support for North Carolina's agriculture sector. This NC State commitment to supporting the needs of the in-state agriculture sector is important to maintain and sustain however, it does not mean that this mission has to be the sole or primary focus of the new Plant Sciences Initiative. **The larger opportunity for North Carolina is to make the state THE global leader in advanced**

agbioscience particularly in the R&D and production operations of agricultural technology companies. These companies have been growing in the state, pay high wages, and export high-value products and services. The global food challenge is such that an all but assured market exists for innovations, technologies and products that advance agricultural yield and other key characteristics of agricultural production.

Achieving incremental increases in North Carolina agriculture is a noble and valid goal, and should indeed remain a core component of the operation of CALS research, education and extension activities. **Overall it is not, however, a big enough vision for the Plant Sciences Initiative. Rather the core goal of the Initiative should be to continue the successful advancement of North Carolina as the recognized hub of the advanced plant science sector, globally. It should work to add a core asset to the plant science mix in North Carolina that cements the State's position as a, if not the, global leader in advanced agbioscience providing a platform for continued growth in agbioscience-based economic development. It should fill the gaps created by aging agbioscience infrastructure at NC State, to propel the institution to the forefront of advanced agbioscience capabilities and collaborative infrastructure. It should also serve as a signature attractor for the best and brightest minds in plant sciences.**

To this end, Battelle recommends that the Plant Sciences Initiative be designed to address the "MUST HAVE" goals in the table below while, ideally being flexible enough to also leverage its infrastructure, assets and personnel to address the second column on the table.

MUST BE	WOULD BE BENEFICIAL IF
The PSI is focused enough to achieve truly "world-class" and, ideally, "world leader" status in three major thrust areas in modern plant science.	Has the flexibility to address long-term fundamental scientific investigations, while also bringing together flexible interdisciplinary teams to address shorter-term identified challenges and applied research projects for NC stakeholders where warranted.
Provides a line-of-sight to reinforcing and further developing North Carolina as a powerful global hub for advanced agbioscience corporations (achieving robust cluster-based economic development) and the leading location for new agbioscience business development.	Makes advancements in technologies and practices that may be applied to improve productivity and output in North Carolina agriculture.

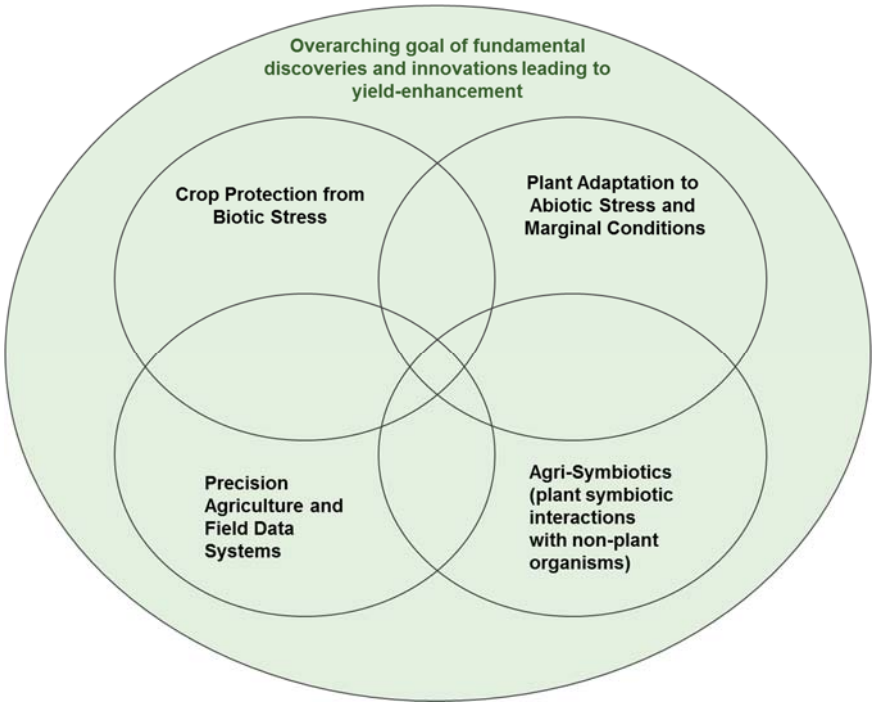
To provide focus to the Initiative, Battelle has conducted a detailed review of plant science and associated R&D core competencies. The review of core competencies and opportunities in the state included:

- Consideration of grand challenges and fast-growing frontier areas of plant science.
- The existing and emerging core competencies in agbioscience contained within NC State, and surrounding complementary institutions, including industry.
- Capabilities and assets at NC State, outside of CALS, that may be leveraged to advance interdisciplinary plant sciences.
- Input and advice from key internal and external stakeholder groups.

Taking these informational resources into consideration, Battelle concludes that the Plant Sciences Initiative should focus its efforts on an overarching theme of "agricultural yield

increase" with an emphasis on four interdisciplinary thematic focus areas (platforms). The recommended platforms include those in Figure ES-2 and discussed further below the figure.

Figure ES-2: Recommended Interdisciplinary Development Platforms for the Plant Sciences Initiative



Platform 1: Crop Protection for Biotic Stress

Focus	Globally, an average of 35% of crop yield is lost to pre-harvest pests.[3] This platform will focus on the control of plant pests (pathogens, insects, weeds and other organisms having a negative impact on plant health and yield).
Fit to NC State capabilities	79 NC State faculty were identified as having research capabilities and interests relevant to this platform. Multiple core competencies were identified via research publication cluster analysis in areas such as plant and pathogen genomics, plant pathology, entomology, and weed control.
Potential Products and technologies	Improved pesticides; biological control products; novel resistance traits for improvement of crops; application technologies for control products; integrated pest-management and decision-support systems.

Platform 2: Plant Adaptation to Abiotic Stress and Marginal Conditions

Focus	In North Carolina, and around the globe, significant agricultural land exists on the margins of sustainable agricultural productivity. Whether because of water, climate, soil fertility, salinity, occasional freeze pressures, or other factors, such land is under permanent or periodic abiotic stress conditions that limit agricultural crop yields. This platform will focus on improving plant performance under conditions of abiotic stress.
Fit to NC State capabilities	35 NC State faculty were identified as having research capabilities and interests relevant to this platform. Multiple core competencies were

[3] Dehne HW, Oerke E, Schonbeck F, Weber A (2004). Crop production and crop protection: Estimated losses in major food and cash crops. Elsevier: Amsterdam.

	identified via research publication cluster analysis in areas such as plant drought resistance, plant physiology and plant nutrition and soils.
Potential Products and technologies	Novel commercializable traits for plant improvement; improved crops and crop cultivars; resistance to abiotic stress; identification of new crops best suited to specific field conditions; soil amendments and inoculants; automated field phenotyping equipment and analytical systems.

Both Platform 1 and Platform 2 intersect in building upon the considerable strengths of NC State in plant breeding and applied plant genomics. There exists notable breadth and depth of faculty working in traditional breeding, marker-assisted selection, trait identification and plant transformation. This is also an arena in which NC State has contributed in the technology development sphere: in high throughput plant genotyping and marker-assisted technologies. An overarching opportunity (raised by faculty, industry and external stakeholder groups) is to cement a leadership position in linking lab genomics with field phenotyping data for trait identification and then to leverage university capabilities and regional industry capabilities in plant transformation to advance yield improvement based on adaptation to stress conditions. Advancing in the genotype-phenotype space lends itself strongly to interdisciplinary collaboration between CALS, the College of Engineering and the analytical sciences contained within the College of Sciences.

Platform 3: Precision Agriculture and Field Data Systems

Focus	The focus of this recommended platform will be on the development of precision agriculture technologies that allow producers to optimize the timing, amount, and placement of inputs (seed, fertilizer, pesticides, irrigation, etc.) for any given area of a field. Advancements in sensor technologies, wireless data transmission, remote sensing, unmanned/autonomous vehicles, robotics, imaging analysis, machine learning, high-speed data analytics, etc. hold promise for the development of agricultural production equipment, and field research equipment, that can significantly increase agronomic yield.
Fit to NC State capabilities	This platform would leverage faculty across several colleges at NC State. 60 NCSU faculty were identified as having research capabilities and interests potentially relevant to this platform. The platform leverages one of the NC State cluster hiring initiatives in Geospatial Analytics, and presents significant opportunities for interdisciplinary work between the College of Engineering and CALS.
Potential Products and technologies	GIS, GPS and precision positioning systems; guidance systems; variable rate application systems; equipment and field-mounted sensor systems; remote sensing and aerial platforms; robotic/autonomous field phenotyping and data gathering systems; data analysis tools and decision support systems; engineering and design of low-cost precision agriculture technologies for small and mid-size farms.

Platform 4: Agri-Symbiotics (plant symbiotic interactions with non-plant organisms)

Focus	This platform would focus 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.
Fit to NC State capabilities	37 faculty were identified as having capabilities and research interests that could be directed towards work in this platform. However, among the four platforms, this is the one in which NC State currently lacks sufficient faculty depth and several new hires would be needed. It is, however, seen as a key area for potential industry-university collaboration in North

	Carolina, with significant interests expressed by large agbioscience industry in the state.
Potential Products and technologies	Novel traits for plant improvement that encourage formation of beneficial symbiotic relationships; custom microbial communities for seed or field application; biological control agents with highly targeted specificity and organic production compatibility; soil amendments and improvement technologies.

By design, the platforms recommended by Battelle have some overlap with one another providing for not just interdisciplinarity within each platform, but also cross-platform interactions and supports. The four platforms each contribute to an overarching theme of **using science for generating discoveries and innovations that may be applied to agricultural yield enhancement.**

Ideally, through this approach of selecting platforms that intersect with one another there is opportunity for the "whole to be greater than the sum of its parts" through encouraging systems thinking across approaches to yield improvement. There is also the opportunity for key existing faculty, and faculty recruits, to have cross-cutting capabilities in support of more than one platform. Similarly, certain instrumentation and key infrastructure assets may serve double-duty across platforms for example, genomics, plant transformation, phenotyping, data analytics, growth chambers and greenhouse facilities (among others).

Scenarios for Plant Science Development Impacts

To estimate the potential impact of the Plant Sciences Initiative as envisioned, Battelle first assessed the current impact of the plant technology sector on North Carolina and then evaluated scenarios for growth based on continuation of current trends, and a positive increase in impacts potentially generated by the research, industry collaborations and technology commercialization potential of Initiative-related innovations.

It was determined that the best baseline data on industry impacts are those contained within the North Carolina Biotechnology Center's database. NCBiotech is well-known for taking a rigorous approach to tracking jobs in NC life science sectors and, given the focus of the recommended platforms on agbioscience technology development, it was determined by Battelle economists that the NCBC data would best relate to the types of economic impacts that may be generated through the PSI. It should be noted that Battelle's estimate of impact is likely quite conservative since it does not attempt to quantify increased farm output that may result from applications of NC State developed technologies, nor the value-added production that may occur in the state downstream of primary agricultural production. In other words, the analysis herein assumes that primary impacts pertaining to the PSI will be the generation of commercializable technologies and the technology-industry growth around this.

The plant science technology industry already has a significant economic impact in North Carolina, employing an estimated 6,497 personnel in 2013, and generating another 18,660 jobs through indirect and induced multiplier effects. The industry boosts the total state economy by circa $8.2 billion (comprising both direct and indirect output impacts). Growth in the state's plant science technology industry has largely been driven by employment gains in the "research and development" sector.

Under present trends, the industry may be expected to grow by a CAGR of 1.8% over the next 10 years. NC LEAD projects direct employment in plant technology industries to grow by 1,427 employees through 2024 to reach a direct employment level of 7,924 and a total employment impact of 29,297 jobs taking into account employment multiplier effects. Battelle's estimates are that the proposed Plant Sciences Initiative, by contributing innovations, corporate partnerships

and incubating new start-up companies, could conservatively generate an additional 143 direct jobs annually in the plant technology sector (starting in 2018 allowing for PSB construction time) thus generating approximately 1,000 additional direct plant technology sector jobs by 2024.

The total impact of the PSI enhancing the plant technology sector in the state, taking into account both direct and indirect jobs and economic impact by 2014, is estimated to be significant. Battelle anticipates that the total direct and indirect impact of the plant technology sector, with the addition of the PSI, will be an increase of 2,365 jobs and an increase in associated economic output of $366 million by 2024.

Further, the Plant Science Initiative comprises a critical element in development of a fully-integrated food production value-chain in North Carolina that presents further significant economic impact benefits (as discussed in the separate report on the proposed Food Manufacturing Initiative).

A Critical Component of a Unique NC Agriculture and Agbioscience Development Ecosystem

Noted in Chapter I of this report, among the most critical challenges facing humankind is the challenge of feeding the world's expanding human population in a sustainable manner. Meeting this grand challenge is no small task, with current estimates indicating a need to increase available food by 70 percent by 2050 in order to be able to feed the world's growing population. This challenge has to be met sustainably, without pressing more marginal lands into production, degrading the environment, or depleting scarce freshwater resources.

There are three macro-areas of innovation and advancement that are needed in order for the challenge to be met: 1) increase agricultural yield and production efficiency; 2) reduce the significant volume of post-harvest food waste that occurs, and 3) provide global consumers with highly nutritious, healthy and affordable food products.

North Carolina has a unique opportunity to be at the forefront of providing research-based solutions to the grand challenge and each of its three macro-solution areas. Each of three major initiativesthe Plant Sciences Initiative (PSI), the Food Manufacturing Initiative (FMI), and the existing Plants for Human Health Institute on the NC Research Campus in Kannapoliscan be coordinated to provide a unique science and technology development ecosystem for addressing the global food challenge. The individual initiatives, and their synergistic connection to the three-part solution equation of "increasing yield-reducing waste-increasing food product, process, and nutrition quality" are shown in Table ES-1:

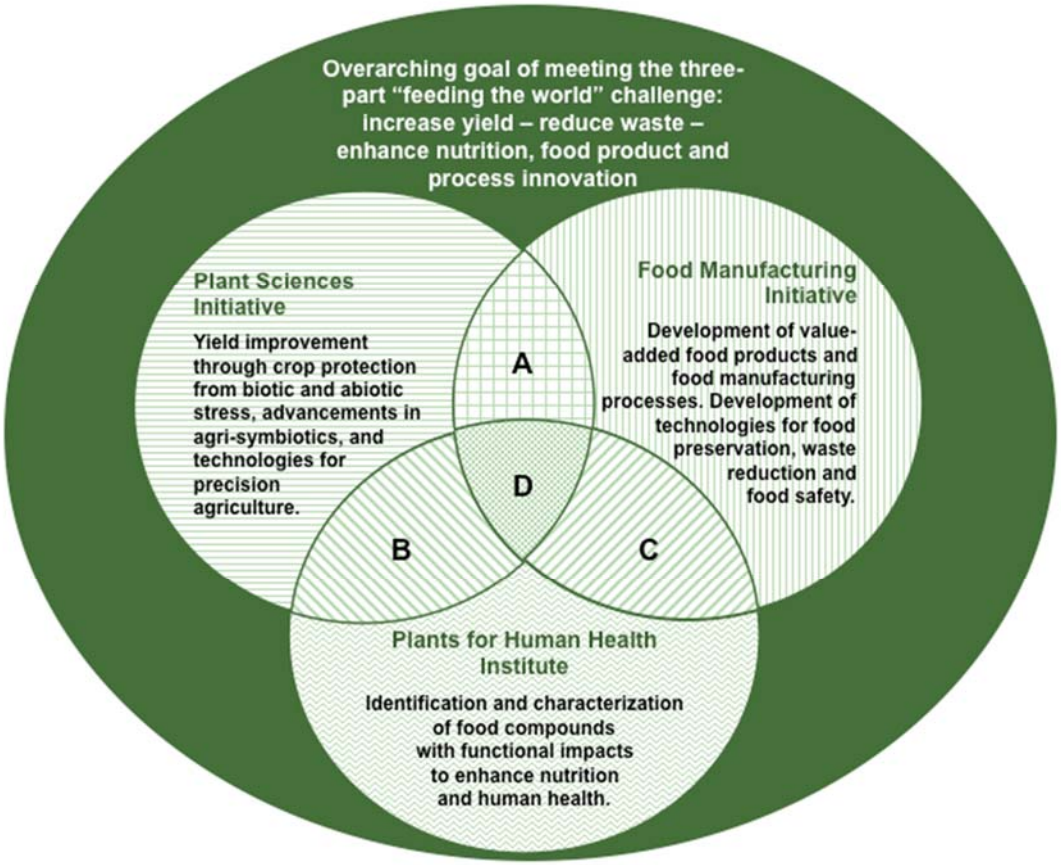
Table ES-1. North Carolina's Integrated Opportunities that Address Challenges of Feeding the World.

Increase Yield	Reduce Waste	Enhance Nutrition/ Food Product & Process Innovation
Plant Sciences Initiative		
An overarching theme of yield improvement accomplished through four principal platforms: • Crop protection from abiotic stress • Plant adaption to abiotic stress and marginal conditions • Precision agriculture and field data systems	Reduction of pre-harvest, in-field loss due to enhanced crop protection and stress management technologies and solutions. Potential to apply plant improvement technologies to identify traits and develop cultivars for improved post-harvest quality and resiliency characteristics that reduce waste, or morphology and	Potential to apply plant improvement technologies to identify traits and develop cultivars with enhanced functional nutrient content and improved sensory characteristics.

• Agri-symbiotics (beneficial plant symbiotic interactions with non-plant organisms).	other characteristics that improve downstream processability.	
Food Manufacturing Initiative		
Application of plant improvement technologies to identify traits and develop cultivars with enhanced functional nutrient content and improved sensory characteristics.	Post-harvest physiology and technology to extend shelf life. Advanced packaging technologies, such as ohmic heating, high pressure processing, ozone processing, continuous microwave heating, and aseptic processing of particulates, to extend shelf-life and reduce waste. Innovations in flavors, extraction and sensory technologies to enhance the ability to use additives to improve safety, freshness, and shelf-life.	Development and application of new product and processing innovations with regards to a wide variety of meat, fruit, vegetable, dairy, and beverage products with improved health, safety, quality, and expanded functionalities. Innovation in food products to enhance consumer desirability and nutritional content, including fortification of traditional foods (i.e. addition of vitamins, minerals, bacterial cultures). New manufacturing techniques that improve sensory and taste qualities such as minimal processing, heat treatments, freeze-drying etc. Innovations in flavors, extraction and sensory technologies to enhance the ability to use additives to improve nutritional value, and improve taste, texture and appearance of food products.
Plants for Human Health Institute		
Identification of compounds in fruits and vegetables that are associated with certain health benefits, such as cancer prevention. Development of plant breeds that have higher levels of anti-carcinogenic and other beneficial compounds. Sequencing plant genomes to understand which genes are responsible for making the health-protective components in the plant.	Storage technologies to enhance functional food compounds.	Establish mechanisms of known and new bioactive compounds and microbes and clarify how food structure contributes to bioactivity. Develop technologies for producing and distributing appealing, healthy foods and ingredients.

The potential integrated nature of North Carolina's ecosystem if these three initiatives are realized is illustrated in Figure ES-3.

Figure ES-3: North Carolina's Integrated Opportunities for Agriculture and Food Development



Intersection A: *Potential to apply plant improvement technologies to identify traits and develop cultivars for improved post-harvest quality and resiliency characteristics that reduce waste, or morphology and other characteristics that improve downstream processability and product innovation.*

Intersection B: *Potential to apply plant improvement technologies to identify traits and develop cultivars with enhanced functional nutrient content and improved sensory characteristics.*

Intersection C: *Development of product innovations, processing technologies, food safety and preservation systems, etc. that preserve functional nutrient availability and quality throughout the production and distribution chain. Creation of value-added advanced food products and processes.*

Intersection D: *Improvement of plants with high nutritional value and functional health characteristics for processability, post-harvest preservation of nutrition content, food product innovations, etc.*

It should be noted that while the above "agriculture and food development ecosystem" emphasizes plant-based agriculture for human consumption, the concept can be readily applied to livestock agriculture improvement as well. For example, the ecosystem could be applied to enhancing plant yield as feed commodities, improving the functional nutrition profile of feed, and technologies for reducing waste, feed spoilage or contamination in the livestock feed chain.

Finally, while this ecosystem has global implications, it is also important to note that it has significant economic implications for North Carolina. By focusing holistically on the entire food value chain, the combination of the efforts ensures that the work does not stop at the farm gate, but instead continues through to food manufacturing and ultimately to the end consumer. By linking activities across departments within NC State CALS and other colleges and institutions across the state of North Carolina, the ecosystem avails itself of the broad and deep expertise found within a variety of scientific and technological disciplines, thereby helping to ensure the ultimate economic benefit to the state of North Carolina.

Conclusion

North Carolina has a significant opportunity to be the global hub for advanced plant sciences research and for the application of that research to expanding agricultural productivity. Given the strong and growing demand for agricultural products into the foreseeable future, driven by expanding populations and global wealth, North Carolina has an unprecedented opportunity to build upon its existing cluster of agbioscience R&D, business operations, and diverse agricultural assets, to drive job growth and economic development in the state.

The Plant Sciences Initiative represents a “must do” project for North Carolina, filling the major gap in the current ecosystem in terms of a need for modern, interdisciplinary academic plant sciences infrastructure and a facility to advance collaborative public/private research and associated industry development.

I. Introduction

A. Grand Challenges and Opportunities in Agriculture

The current and future importance of agriculture to global wellbeing and progress is hard to overstate. Agriculture and related agricultural science and value-chain activities (agbioscience) are faced with the awesome responsibility of feeding a rapidly expanding global population, enhancing and protecting human health, preserving the environment and global biodiversity, and providing inputs to a growing green industrial economy.

Agbioscience 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).

Just the food challenge alone is of such scale and importance that is difficult to comprehend. Table 1 illustrates this challenge and compounding factors:

As a leading economic sector, agriculture is responsible for employing over two billion persons globally providing for the economic wellbeing of countless families in both the developed and developing world. Closer to home, the agricultural sector is currently responsible for one in every 12 U.S. jobs. In North Carolina, agriculture and its value-chain represents the largest industry in the state.

Table 1: The Global Food Challenge

Increasing Population	Increasing Wealth-Driven Food Demand	Finite Farmland	Finite Water	Environmental Protection
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] These people need to be fed, clothed and sheltered.	Increasing incomes, driven largely by global industrialization, are correlated with increasing demand for processed foods, packaged foods and meats. These "developed world" foods consume considerably more resources in their production than basic foodstuffs.	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 or too cold for agriculture.[5] In addition, poor farming practices in much of the developed world are degrading existing farmland.	The UN FAO reports that 70% of freshwater resources are consumed by agriculture annually (whereas 19% is consumed in industrial processes, and just 11% is used for municipal consumption).[6] Freshwater withdrawals have tripled in the last 50 years and current usage levels are unsustainable in much of the world.	Pressing 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 and greenhouse gas emissions.

[4] http://www.worldometers.info/world-population/
[5] Human Appropriation of the World's Food Supply. http://www.globalchange.umich.edu/globalchange2/current/lectures/food_supply/food.htm
[6] http://www.fao.org/nr/water/aquastat/water_use/index.stm

Net Result: **Feeding an expanding global population and meeting global food demand, while preserving natural resources, is an intense challenge for humankind. Estimates are that global food production will need to increase 70% by 2050 to meet population and wealth-driven demand and this will have to be achieved without increasing agricultural land acreage and water consumption.[7]**

In addition to the above challenge of feeding the world, agriculture is also part of a substantial value-chain that contributes non-food biomass into the production of value-added industrial products. Agricultural production of crops such as cotton, kanaff, hemp, etc. provides inputs for textiles and fiber production. Starch, sugar and oil seed crops (and increasingly woody ligno-cellulosic crops) are being used in the production of biofuels and industrial bio-based chemicals and plastics. On the frontiers of plant science, modified plants are being used to produce biopharmaceuticals such as biomedical therapeutics and vaccines. These industrial applications of agricultural production further factor into the food security equation and are of significant importance in driving development of a more sustainable, bio-based global economy as fossil resources deplete.

When examining the diverse geographic nature of agriculture, the scope of challenges addressed, and it's critically important role in supporting global and local economic systems, agriculture is as important today, and into the foreseeable future, as it has ever been. Because of this, the opportunities for agbioscience-based economic development are of great interest.

> "This is the great challenge: To adequately feed more than nine billion people by 2050, the world must close a 70 percent gap between the amount of food produced today and that needed by mid-century. At the same time, to advance sustainable development, we must close this "food gap" in ways that enhance the livelihoods of poor farmers and reduce agriculture's impact on the environment. Failure to address the environmental impacts would hamper food production in coming decadesthrough land degradation, water shortages, and adverse effects from climate change.[1]"
>
> World Resources Institute. 2013. "Creating a Sustainable Food Future."

B. Potential Solutions

Clearly the global food challenge represents a complex, multi-dimensional, problem. Potential solutions to the challenge cannot come from any single "silver bullet", rather action and innovation is required along three primary pathways:

- **Increasing Agricultural Yield and Production Efficiency** Plant and crop scientists, agronomists, agricultural engineers and other agbioscience specialists have made tremendous strides in increasing agricultural productivity. Global cereal yield, for example, has doubled since the 1960's. Increasing yield moving forward, through a "second green revolution" requires the application of the best of previously used yield enhancing technologies, in combination with modern biotechnology, farm management and information systems to sustain upward yield trajectories. The frontiers of plant science and agronomic technologies are opening new opportunities for molecular transformation of plants, the development of crop varieties that can better withstand abiotic and biotic stresses, development of genetic pest and disease resistance to reduce chemical and mechanical pest control, precision agricultural technologies for improved soil and crop management, and overall understanding and improvement of holistic agricultural production systems. It is similarly important, given rising demand for meat, to

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

achieve yield gains in the animal agriculture sector through development of advanced livestock feeds, improved conversion of nutrients into edible livestock tissue, and improved livestock management practices.

- **Reducing Post-Harvest Losses and Food Waste.** Technologies and practices that would reduce food loss and waste[8] 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% of food (by weight) is lost or wasted in the current global food system, and the World Resources Institute (WRI) estimates that this translates into 24% 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% of the projected food gap.[9]

> "Plant genome sciences, and plant biology as a whole, are vital enterprises that contribute significantly to human health, energy security, and environmental stewardship."
>
> The National Academies. "New Horizons in Plant Sciences for Human Health and the Environment."

- **Modifying Human Diets and the Nutrition Profile of 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 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.

> Two billion people worldwide suffer from micronutrient deficiencies. Through both traditional breeding and biotechnology approaches, plant science offers opportunities to develop foods with higher nutritional values, novel health benefits and reduced levels of undesirable compounds.
>
> Society of Biology and the UK Plant Sciences Federation. "UK Plant Science: Current Status and Future Challenges." January 2014.

Each of the three categories above requires multi-disciplinary scientific approaches to achieve solutions. Increasing agronomic yield requires diverse scientific skills and technologies in plant improvement, crop science, horticultural sciences, plant physiology, plant pathology, entomology, and animal sciences to name just a few. Fundamental science advancements are needed in molecular biology, microbiology, evolutionary and developmental biology, genomic and metagenomic sciences, big data analytics and other scientific fields to sustain the expansion of the basic science discoveries upon which progress is made. As fundamental knowledge expands, translation into technological and practice solutions can occur to enhance yield, and the

[8] "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.
[9] World Resources Institute. 2013. "Creating a Sustainable Food Future."

power of agricultural extension services can be brought to bear to educate producers in the use of modern agbioscience solutions to increase yield.

Reducing post-harvest losses and waste presents a multi-faceted challenge incorporating a need for both technological solutions and behavioral changes. Similarly, changing human diets and the nutritional profile of the foods we consume requires not just technological solutions and innovations, but also changes in consumer knowledge and behavior, and the development of a regulatory environment conducive to the introduction of advanced nutrition and functional food products.

> "To meet global production targets, plant scientists must develop higher yielding, more resilient and resource-efficient crop varieties alongside more efficient agricultural practices."
>
> Society of Biology and the UK Plant Sciences Federation. "UK Plant Science: Current Status and Future Challenges." January 2014.

It is also true that more equitable distribution of the foods already produced by global agriculture would also contribute to food security. However, achieving significant change in this regard largely requires socio-economic and socio-political changes within a global economic system and is less likely to be derived from technology and innovation solutions. Changing a global economic system that is rooted in purchasing power, economic productivity and associated distribution of resources is perhaps the toughest mountain to climb in the search for solutions to global food security needs.

The above categories do not represent the only challenges and potential solution pathways. The industrial biomass (especially fuels) versus food debate will continue until economic solutions are found to convert non-food woody biomass or crop residues into fuels and chemicals (rather than using grains and oil seeds). Advancements are also needed to reduce the atmospheric emissions and water pollution issues associated with agriculture. There is no shortage of global challenges for agbioscience to address.

As the National Research Council of the U.S. National Academies notes:

> *"With global populations rising rapidly, U.S. agriculture faces the challenge of producing enough food, feed, and fiber to meet increasing demand in conditions of changing climate and scarce natural resources. Innovative policies and new farming approaches based on a strong scientific foundation are needed to tackle the challenge of increasing production while also meeting environmental, economic, and social goals."*[10]

Multiple recent research reports have served to highlight that there are widespread needs and opportunities for advancements in agbioscience knowledge. In plant sciences, for example, an excellent summary of the frontiers of the discipline is provided by the American Society of Plant Biologists, whose decadal vision for plant science sets specific goals for advancement: [11]

[10] http://dels.nas.edu/resources/static-assets/materials-based-on-reports/reports-in-brief/Systems-Ag-Report-Brief.pdf
[11] Am. Soc. Of Plant Biologists. "Unleashing a Decade of Innovation in Plant Sciences: A Vision for 2015-2025."

American Society of Plant Biologists
Key Themes in the Decadal Vision

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

As plant science advances along these and other lines of inquiry, other areas of agbioscience will similarly advance using engineering, life sciences, physical sciences, economics and other disciplines to provide solutions to identified challenges.

C. Great Challenges Present Great Opportunities

The fact that all 7 billion (and counting) of us need to eat, in combination with pressing needs for environmentally sustainable industrial inputs, means that agriculture enjoys assured demand. As such, **the advanced technologies, innovations and practice advancements that serve to improve yield, reduce waste, enhance nutrition, and advance a bio-based industrial economy will benefit from robust demand conditions for the foreseeable future.**

> "There is a huge opportunity to capture and expand upon the momentum of the past 10 years of plant research to tackle national and global challenges."
>
> The National Academies. "New Horizons in Plant Sciences for Human Health and the Environment."

While agricultural production is distributed widely across the planet, the advancement of the science of agriculture and the production of the tools and advanced technologies that drive modern agricultural productivity are far more geographically concentrated. The development and production of advanced seed, crop protection chemicals, soil fertility enhancement products, genetically superior livestock strains, precision agricultural production equipment, advanced processing technologies, etc. are concentrated in economic clusters in several key global locations most notably, but not exclusively, within North America and Western Europe. Existing geographic hubs of agbioscience innovation are best positioned to leverage the great opportunities that the growing demand for agricultural solutions presents. **In particular, those locations that combine certain key elements (as shown on Table 2) will be particularly well-positioned to realize agbioscience-based economic development and economic growth.**

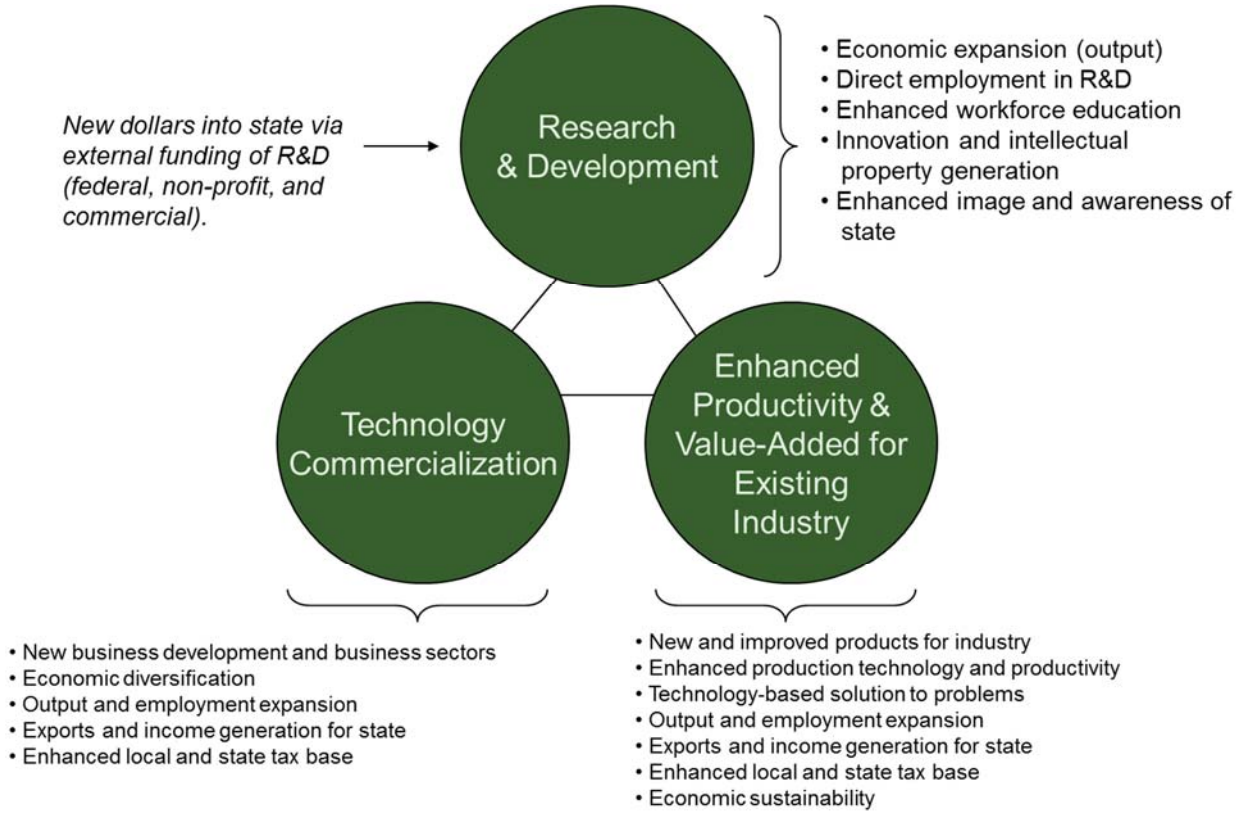
Table 2: Likely Elements of Successful Future Agbioscience Hubs

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 agbiosciences research. In the U.S. this is a clear focus of the U.S. Department of Agriculture 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 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 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.
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 runs on 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.

When the elements shown on Table 2 converge within a particular state or region there is likely to be a significant comparative advantage for agbioscience-based economic development. Such development can then provide economic benefits along multiple paths, as shown in Figure 1:

Figure 1: Pathways to Agbioscience and Technology-Based Economic Development



As seen above, 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.

D. North Carolina is one of the Preeminent Global Hubs for Agbioscience

Examining North Carolina across the factors shown on Table 2 reveals that the State is generally operating from a position of strength in agriculture and agbioscience (Table 3):

Table 3: North Carolina Performance on Factors for Successful Future Agbioscience Hubs

Success Element	North Carolina Position
Presence of major multi-national agbioscience corporations (especially R&D operations of these companies).	North Carolina, especially in the RTP region, is a major R&D hub for multiple global agbioscience corporations. Major research operations include those of Syngenta, Bayer CropScience and BASF, together with Novozymes and Monsanto. These companies have made significant investment in facilities and infrastructure in recent years, indicative of a commitment to growing within North Carolina.
Presence of major academic or independent research institutes with a robust program of agbioscience R&D and world-class infrastructure.	NC State University, ranked 6th by the NSF in agricultural research expenditures, is one of the premiere national academic institutions for agbioscience research. The university sustains a network of 18 agricultural research stations within the state. Like most of its peer land-grant universities physical infrastructure and facilities at NC State are dated and significant investment is needed to bring resources in agbio up to the level seen in other areas of life science at leading universities.
Presence of government agbioscience R&D institutes	The USDA maintains ARS activity in North Carolina co-located with NC State in Raleigh. Key focus area include plant science research, soybean and nitrogen fixation research, and food science.
Diverse agronomic production environment	North Carolina benefits from a location in the "transition zone" between northern and southern U.S. states and enjoys a diverse geography in terms of elevations, soil types and climatic zones. Indicative of the agronomic diversity of NC there are 95 separate agricultural commodity groups in the State. North Carolina produces diverse grains, oil seed, and vegetable and fruit crops and has a significant base of production in non-food crops (tobacco, cotton, and ornamentals). North Carolina is also a leading livestock production state especially in hogs and poultry.
Engaged and Collaborative Stakeholder Groups	Agricultural biotechnology interactions are facilitated by the North Carolina Biotechnology Center, and the AgBio[sphere] organization has been organized to facilitate collaborations and promotion of the state as an agbioscience hub. A robust base of commodity groups, a highly engaged state department of agriculture, together with a substantial agricultural extension network provides good connectivity between key stakeholders.

A business environment conducive to entrepreneurial business development	North Carolina has grown several notable agbioscience start-up companies, and has seen some significant liquidity events in recent years via acquisition of growing agbioscience companies by major multinational agbio corporations. That said, entrepreneurs and business leaders in North Carolina note that access to early stage capital is a considerable challenge for agbioscience companies in North Carolina, and the state lacks available business incubation/acceleration space suited to the needs of agbioscience company growth (where affordable wet lab, growth chamber and research greenhouse space is needed).
Presence of a science-based regulatory and policy environment that is predictable over the long-term	Primarily regulations and policies impacting the sector are driven at a federal government level. In this regard the U.S. is positioned comparatively well versus the other large agbio hub in Europe (which is increasingly seen as highly challenging for agricultural biotech operations).
The presence of a robust education and workforce development pipeline meeting the needs of R&D and industry sectors.	Because North Carolina has an existing cluster of major agbioscience companies, and a small but growing base of entrepreneurial agbioscience endeavors, it is an attractive location for recruits. The state, via the North Carolina Biotechnology Center, Biomanufacturing Training and Education Center (BTEC) and other initiatives has proven itself to be dedicated to assuring that the needs of industry for a skilled workforce are addressed in biosciences and biotechnology. Similarly, NC State is one of the leading national producers of students with agbioscience undergraduate and post-graduate degrees, and the educational environment in North Carolina is also advanced by additional life science, physical science, engineering, and other relevant degree providers such as UNC, Duke, Wake Forest, NC A&T and others.

It is clear that North Carolina is presently operating from a position of comparative strength in agbiosciences, especially in plant science disciplines where there is a strong combination of corporate, university and USDA research taking place. This, in combination with a diverse agronomic environment and an attractive location for skilled human capital position the State well to advance agbioscience-based economic development. The position of North Carolina is further examined in the following chapter.

II. Agriculture and Plant Sciences in North Carolina

As established in the introduction, North Carolina is well positioned to seize a significant opportunity in advancing plant science related technologies, commercialization, and economic development. Critical core elements of a thriving agbioscience and plant science cluster are in place in the state and opportunities are evident in several key areas of research and industrial development. The focus of this section is to profile the agricultural production currently taking place in North Carolina and to present the current economic position of the state's industrial plant sciences sector.

Key findings and highlights from the economic analysis include:

- North Carolina has a sizable, yet relatively under-concentrated, position in its plant sciences industry though it has highly specialized, and high-value, areas of strength and key assets upon which it can build.
- Both the state and U.S. experienced a recent employment peak in the plant sciences industry in 2008 but since then the U.S. has *added* 1 percent to its base while North Carolina has *declined* in jobs by 5 percent.
- The strengths in North Carolina's agricultural "input" subsectors including its highly specialized agricultural and plant-related R&D and agricultural chemicals sectors are critical for establishing a premier plant sciences cluster, and stand out as a unique asset for the state relative to other regions and nations competing in this global market. The significant clustering of scientific research, talent, and other resources is truly unique to North Carolina and has positioned the state's plant sciences industry as a global hub for innovation and commercialization.
- Since the trough of the deep national recession in 2009, 6 of 13 North Carolina plant sciences subsectors have added jobs. The net job decline in the plant sciences sector occurred as the larger subsectors have generally shed jobs during this difficult economic recovery.
- While the state has clear strengths in its plant sciences industry base from which to build, there is a potential gap in the industry value chain with respect to wholesale distribution of agricultural products.
- North Carolina is a national leader in the manufacturing of agricultural chemicals. State employment is highly concentrated and specialized, and places North Carolina 4th among all states (behind only FL, TX, and LA).
- North Carolina's plant sciences sector is competing well on a value-added per worker basis, out-performing the national industry sector in each of its major industry subsectors.
- The industry is largely concentrated in two North Carolina regionsthe Coastal Plains and the Piedmont, though it is emerging in the Mountains.

Looking to the future, North Carolina has opportunities to leverage its large and leading position as a global hub of biotechnology and agbiosciences innovation for growth and development in and around its commercial plant sciences industry. The state's world-class university research competencies, combined with the unique asset and draw that is Research Triangle Park, are pulling in global leaders in the plant sciences to establish and expand their R&D base in North Carolina. The industry faces challenges including recent job losses and some identified gaps in the industry value chain, but overall it is poised for growth and a significant and targeted investment in plant sciences academic research can yield a major payoff.

A. Agricultural Production in North Carolina: Overview

North Carolina has a rich history in agricultural production and forestry full of challenges posed by quality of soil, trade-offs between cash versus food crops, societal and economic challenges raised during wars and the Great Depression, and topographical challenges in dealing with swamps and mountains. In J. Paul Lilly's summary of the "Agricultural History of North Carolina," the NC State University Professor Emeritus notes that under "natural conditions" the soils in the state will not support crop production due to insufficient nutrient levels.[12] Sustainable farmland was in short supply so North Carolina farmers traditionally shifted cultivation and utilized the "slash and burn" approach, while also exploring swamp and lake drainage. Sustainable farming was not established in North Carolina until the introduction of commercial fertilizers in the late 1800s.

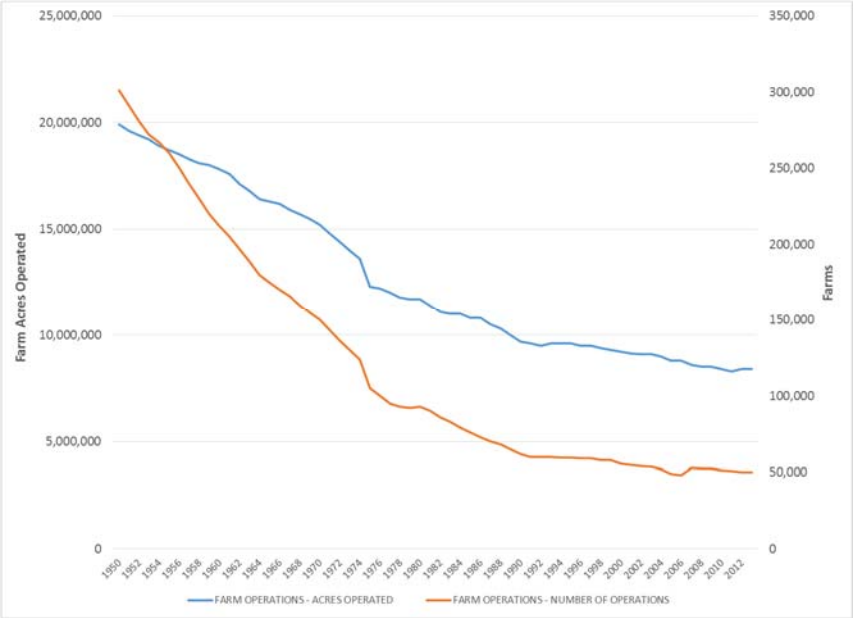
Farm and broad economic prosperity during and just after World War II led to the largest number of farm operations in the state's history. Since that peak around 1950, that figure has steadily and dropped (see Figure 2), along with acreage farmed. In 1950, there were 301,000 North Carolina farms, today that figure is 50,000. As has been the case nationally, small farms have agglomerated into large farms, and increased productivity on farms has led to smaller amounts of land and workers needed to produce similar yields.

Dr. Lilly cites two important, relatively recent, shifts in North Carolina agriculture:

- Animal agriculture replaced crops as the leading source of farm income; and
- A shift in agricultural production within the state from West to East.

Agriculture, along with the related food manufacturing, forestry, and natural fiber industries are incredibly important to North Carolina's economy. NC State University recently put the value of agriculture and agribusiness or "food, fiber, and forestry" at $78 billion or nearly one-fifth of the state's GDP; and 642,000 of the state's 3.8 million employees in 2012.[13]

Figure 2: Farms and Farm Acreage Operating in North Carolina, 1950-2013



[12] Lilly, J. Paul, "Agricultural History of North Carolina," available online at: http://www.ncagr.gov/stats/general/history.htm.
[13] NC State University, College of Agriculture and Life Sciences, "Agriculture and Agribusiness: North Carolina's Number One Industry," Fact Sheet, 2013.

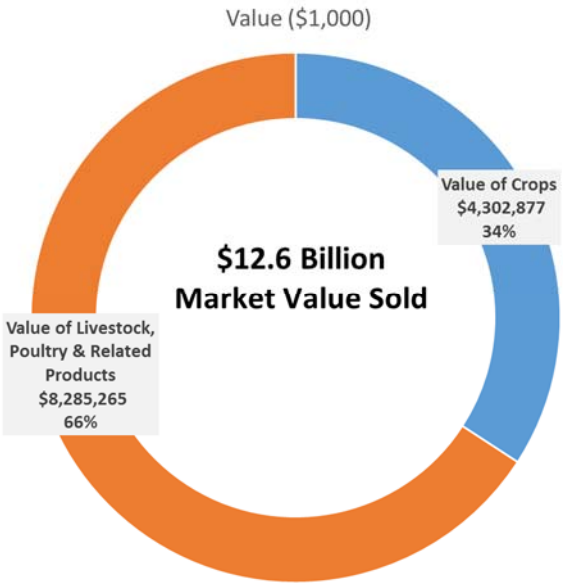
In selling $12.6 billion in total agricultural goods in 2012, North Carolina ranks 8th among all states in its agricultural production market value. Two-thirds of this value is represented in livestock, poultry, and related animal products receipts, the remaining 34 percent is the market value of crops (see Figure 3 and Table 4). Animal production is led by the $4.8 billion in poultry and eggs sold in 2012, ranking North Carolina 1st among all states in value; and sales of $2.9 billion in hogs and pigs (2nd nationally). Crop production receipts were highest among grains, oilseeds, dry beans, and peas ($1.8 billion); tobacco ($732 million); nursery and greenhouse products ($580 million); vegetables, melons, potatoes and sweet potatoes ($435 million). North Carolina is among the national leaders in tobacco (1st), cut Christmas trees (2nd), and cotton (5th).

Table 4: Value of North Carolina Sales by Commodity Group (dollars in thousands), 2012

Commodity Group	Market Value Sold ($1,000)	U.S. Ranking
Poultry and eggs	$ 4,837,026	1
Hogs and pigs	$ 2,873,988	2
Grains, oilseeds, dry beans, and dry peas	$ 1,774,127	18
Tobacco	$ 732,772	1
Nursery, greenhouse, floriculture and sod	$ 580,230	7
Vegetables, melons, potatoes and sweet potatoes	$ 434,974	10
Cotton and cottonseed	$ 403,366	5
Cattle and calves	$ 332,733	34
Other crops and hay	$ 225,162	26
Milk from cows	$ 179,265	29
Fruit, tree nuts, and berries	$ 85,150	17
Cut Christmas trees and short rotation woody crops	$ 67,097	2
Horses, ponies, mules, burros, and donkeys	$ 23,548	17
Aquaculture	$ 23,365	16
Other animals and other animal products	$ 8,089	33
Sheep, goats, wool, mohair, and milk	$ 7,251	31

Source: USDA, Census of Agriculture.

Figure 3: Market Value of North Carolina Agricultural Products Sold, 2012 (dollars in thousands)



Crop acreage in North Carolina is heavily tilted toward grain and soybean production (Table 5), however, this does not reflect the importance to the state of key crops for which North Carolina is a national leader. Specifically, these include tobacco, cotton, cucumbers (for pickling), and sweet potatoes.

Table 5: Top North Carolina Crop Acreage, 2012

Crops	Acres	U.S. Rank
Soybeans for beans	1,564,806	15
Corn for grain	803,020	18
Wheat for grain, all	753,713	13
Winter wheat for grain	753,489	10
Forage-land used for all hay and haylage, grass silage, and greenchop	643,186	28

Source: USDA, Census of Agriculture.

- North Carolina is firmly positioned as the nation's leader in tobacco production with its $755 in production value (annual survey data differs slightly from the Agricultural Census data presented above) accounting for about half of all tobacco produced in the U.S.
- North Carolina is the nation's top producer of sweet potatoes with only California close in production. North Carolina's 2012 production was valued at $161 million, representing 37 percent of all U.S. production value.[14]
- The state is a major producer of cucumbers, both processed (for pickles) as well as fresh market. In processed cucumbers, North Carolina's $12 million in production value was 3rd among states representing 8 percent of national production value (well behind Florida and Michigan). In fresh market cucumbers, the state produced nearly $14 million in value or 7 percent, with a ranking in market value of 7th.

[14] Data referenced here are from the 2012 USDA, National Agricultural Statistics Service annual survey.

- North Carolina is also a major producer of watermelons and squash, with annual production values of $24 million (7th) and $16 million (6th), respectively in 2012.

North Carolina's production strengths also translate into value-adding food manufacturing with key companies and a major economic footprint in the production of value-added products from poultry and hogs, pickles, sweet potatoes, and tobacco, to name a few.

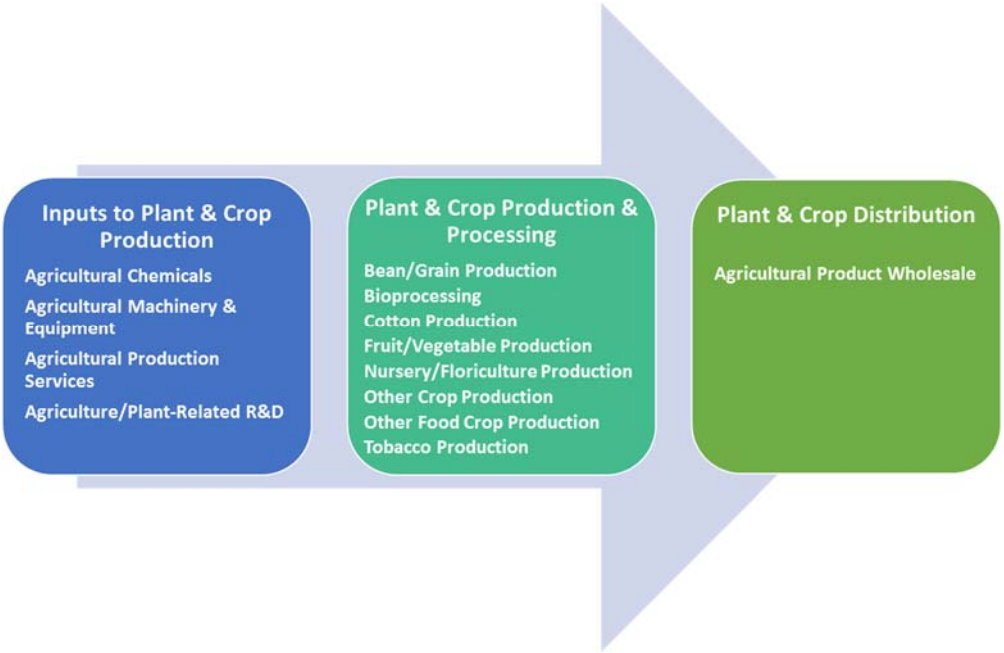
The next section examines to the current position of the state's plant sciences industry sector, which builds off of the state's position and competencies in crop production, but also looks toward the future in leveraging advanced biotechnologies linked to crop protection, among other industry focus areas, to enhance and ensure food quality and productivity for a growing global population.

B. The Plant Sciences Industry Sector in North Carolina

Industrial activity in and around the plant sciences spans numerous companies and sectors around the broader industrial value chain. A robust and active plant sciences cluster will move from research and development activities at universities and within companies through to the development and production of inputs for plant and crop production, to plant and crop production and processing, and on to market through an often intricate distribution network.

Battelle has organized 57 individual North American Industrial Classification System (NAICS) industries at their most detailed (6-digit) level into 13 "subsectors" along the North Carolina plant sciences value chain in order to profile the industry in terms of its present size, relative concentration, and recent trends compared with the nation (see Figure 4). In addition, the analysis includes information on individual business establishments and wages as well as industry productivity.

Figure 4: North Carolina's Plant Sciences Industry Value Chain



North Carolina companies employ more than 32,000 across these pillars of the plant sciences value chain and when unincorporated farm proprietors are included, this figure expands to more than 73,000 jobs, or just over 2 percent of total state private sector employment. The focus of this economic analysis will be on the 32,000 private sector jobs, as available federal employment data do not detail the agricultural production activities of these additional unincorporated farm proprietors.

In 2012, firms in the state's plant sciences sector operated 2,422 individual business establishments, a physical footprint that has grown by 3.2 percent during the recovery years since the recession ended in mid-2009. Sector employment reached 32,285 in 2012 after employment declined by 3.1 percent over this same recovery period.

North Carolina is relatively under-concentrated in plant sciences related industries given an economy of its size. This gauge of relative employment concentration is measured using a location quotient (LQ). Location quotients measure the degree of job concentration within a state

or region relative to the nation.[15] A regional LQ greater than 1.0 is said to have a greater concentration than the national average. When the LQ is significantly above average, 1.20 (or 20 percent greater), the region is said to have a "*specialization*" in the industry. In 2012, the LQ for North Carolina in its plant sciences sector was 0.81 or just 81 percent of the employment level we'd expect to see given the size of the state's private sector. Put another way, the plant sciences sector is 19 percent *below* the average concentration of plant sciences jobs one would expect to see in a state of this size.

Table 6: Summary Employment Metrics for the NC Plant Sciences Sector, 2012

Plant Sciences Sector & Key Subsectors	Establishments, 2012	Estab. Change, 2009-12	Employment, 2012	NC Empl. Change, 2009-12	US Empl. Change, 2009-12	NC LQ, 2012
Total Private Sector	**250,607**	**2.5%**	**3,223,192**	**2.8%**	**3.3%**	**1.00**
Plant Sciences Sector, Total	**2,422**	**3.2%**	**32,285**	**-3.1%**	**3.7%**	**0.81**
Inputs to Plant & Crop Production						
Ag Machinery & Equipment	210	-18.3%	4,334	-0.7%	6.3%	0.82
Ag Production Services	210	14.1%	2,665	-0.6%	9.5%	0.30
Ag Chemicals	37	15.6%	2,382	-0.8%	-0.6%	**2.23**
Ag/Plant-Related R&D	63	19.8%	1,679	3.0%	4.1%	**3.85**
Plant & Crop Production & Processing						
Tobacco Production	320	2.9%	4,784	-20.1%	-2.4%	**5.31**
Nursery/Floriculture Production	264	-5.4%	3,605	-5.0%	-5.0%	1.01
Fruit/Vegetable Production	167	18.4%	3,107	9.2%	3.1%	0.37
Other Crop Production	318	0.6%	2,092	-2.5%	-1.1%	**1.63**
Bioprocessing	27	12.5%	1,298	18.8%	0.6%	0.90
Bean/Grain Production	155	37.2%	809	33.3%	27.1%	0.57
Cotton Production	96	7.9%	570	8.4%	-5.1%	**1.30**
Other Food Crop Production	20	53.8%	144	29.7%	2.7%	0.23
Plant & Crop Distribution						
Agricultural Product Wholesale	535	0.0%	4,816	-5.9%	-0.2%	0.80

Source: Battelle analysis of Bureau of Labor Statistics, QCEW data; enhanced file from IMPLAN.
*Note Agricultural production data do not include unincorporated self-employed Farm Proprietors.
Data in Red font indicate specialized location quotients for NC.

Despite its lower overall concentration, North Carolina has established strong, highly specialized industrial niches in 5 of 13 key areas across the plant sciences value chain including:

- 431% greater concentration in Tobacco Production
- 285% greater concentration in Ag/Plant-related R&D
- 123% greater concentration in Ag Chemicals
- 63% greater concentration in "Other" Crop Production
- 30% greater concentration in Cotton Production

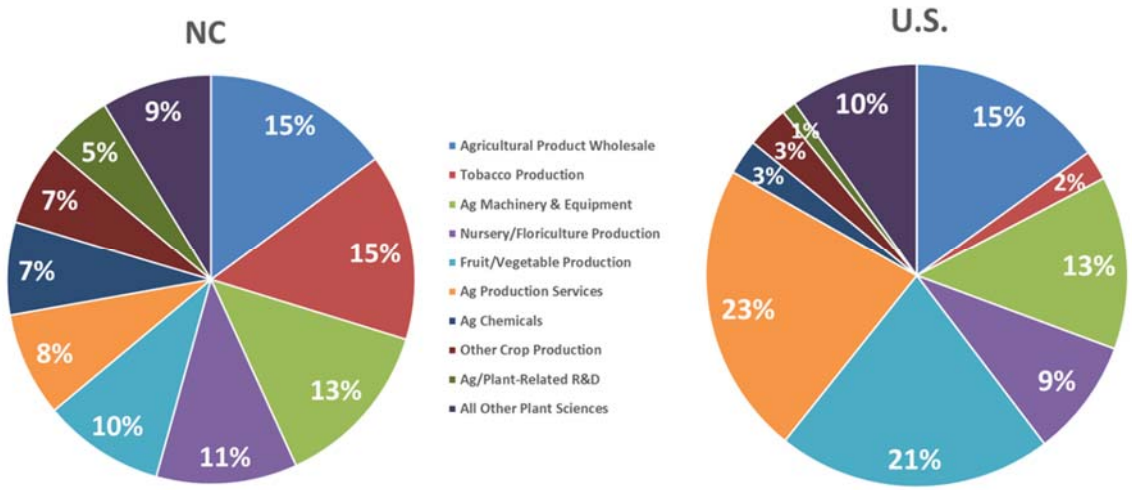
[15] Location quotients (LQs) are a standard measure of the concentration of a particular industry in a region relative to the nation. The LQ is the share of total state or regional employment in the particular industry divided by the share of total industry employment in the nation. An LQ greater than 1.0 for a particular industry indicates that the region has a greater relative concentration, whereas an LQ less than 1.0 signifies a relative underrepresentation. An LQ greater than 1.20 denotes employment concentration significantly above the national average. In this analysis, regional specializations are defined by LQs of 1.20 or greater.

The strengths in North Carolina's agricultural "input" subsectors such as agricultural and plant-related R&D and agricultural chemicals are critical for establishing a premier plant sciences sector, and stand out as a unique asset for the state relative to other states and nations competing in this global sector.

While the state has clear strengths in its plant sciences industry base from which to build, there is a potential gap in the value chain with respect to wholesale distribution. North Carolina is relatively under-concentrated in wholesale distribution of agricultural products with an employment concentration 20 percent below the national average. The largest of the component industries within this subsector, farm supplies wholesalers, which includes distribution of agricultural chemicals, seeds and bulbs, is shedding jobs and driving this under-concentration.

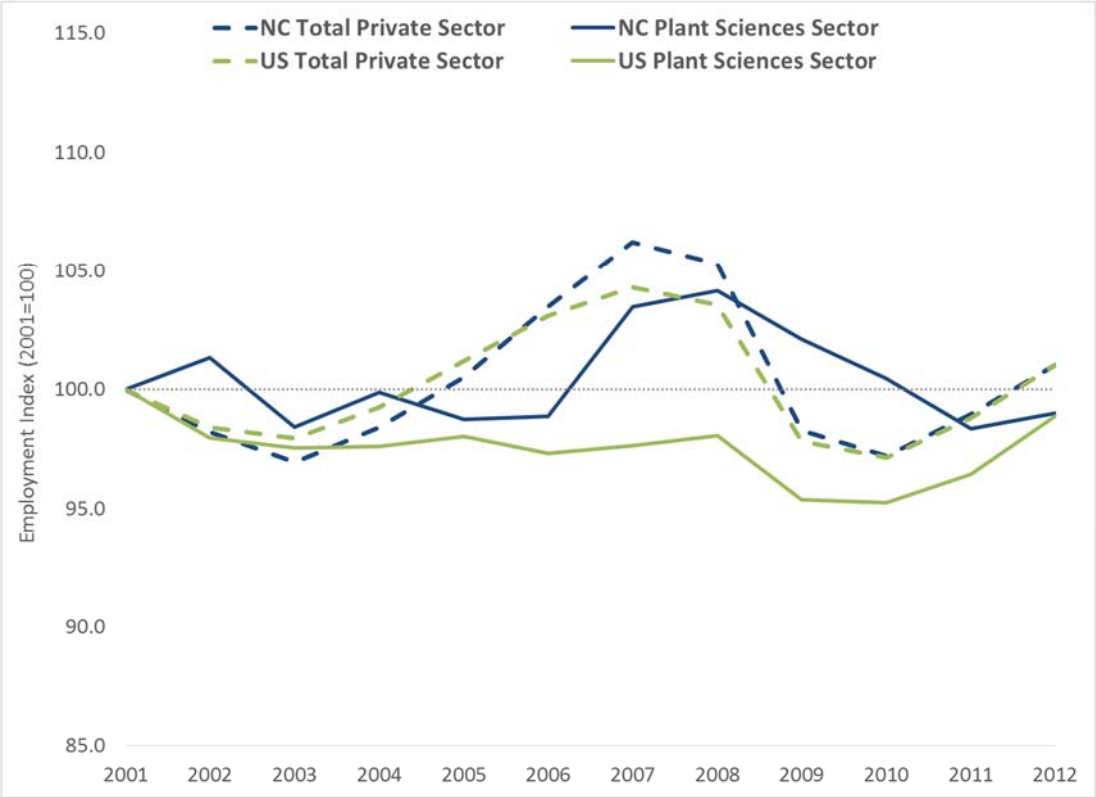
North Carolina's strong specializations within its plant sciences sector, as well as those areas across the value chain that are less concentrated are evident in the composition of employment shown in Figure 7 below. Tobacco, agricultural chemicals, and ag/plant-related R&D stand out as having a greater share of the North Carolina sector, while subsectors such as fruit and vegetable production and agricultural production services demonstrate a lower concentration in the state value chain.

Figure 7: Employment Composition of the Plant Sciences SectorNorth Carolina vs. the U.S., 2012



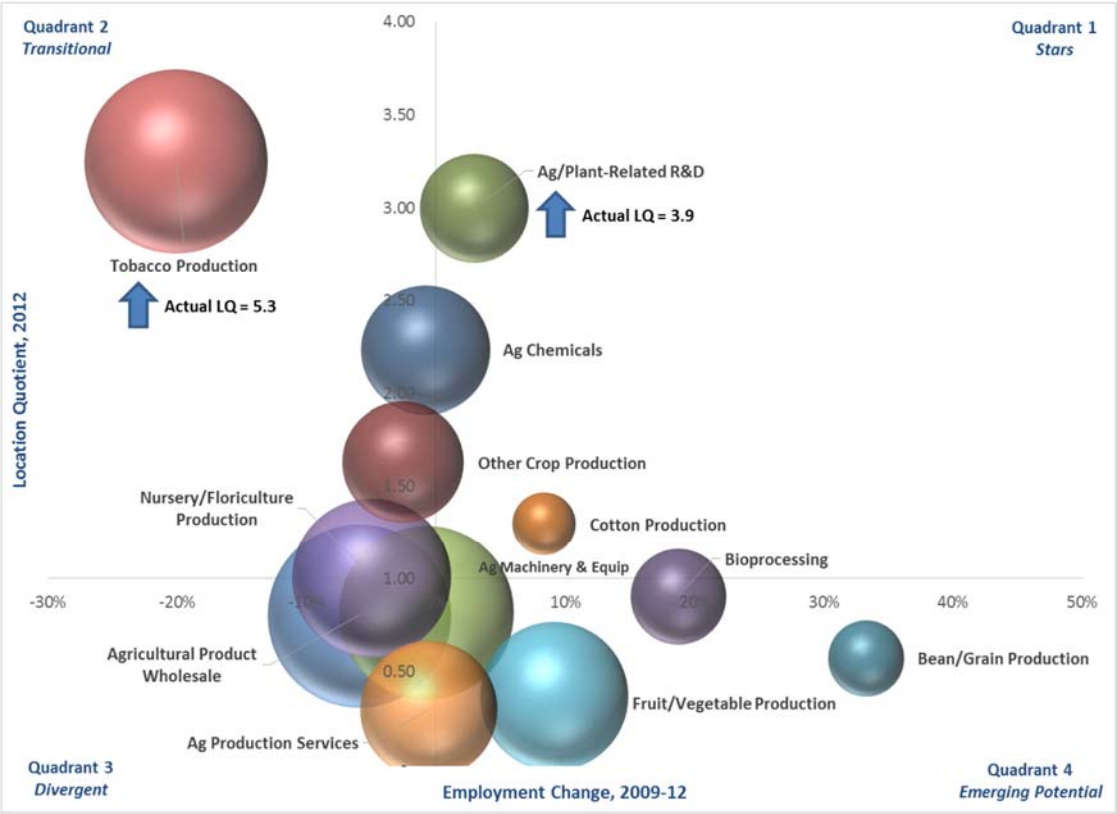
Since 2001, both the North Carolina and national plant sciences sectors have seen a net decline in jobs of just 1 percent. This relatively flat and similar net change hides what has actually been a substantially different underlying trend line over the decade (see Figure 8). Both the state and U.S. experienced a recent employment peak in 2008 but since then the U.S. has *added* 1 percent to its base while North Carolina has *declined* in jobs by 5 percent or about 1,700 fewer jobs.

Figure 8: Employment Trends in the Plant Sciences Sector, NC and U.S., 2001-12 (Indexed, 2001=100)



While North Carolina has shed jobs in recent years, the underlying performance of its 13 core subsectors is quite varied, as shown in the bubble chart in Figure 9. A bubble chart is useful in presenting three key variables on one chartthe size of the subsector (size of each bubble); the relative employment concentration (location quotient on the vertical axis); and recent trends (employment change on the horizontal axis).

Figure 9: Employment Size, Concentration, and Recent Trends in the NC Plant Sciences Sector



From the trough of the deep national recession in 2009 through the most current detailed data available in 2012, 6 of 13 North Carolina plant sciences subsectors have added jobs. The net job decline of 3 percent for the broader sector occurred as the larger subsectors have generally shed jobs during this difficult economic recovery. Highlights among the major subsectors are presented here, with key component specializations and growth areas shown in Table 7 below.

North Carolina is a global leader in **tobacco cultivation** and the top U.S. producer in terms of market value. The employment concentration in the subsector relative to other U.S. states is extremely high, with a state location quotient exceeding 5 in 2012. The subsector is in transition, however, with two of three component industries shedding jobs since the economic peak in 2007 and even through the nascent recoverytobacco stemming and redrying has lost nearly half its state jobs base (down 42 percent since 2007) while tobacco wholesale is down nearly 8 percent. Tobacco farming, however, has steadily added jobs in recent years, increasing even through the recession and is up 20 percent since 2007.

Agricultural and plant-related research and development is a high-value and sought-after component of any robust plant sciences or agbiosciences industry cluster, signaling the deployment of top scientific talent and capital resources working toward scientific and technological breakthroughs in the field. **North Carolina's corporate R&D subsector is considered to be highly specialized in its concentration, and growing. Over the past decade, the subsector has nearly doubled its state jobs base (up 98 percent since 2001) and employment growth continued in recent years despite the deep recession and its location quotient stands at 3.85 in 2012.** Private sector research is a key complement to that conducted by the state's universities and partnerships and collaborations are often critical to advancing new technologies. North Carolina, and Research Triangle Park in particular, is a major

draw for global leaders in seed and agrichemicals development (see text box on the right). **This clustering of scientific research, talent, and other resources is truly unique and has positioned the state's plant sciences industry as a global hub for innovation**.

Much of the ongoing R&D activities of these multinational firms is directly related to advancing crop protection and plant biotechnology which encompasses pesticides and fertilizer technologies. **North Carolina is a national leader in the manufacturing of agricultural chemicals**. The subsector employs nearly 2,400 in the state, an employment level that is highly concentrated and specialized with an LQ of 2.23, and places the state 4th among all states (behind only FL, TX, and LA). Employment has been flat during the economic recovery since 2009 (-0.8 percent) but is actually up from the peak in the previous business cycle, increasing jobs by a net 2.4 percent since 2007 while the national sector declined by nearly 1 percent.

Examples of North Carolina agricultural chemicals developers and producers include:

- Arysta Lifescience. Founded in 2001 and headquartered in Cary, NC, Arysta Lifescience produces a variety of pest control and life science products. Its products include fungicides, insecticides and herbicides as well as a miticide and bactericide product. Arysta also produces two plant growth regulation products specifically designed for cotton plants. Arysta Lifescience provides agricultural protection products to more than 125 countries and is one of the world's largest crop protection companies with revenues of $1.6 billion in 2013.
- Cheminova Inc. engages in the development, production and sale of agricultural protection products in over 100 countries. With its U.S. headquarters in North Carolina's Research Triangle Park, Cheminova produces fungicides, herbicides and insecticides which can be used on a variety of crops from vegetables and legumes to fruit, corn and cereals. Their products also can be used in the production of grass hay, range grass and pastures. Cheminova is ranked as one of the top 15 largest players in its industry.
- Located in Hillsborough, NC, Mycosynthetix specializes in the analysis of fungi. The company owns one of the largest collections of fungal samples in the world which can be used in the development of the next medical or agricultural breakthrough. They also provide a number of related services including substrate isolation, metabolite fermentation and in vitro bioassays. Mycosynthetix has established its own in-house program for the research of neglected diseases, and collaborates with the University of North Carolina at Greensboro, Ohio State University, University of Illinois at Chicago and the University of South Florida.

North Carolina is Home to Major Corporate Ag/Plant Sciences R&D Facilities

Several global leaders in seed and agrichemicals development have established significant R&D operations in North Carolina including:

Bayer CropScience has its headquarters, business operations, and major R&D facilities in RTP and other R&D operations nearby. Bayer is broadly focused on research in seed development and crop protection, with focused R&D in NC around pesticides, genetics/genomics, and bioanalytics.

BASF's Plant Science unit is conducting R&D in Research Triangle related to crop protection and plant biotechnology.

Monsanto is conducting plant and crop research related to food and nutrition; increased yields, insect resistance, and stress tolerance at multiple locations including Kannapolis, Research Triangle, and Mount Olive.

Syngenta Biotechnology has a major presence in RTP focused on plant biotech for insect control and drought tolerance; RTP is home to its Advanced Crop Research Lab and its biofuels development.

North Carolina has a modest corporate presence in **agricultural machinery and equipment** with the bulk of the 4,334 subsector jobs concentrated in wholesaling activities. Farm and garden equipment wholesalers employ three quarters of the subsector in the distribution of everything from farm and crop preparation machinery and conveying equipment to lawn mowers, tractors, and sprayers. While not considered specialized, the wholesale activity has a 12 percent greater employment concentration relative to the national average (LQ of 1.12). In manufacturing, lawn and garden equipment is also well concentrated and growing with nearly 600 jobs in 2012, a state LQ of 1.11, and employment that has nearly doubled since 2001 though from a modest base of jobs. Evans-MacTavish-Agricraft, in Wilson, NC, manufactures tobacco processing machinery including threshers, separators, vibrating conveyors, feeders, and splitters.

Among the incorporated farming sectors, several are showing "emerging potential" as they recover from the recession including:

- **Bean and grain production** has increased employment by one-third during the recovery and stands at just over 800 state jobs. Soybean farming has a specialized concentration.
- **Bioprocessing**, which includes specialized niches in flour milling and soybean processing, has grown by 19 percent since 2009 while the national subsector has been flat.
- **Fruit and vegetable production**, which is very much under-concentrated in North Carolina (LQ is 0.37), has increased employment by 9 percent during the economic recovery and now stands at more than 3,100 jobs in the state.
- **Cotton production** is specialized and growing in the state, reflecting North Carolina's position among the top five states in market value. Incorporated employment is 30 percent more concentrated in the state and has grown by 8 percent since 2009.

Table 7: Key Specialized and Growing Components of the NC Plant Sciences Sector, 2012

Plant Sciences Subsectors	*Specialized Components*: Location Quotient ≥ 1.20	*Growth Components*, 2009-12 (During Economic Recovery)
Inputs to Plant & Crop Production		
Agricultural Machinery & Equipment	• N/A	• Lawn & garden equipment
Agricultural Production Services	• Cotton ginning	• Soil preparation, planting, and cultivating • Cotton ginning • Farm labor contractors and crew leaders
Agricultural Chemicals	• Phosphatic fertilizers • Pesticides & other ag. Chemicals	• Phosphatic fertilizers • Pesticides & other ag. chemicals
Ag/Plant-Related R&D	• R&D in the Life Sciences (Ag/Plant Component Only)	• R&D in the Life Sciences (Ag/Plant Component Only)
Plant & Crop Production & Processing		
Tobacco Production	• Tobacco farming • Tobacco stemming & redrying • Tobacco & tobacco product wholesale	• Tobacco farming
Nursery/Floriculture Production	• N/A	• N/A

Plant Sciences Subsectors	*Specialized Components*: Location Quotient ≥ 1.20	*Growth Components*, 2009-12 (During Economic Recovery)
Fruit/Vegetable Production	• Potato farming	• Potato farming
Other Crop Production	• All other misc. crop farming	• N/A
Bioprocessing	• Flour milling • Soybean processing	• Soybean processing
Bean/Grain Production	• Soybean farming	• Soybean farming
Cotton Production	• Cotton farming	• Cotton farming
Other Food Crop Production	• N/A	• N/A
Plant & Crop Distribution		
Agricultural Product Wholesale	• Other farm product raw material wholesale • Nursery & florist wholesalers	• Grain and field bean wholesalers • Nursery & florist wholesalers

Source: Battelle analysis of Bureau of Labor Statistics, QCEW data; enhanced file from IMPLAN.
Note: Industry detail limited to those with minimum 200 North Carolina jobs.

Plant Sciences Industry Productivity: the Value-Adding Context in North Carolina

The nature of industrial activity in and around the plant sciences can vary substantially by state, region, or nation. Some states have companies involved in relatively routine production activities for goods or services that compete primarily on volume or replication; while others have firms within the same industries heavily vested in research and unique product design that yields higher-value products or pricing based on intellectual property or trade secrets. The nature of production and the ultimate value of goods is impacted by the value and nature of inputs including skilled human capital, investments in plant and equipment, and in R&D, all contributing to state and national GDP. As we'll see with respect to North Carolina's plant sciences sector, these contributions to value added and economic output can differ substantially.

Some industries may lag in employment growth, but excel in efficiency and productivity which points not to weakness, but rather to underlying strength. More specifically, estimates of "value-added" attributed to an industry cluster allow one to gauge the contribution to Gross State Product made by the sector beyond the cost of inputs to production. In other words, value added represents the difference between an industry's total output and the cost of its intermediate inputs. The metric of value-added per employee is a useful measure of the overall contribution to GSP by each worker and is thus a proxy for industry productivity and the value of that state industry above and beyond input costs like goods and services purchased from other industries or imported. Higher productivity makes companies and industries more competitive as they produce at a greater value given the same inputs, in this case, human capital.

North Carolina's plant sciences sector is competing well on a value-added per worker basis, out-performing the national industry sector in each of the major industry subsectors for which data are available.[16] Among the sectors for which detailed data are

[16] Productivity estimates were developed from IMPLAN's North Carolina and U.S. Input/Ouput models. Battelle was unable to develop estimates for the wholesale and R&D segments due to limited industry detail within the model. This includes inability to include the relevant wholesale segments within Ag Machinery & Equipment and in Tobacco. Despite the limitation, data for North Carolina presented here are comparable with those for the U.S. Data for two subsectorsNursery/Floriculture and Other Food Crop Productionwere combined in this analysis due to a similar underlying NAICS structure.

available from the IMPLAN Input/Output models, North Carolina's plant sciences workers produce, on average, just over $360,000 in value added output per worker, a figure more than five times the national average (see Table 8). This, in part, reflects the composition of the state sector versus the U.S.the national industry sector has a greater share of jobs in the lowest value adding sectorsbean and grain production and agricultural production services. Regardless of this composition, however, **North Carolina is consistently outperforming the nation in worker productivity across the subsectors.**

Table 8: North Carolina Plant Sciences SubsectorsValue-Added per Worker, NC vs. U.S., 2012

Plant Sciences Industry Subsectors	North Carolina V/A per Employee, 2012	U.S. V/A per Employee, 2012	NC as a Share of U.S.
Total Private Sector	**$ 95,035**	**$ 93,779**	**101%**
Plant Sciences Total*	**$ 360,433**	**$ 66,788**	**540%**
Tobacco Production	$ 1,074,527	$ 668,427	161%
Agricultural Chemicals	$ 540,278	$ 295,157	183%
Bioprocessing	$ 229,767	$ 168,285	137%
Fruit & Vegetable Production	$ 225,998	$ 119,396	189%
Agricultural Machinery & Equipment	$ 219,338	$ 170,138	129%
Nursery/Floriculture & Other Food Crops	$ 197,872	$ 97,492	203%
Other Crop Production	$ 142,281	$ 65,467	217%
Cotton Production	$ 94,799	$ 43,993	215%
Bean & Grain Production	$ 41,230	$ 35,996	115%
Agricultural Production Services	$ 25,192	$ 24,500	103%

Source: Battelle analysis of IMPLAN Input/Output model data for NC and the U.S.
*Note: data not available for wholesale distribution and R&D sectors due to insufficient industry sector detail within the IMPLAN models; refer to text footnote for more information. Plant Sciences total presented here includes only those sectors for which data are available.

Tobacco production, a high-value cash crop, offers the greatest value-added at more than $1 million per worker. The strength of North Carolina's top-tier agricultural chemicals subsector is further established by the strong value-added context with the gauge of productivity 83 percent greater than the national average. Within agricultural chemicals, the state industry is almost evenly split between fertilizers and pesticides; however, the latter has a much greater value-adding context with more than two-and-a-half times the level of value-added per worker. Beyond tobacco product manufacturing, pesticides are the next largest value adding activity within the state's plant sciences industry, by far, contributing more than $900 million in value-added in 2012.

The remaining agricultural production and processing subsectors (while some are more modest in size) continue to exceed U.S. productivity metrics. It is critical to note, from an industry development standpoint, that global agricultural productivity has been increasing over the long-run for many decades now while employment related to agricultural production has generally declined. The high-productivity context for North Carolina is critical for bringing new wealth into the state through exports and trade, however, agricultural primary production (farming) should not be expected to be a major new job generator for the state.

Industry Wages in the Plant Sciences

Industry wages are affected by, and signal a whole range of factors including the value of goods and services produced by individual companies; the skill sets and education levels demanded of workers; the cost of living and doing business in a particular state, region, or nation; and the

composition of an industry and whether it tends to be concentrated and focused in higher-value production.

Workers in North Carolina's plant sciences sector earn, on average, $42,560 in 2012 which is nearly $5,000 or 13 percent more than the average paid to their counterparts in the sector nationally. This figure is, however, just below that for the overall statewide private sector average (see Table 9), reflecting the significantly lower average wages paid to workers in farming relative to other major industries across the state.

What brings up the average, and positions North Carolina earners above the national sector is the strong wage premium paid to workers in the state's highly specialized agricultural chemicals and R&D subsectors. This wage premium is especially high for workers in agricultural chemicals, where North Carolina companies pay more than $22,000 or 29 percent more, on average per year.

The strong value-added per worker context in which the North Carolina plant sciences industry competes is reflected in the overall higher wages, however, the greater productivity levels across the state subsectors do not fully translate into higher wages. The rural and generally lower-paying nature of agricultural production undoubtedly has an effect on earnings for these workers. **North Carolina, across much of the lower-paying plant sciences sector, is therefore in a highly competitive position with generally stronger value-added productivity pared with relatively lower wages**. There is significant value to offer companies considering a North Carolina location.

Table 9: Average Annual Wages in the Plant Sciences Sector, NC vs. U.S., 2012

Plant Sciences Industry & Subsectors	Avg. Annual Wages	
	NC	U.S.
Ag/Plant-Related R&D	$ 102,158	$ 112,404
Ag Chemicals	**$ 99,830**	**$ 77,334**
Ag Machinery & Equipment	**$ 55,336**	**$ 52,746**
Total, all industries	$ 43,028	$ 49,194
Total Plant Sciences Sector	**$ 42,560**	**$ 37,790**
Agricultural Product Wholesale	$ 40,231	$ 51,606
Bioprocessing	$ 38,422	$ 65,323
Ag Production Services	**$ 33,806**	**$ 24,836**
Bean/Grain Production	$ 32,136	$ 34,415
Nursery/Floriculture Production	**$ 27,849**	**$ 26,943**
Tobacco Production	$ 26,821	$ 44,443
Other Crop Production	$ 25,065	$ 31,566
Cotton Production	$ 24,282	$ 28,272
Other Food Crop Production	$ 23,296	$ 30,299
Fruit/Vegetable Production	$ 21,518	$ 25,136

Source: Battelle analysis of Bureau of Labor Statistics, QCEW data; enhanced file from IMPLAN.
Industries in Bold represent higher average wages in NC compared with the U.S.

Figure 10 highlights the wage context for the plant sciences sector compared with other major North Carolina industries where average wages are similar to those paid in construction, health care, and transportation and warehousing though well below the averages in professional and technical services, information, and finance.

Figure 10: Average Annual Wages, NC Plant Sciences vs. Other Major NC Industries, 2012

The Plant Sciences Industry in North Carolina's Major Regions

So where do the plant sciences subsectors play out across the state? Are there regional specializations and niche strengths or growth patterns that differ from those seen statewide?

The analysis here breaks down the statewide industry assessment across the three major regions of North CarolinaMountain (24 counties in Western NC), Piedmont (35 counties in Central NC), and Coastal Plains (41 counties in Eastern NC). The regions are shown in the map below.

Figure 11: North Carolina's Three Major Regions

North Carolina's **Coastal Plains region**, with nearly 18,000 plant sciences industry jobs and more than 1,300 individual establishments in 2012, has the largest industry presence (see Table 10). The region's employment base is highly specialized at more than twice the national employment concentration and accounts for more than half of state sector jobs (56 percent, see Figure 12). Employment in the region has contracted over the recent economic recovery, down 5.4 percent.

Table 10: Plant Sciences Summary Employment Metrics for NC Regions, 2012

NC Region	Establish-ments, 2012	Change in Estabs., 2009-12	Employment, 2012	Change in Empl., 2009-12	Location Quotient, 2012	Avg. Wages, 2012
Piedmont	805	0.2%	11,372	-2.2%	0.42	$58,000
Coastal Plains	1,321	4.6%	17,958	-5.4%	2.05	$35,124
Mountain	296	5.5%	2,954	9.9%	0.77	$28,319

Source: Battelle analysis of Bureau of Labor Statistics, Quarterly Census of Employment & Wages (QCEW) data; enhanced file from IMPLAN.

The **Piedmont region** also has a sizable plant sciences sector jobs and establishment base with more than 11,000 employed in 2012 across just over 800 establishments. Relative to the large regional population and private sector employment base, however, the industry is under-concentrated with a regional LQ of just 0.42. Wages are particularly high in the region, averaging $58,000 annually.

In the **Mountains**, the plant sciences industry is more modest in size but demonstrating strong job growth during the recovery. Regional employers operate nearly 300 establishments in the sector employing nearly 3,000. Hiring has been strong with employment up about 10 percent since 2009. The jobs added in the plant sciences since 2009 in the Mountain region were not enough to offset job losses in the larger regions (see Figure 13).

Figure 12: Employment Composition of the NC Plant Sciences Industry by Region, 2012

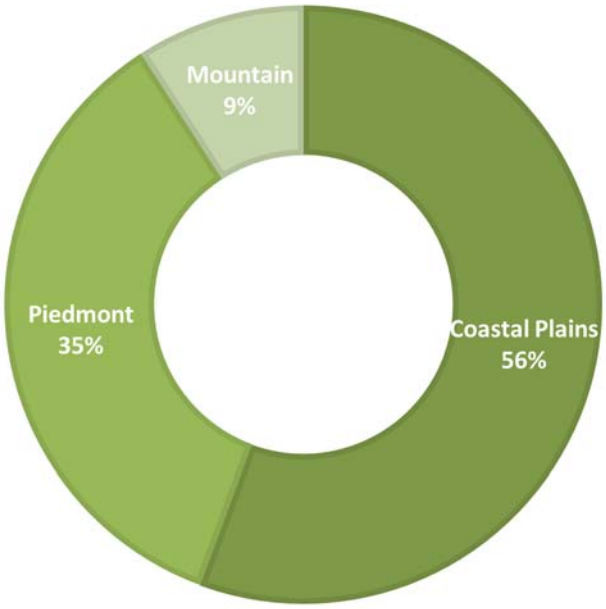
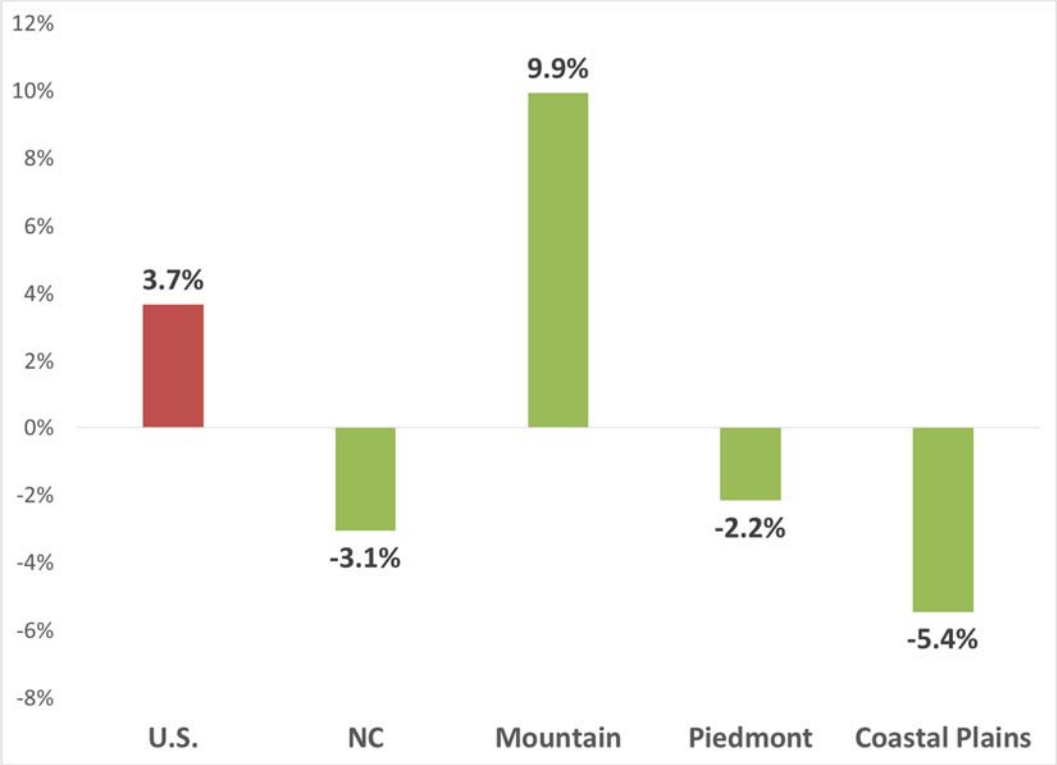


Figure 13: Plant Sciences Employment Trends During the Recovery, 2009-12



The subsectors that are driving the overall regional employment trends and concentrations can be characterized by their own degree of specialization and growth within each region.[17] Table 11 below shows the positioning by key performance category described here:

- *Current Strengths* a specialized industry (LQ≥1.20) that is growing jobs.
- *Emerging Strengths* a growing industry that is not yet specialized.
- *Specialized Opportunities* a specialized industry (LQ≥1.20) that is losing jobs.

Table 11: Plant Sciences Subsector Strengths and Opportunities by NC Region

NC Region	Current Strengths	Emerging Strengths	Specialized Opportunities
Piedmont	• Ag/Plant-Related R&D	• Bioprocessing • Fruit/Vegetable Production • Agricultural Product Wholesale	• Tobacco Production
Coastal Plains	• Cotton Production • Ag/Plant-Related R&D • Bean/Grain Production • Ag Machinery & Equip. • Fruit/Vegetable Production	• N/A	• Tobacco Production • Agricultural Chemicals • Other Crop Production • Ag Product Wholesale • Nursery/Floriculture Production
Mountain	• Nursery/Floriculture Production	• Ag Production Services • Fruit/Vegetable Production • Ag Product Wholesale	• N/A

Source: Battelle analysis of Bureau of Labor Statistics, Quarterly Census of Employment & Wages (QCEW) data; enhanced file from IMPLAN. Analysis limited to subsectors with at least 200 regional jobs.

Despite a net job loss in the Coastal Plains, there is an impressive array of current strengths that emerge from the regional analysis with particularly strong growth in the specialized agricultural machinery subsector (up 6 percent), and in the smaller but growing areas of bean and grain production (up 24 percent), and cotton (up 8 percent). The Coastal Plains region is home to the bulk of tobacco production as well as the state's agricultural chemicals strengths. Five subsectors are specialized in the region but have shed jobs in recent years including sizable employment declines in tobacco production, agricultural production services, and agricultural product wholesalers.

The Piedmont region includes Research Triangle Park and thus has a large, highly specialized, and growing base of agricultural and plant-related R&D. In addition, the region is emerging in three subsectors including bioprocessing and fruit and vegetable production which have seen strong job growth of 41 percent and 36 percent, respectively just since 2009. Despite these growth areas, regional employment is down over the recovery, due in part to declines in the region's specialized tobacco production subsector which has shed 19 percent of its jobs (about 200) during the recovery.

Plant sciences industry growth in the Mountains was driven, in part, by gains in the region's specialized nursery/floriculture subsector which has grown by 8 percent since 2009 and now tops

[17] Detailed regional employment tables are provided in the Appendix.

1,000 jobs and has a LQ of nearly 3.0. Other emerging areas include ag production services, fruit and vegetable production, and wholesale.

C. Plant Sciences Patenting in North Carolina

North Carolina Innovation Activity in Plant Sciences

NC State University is uniquely positioned at the epicenter of North Carolina's innovation activities in plant science, making it important to understand the broader picture of innovative activity in order to determine linkages back to existing university capabilities as well as targets for future translational research. A common indicator used to assess innovation activity in specific technology or research areas is the extent of patenting generated by local inventors or assigned to local industry firms. Examination of in-state inventor patenting activity can point to areas of technology or market application specialization where North Carolina has a competitive advantage in innovation. Similarly, examination of the patent holdings assigned to North Carolina companies can yield insights on the current industry environment and short term market needs related to plant science products and services.

The area of plant sciences encompasses a broad spectrum of technologies and applications that are represented across a diverse number of patent classifications. NC-invented and assigned patents across patent classes related to agriculture, horticulture, pest/plant control, and plant-related biochemistry from 2009-2014 were extracted and analyzed to determine key areas of innovation strength, and to benchmark the state's activity against national trends.

North Carolina stands out as a significant national contributor to patent generation in agricultural and plant science applications. Patents awarded to either NC inventors or assignees represent 5.3% of all US patents awarded in this time period in agricultural and plant science technology areas, making it one of the highest ranking states in patent generation for these categories. Table 12 shows the total number of patent awards and applications over this period as well as the number of forward citations, or citations by other patents of NC-invented patents in documenting new intellectual property. Forward citations are one measure of the extent to which innovation activity in the form of patents generates follow-on or downstream innovation activity, since patents or patent areas with high numbers of forward citations are often foundational technologies or methods that others have used to further advance innovative ideas. The high ratio of patent awards to forward citations in the state shows that in addition to producing a high volume of intellectual property, North Carolina's patents have also contributed significantly to further innovations in agriculture and plant science.

Table 12: NC Agriculture and Plant Science Patenting Activity 2009-2014

	Applications	Awards	Forward Citations
NC Inventors	760	684	624
NC Assignees	520	424	314
Total	1280	1108	938

Patents with in-state inventors are particularly indicative of areas of local innovation experience, since the intellectual property is not "imported" from other geographic regions by local industry and instead originates from locally-sourced research or expertise. Table 13 shows the 1,444 patent awards and applications from 2009-2014 with North Carolina inventors by the primary patent class area.

Table 13: NC-Invented Patents by Patent Class Area 2009-2014

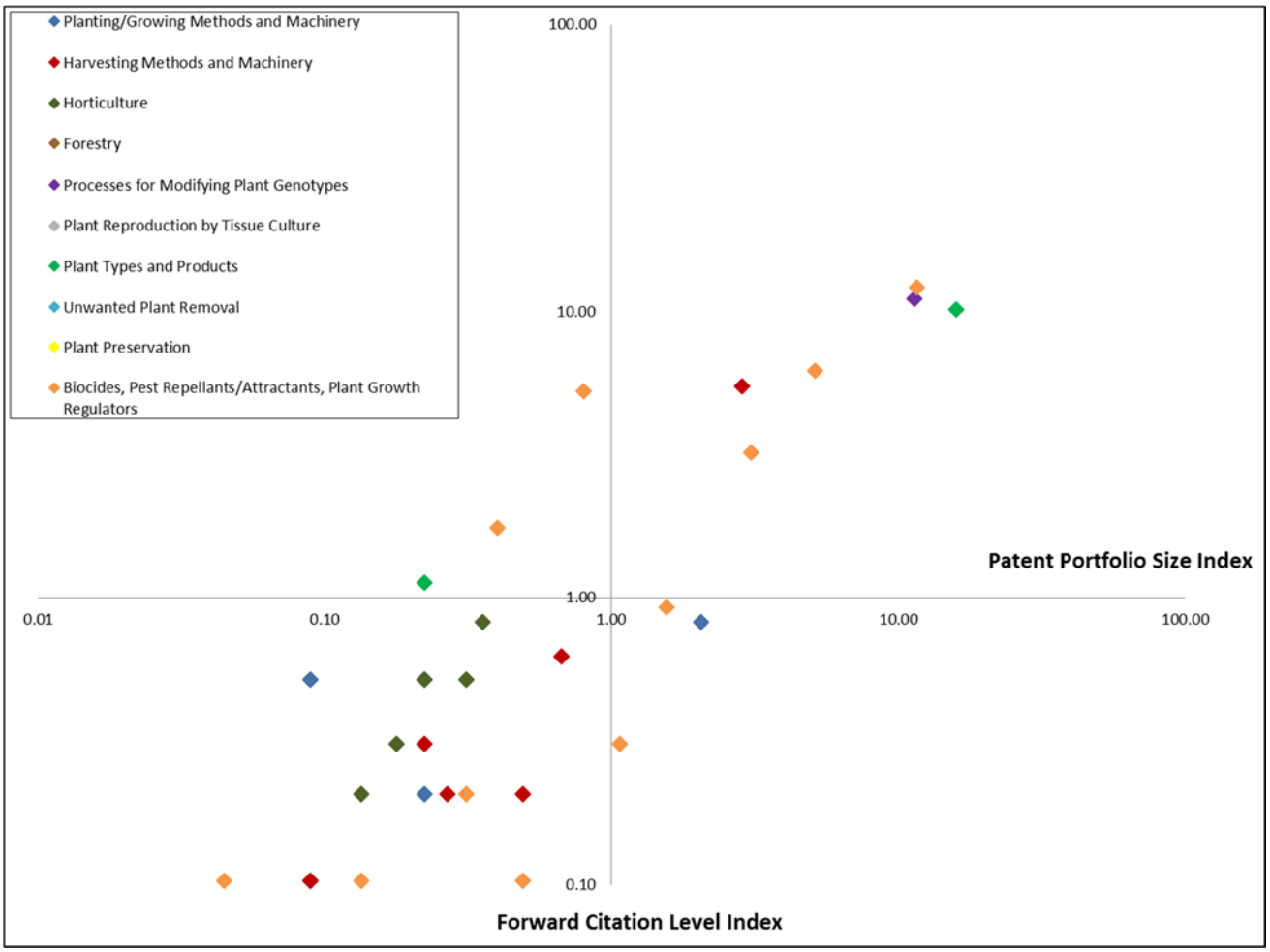
Patent Class Area Description	Applications	Awards	Forward Citations
New Plants or Processes for Obtaining Them, Plant Reproduction by Tissue Culture Techniques	355	302	218
Pesticides, Herbicides, Biocides, Plant Growth Regulators	279	273	295
Harvesting, Mowing	50	63	67
Planting, Sowing, and Fertilizing Methods	41	13	8
Horticulture, Cultivation of Vegetables, Flowers, Fruits, Vines, Hops, Etc.; Forestry; Watering	22	20	23
Soil Working and Agricultural Machinery	10	13	13
Plant Science Applications of Chemical Compound Activity/Preparations	2	0	0

One of the state's primary areas of local patenting activity is in identification and production of new plant varieties. Innovations in this category, as well as in the biocides patent classes, are closely linked with the specializations in plant sciences research and facilities at NCSU. Within this top patent class area, approximately 53% of patents are for specific flowering plant line and product genotypes, 28% of patents are for specific genetic engineering processes used to modify plant genotypes, and 6% are for hybridization and artificial pollination methods.

Areas of particular innovation strength in patenting possess both a critical mass of patents as well as a high level of forward innovation generation. Both these attributes are critical to a self-sustaining innovation cluster high patenting numbers alone may not be indicative of real innovation if the patents are just sequential improvements on existing technologies and do not produce forward innovation, while high levels of forward innovation that occur in isolation may not be indicative on their own of an existing infrastructure that supports further development of patented technologies. To assess the picture of NC's local innovation specializations in plant sciences, these two attributes are compared using the detailed 6-digit International Patent Classification (IPC) categories in Figure 14 below. If a detailed patent class has a patent portfolio size index greater than one, it indicates that there is a larger than average amount of patents

invented in North Carolina relative to other plant science areas; a portfolio size index of less than one indicates that there is a lower than average amount of patents invented relative to other plant science areas. Similarly, a forward citation level index of greater than one indicates that patents in the detailed class category are producing larger than average amounts of forward citation references by other patents and an index of less than one indicates that patents in the class are producing a lower than average amount.

Figure 14: Detailed IPC Patent Class Portfolio Size Versus Forward Innovation Level for NC-Invented Plant Science Patents 2009-2014



As evidenced by the clustering of several related patent class areas towards the upper right hand quadrant of Figure 14, **North Carolina demonstrates strong specializations in patent classes related to herbicides, pesticides, and other biocides.** The state has a recent history of producing large quantities of new intellectual property related to biocidal compounds as well as evidence that these patents have generated high levels of attention from other patents seeking to advance the state of science. Key activity from in-state inventors has involved areas related to:

- Endotoxic genes that can be implanted into crops to induce natural production of pesticide compounds
- Herbicide coatings and mixtures using microencapsulated compounds to improve efficacy and reduce likelihood of cross-contamination with soil and water

- Pesticide adjuvants to improve the shelf life, efficacy, and safety of existing widely-used compounds
- Antimicrobial and fungicidal compounds used for prevention of biofilms and infections in soil and plant surfaces.

Strong specialization also exists for creation of novel plant types and products. Table 14 shows the distribution of the approximately 167 novel plant patents related to a specific plant or crop type. Soybean varieties represent the overwhelming majority of specific plant genotype patents generated by North Carolina inventors, indicating a local base of specialization and innovative knowledge around modifying this crop type.

Table 14: Distribution Plant Types in NC-Invented Patents Related to Specific Plant Lines/Cultivars

Plant Type	Percentage of Patents (Applications and Awards)
Soybean	34%
Corn/Maize	19%
Shrubs	13%
Tobacco	8%
Ornamental Flowering Plants	5%
Duckweed	4%
Sweet Potato	4%
Redbud Tree	3%
Rice	2%
Pine Tree	2%
Blueberry Plants	2%
Cotton	2%

A linked specialization for state-generated innovation involves processes for modifying plant genotypes through genetic engineering to produce desirable traits that improve hardiness, yield, or quality of plants and plant products. Major themes of state patenting activity in this area include:

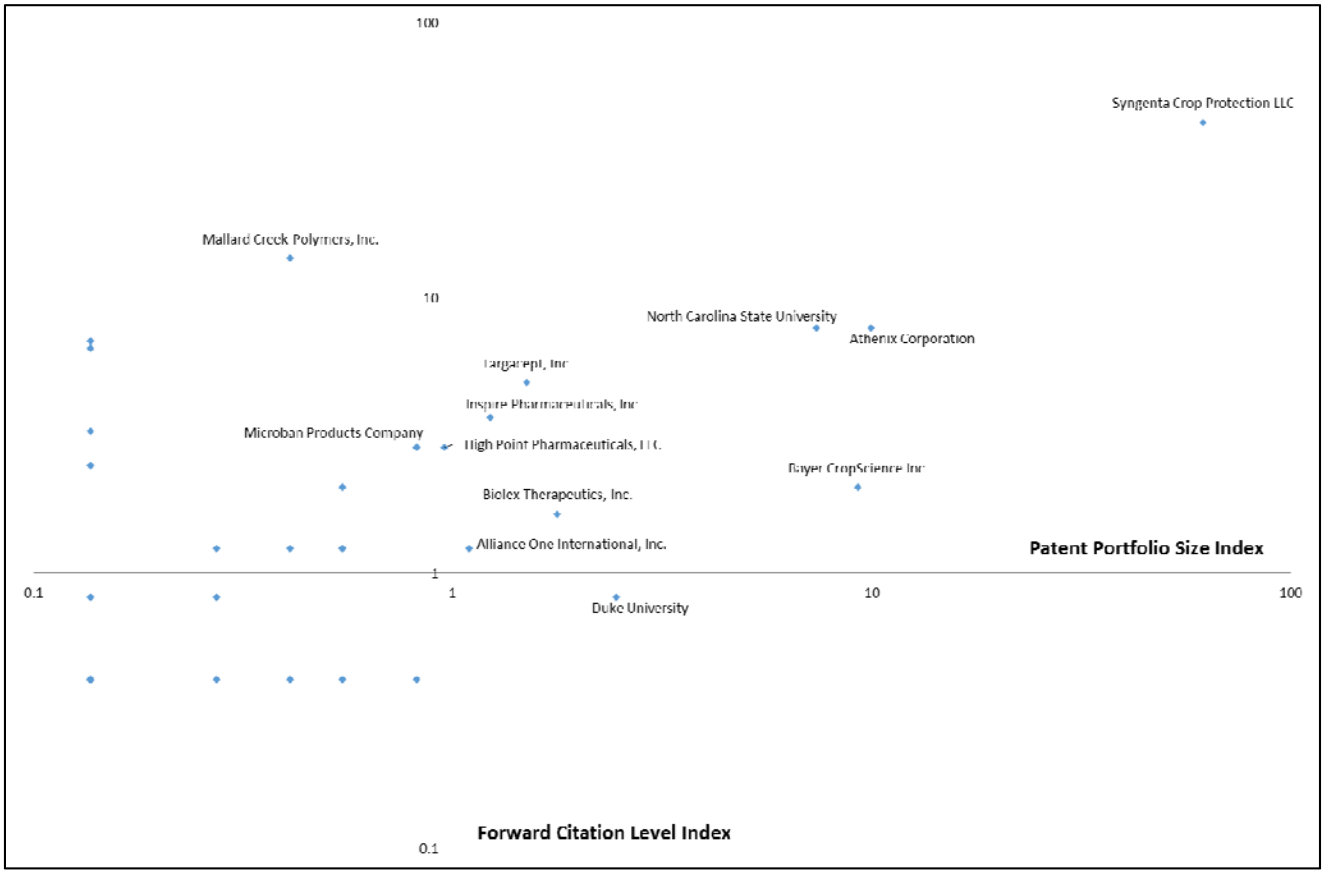
- Novel proteins used to increase tolerance to climate stresses and increase crop yields
- Introduction of genes that produce resistance to nematodes and other soil parasites
- Introduction of genes that promote herbicide tolerance in crops
- Biomarkers related to specific crop diseases and methods of altering their expression

Finally, North Carolina displays innovative specialization in machinery parts related to mowers and moving components of harvesting machinery. Innovative strengths in these areas relate to development of rotary cutting components as well as automated and robotic mower systems.

While North Carolina invented patents provide a good indication of the innovative specializations found in the state, patent assignees also provide a perspective on which innovative areas are perceived as most valuable to local industry. Locally-based firms involved in providing plant science products and services will purchase the rights to patents that are critical to their business, which provides a snapshot of major consumers of innovation in the state as well as areas of current market applications. There were a total of 944 patents in plant science areas with North Carolina assignees from 2009-2014, giving the state relatively average patent holdings in these areas relative to the rest of the U.S.

Figure 15 below shows a similar plot to Figure 14 comparing the patent portfolio size against forward innovation generated by patents for all patents with North Carolina assignees from 2009-2014. Patents generating high levels of forward innovation are especially important to firms when purchasing or licensing assignee rights, as they can protect larger market shares with breakthrough technologies and license further derivative products from the original patent's subject matter.

Figure 15: North Carolina Assignee Patent Portfolio Size Versus Forward Innovation Level for Plant Science Patents 2009-2014



Syngenta's operations in the state represent the primary consumer of innovation and interface directly with in-state innovation pipelines and translational research facilities. Their large portfolio of intellectual property based primarily around herbicides, pesticides, antimicrobials, and protective coatings for crops provides a direct outlet for North Carolina's innovation activities in these areas. **Other major private holders of innovative plant science technologies include Bayer CropScience, with holdings in specific cotton lines and insecticides, and Athenix (now part of Bayer), with holdings in endotoxic and herbicide-**

resistant plant genes. Many local pharmaceutical companies also hold patents related to therapeutic applications of plant compounds.

NC State University also unsurprisingly represents a significant public holder of innovative plant science patents. Primary areas of patenting activity for which NCSU is the assignee include:

- Specific flowering shrub and tree genetic lines
- Engineered bacterial reactions and bacterial synthesis of compounds related to plant science applications
- Herbicidal and antifungal compound formulation
- Inhibition and dispersion of biofilms in plants.

The majority of NCSU's patents are developed by in-state inventors and have close linkages to the innovative activity occurring at private plant science firms. Although it is not possible to track how many privately assigned patents were developed using some degree of NCSU faculty collaboration and resources, discussions with local private and academic stakeholders suggest that NCSU is relatively well-established as a focal point for the translation of plant sciences innovation into marketable intellectual property acquired by local industry.

As shown in Table 15, patent assignees in North Carolina hold a vast majority of their innovative intellectual property over the last five years in the area of biocide applications. This suggests that advances in other major key in-state innovation areas are being "exported" to other non-local firms for ultimate ownership or licensing, and that companies in North Carolina have highly concentrated innovation resources in one major set of market applications in the plant sciences area.

Table 15: Distribution of NC Assignee Patents from 2009-2014 by Patent Class Area

Patent Class Area Description	Percentage of Patents
Pesticides, Herbicides, Biocides, Plant Growth Regulators	75%
New Plants or Processes for Obtaining Them, Plant Reproduction by Tissue Culture Techniques	16%
All Other	7%

Conclusions from Plant Sciences Patent Analysis

Analysis of recent innovation trends in North Carolina's plant sciences capabilities through examination of patenting activity over the past five years yields several key conclusions:

- North Carolina is a leading state in agriculture and plant science innovation activity driven by its strong in-state specializations in biocides, novel plant and crop genetic engineering methods, and specific plant and crop genetic lines with key resistance or improved yield traits
    - Forward innovation generated by state-invented patents is also strong, indicating that the advances being made are foundational to further development of plant science capabilities rather than just marginal improvements on existing technologies.

- State industry pipelines to the innovation that is occurring are strong, as evidenced by the presence of large patent holdings by major plant science corporations generated by in-state inventors.

- However, industry-owned patent areas suggest that translational activity is highly concentrated in only one of North Carolina's innovation strengths, biocide (pesticide) applications.

- Given its capabilities in plant sciences research, NCSU is well-positioned as a central hub for continued growth of the existing innovation ecosystem and as a key driver of expanding translational activity in other areas of state innovation strength.
    - NCSU can serve as a bridge for industry to other areas of state innovation strength that do not currently have as strong of an innovation presence in local industry, such as plant science-related genetic engineering capabilities.

The role of NC State in the agbioscience innovation ecosystem in North Carolina, and the University's research core competencies are examined in the next chapter.

III. NC State University: A Hub for Agbioscience Advancement

Established in 1887 as the North Carolina College of Agriculture and Mechanic Arts, NC State University is ranked in the elite Carnegie Classification of "very high research activity" institutions. As one of the nation's premiere land-grant universities, a key component of NC State's research, education and extension activity has always been focused in agricultural sciences and associated disciplines. This tradition continues, with the College of Agriculture and Life Sciences (CALS) at NC State undertaking over $56 million in research activity in 2013. In a nation where agricultural research occurs in all 50 states, NC State's performance in research places it in a strong position of 6th in overall agricultural sciences R&D expenditures.

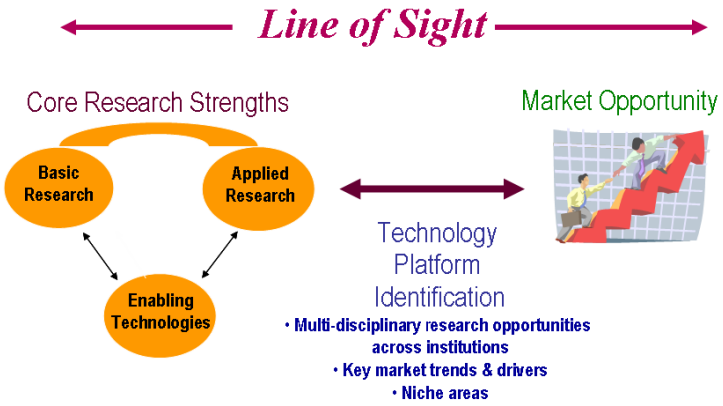
The strength of NC State and CALS in plant sciences research and associated agbioscience disciplines is important because without a strong R&D foundation within universities and research institutions, it is difficult for any state to initiate or sustain major cluster-based economic development. In agbioscience it is clear that land-grant universities are particularly important contributors to basic and applied research especially research targeted at the specific needs and characteristics of their "home" agronomic environment. While multinational and domestic agbioscience companies also perform very important R&D activities, the "local environment dependency" of agricultural production lends itself to the customization of solutions to meet local needs and academic research institutions, in the U.S., play a critical role in providing that function (as well as feeding novel innovations into domestic and multinational agbioscience companies for commercialization). In North Carolina, the base of basic and applied R&D capability within NC State, and in smaller niche areas within other universities and colleges in the state, is considerably extended by the intensive R&D operations of leading global agbioscience corporations, including Syngenta, BASF, Bayer CropScience, Novozymes, Monsanto and an emerging base of new agbioscience companies.

Because research is the driving force behind innovation and commercialization in agbioscience, and because research core competencies have been shown to be the foundation of technology cluster development, it is imperative that the State of North Carolina, NC State University, and other key stakeholders in North Carolina have a formal understanding of their plant science and associated agbioscience core competencies. As such, Battelle has performed an independent assessment and evaluation of plant science and agbioscience research core competencies at NC State. Battelle then evaluates the core competencies, potential linkages with NC industry and agriculture, and line of sight to significant market opportunities to identify robust platforms for plant science based economic development.

A. Methodological Approach to Core Competency Evaluation

Underpinning the successful translation of research strengths into economic development opportunities requires the recognition of the importance of "market-driven" processes (Figure 16). The traditional model of commercialisation assumes a "research-driven" pathway. This research-driven commercialisation process proceeds in a pipeline fashion from basic research leading to a major scientific breakthrough, to applied research leading to product development, and ending with industrial manufacturing and marketing. While that process can and does work in some instances, the shortcomings of the research-driven approach are that it is too divorced from commercialisation and product development needs (the voice of the market) and has uncertain line-of-sight to economic value. An applications and market-oriented approach recognizes that commercialisation is a highly interactive process involving close ties between research activities and business development activities. Success depends, as the Council on Competitiveness points out, "on a team effort that includes carefully focused research, design for manufacturing, attention to quality and continuous market feedback."[18]

Figure 16: Market Opportunity, Technology Platforms and Core Competency Assessment



A core competency ideally brings together basic research, enabling technology, and applied research activities with a "line of sight" that moves seamlessly to address specific needs and market opportunities, and can form robust technology platforms. Core competency areas that lack this linkage and connection to needs and market opportunities typically offer more limited economic development opportunities and in the case of the Plant Sciences Initiative at NC State, the state of North Carolina is certainly hoping that investment in the initiative and associated facilities will result in the advancement of platforms that promote economic development in the state.

B. Defining Core Competencies

There is no one single source of information that serves to identify core research competencies and focus areas. Rather, a variety of integrated and complementary analyses are required to help identify a university or state's current position and areas of focus that may lead or contribute to future growth.

In identifying core research focus areas, **Battelle's objective is to identify those fields where there is a critical mass of activity ongoing along with some measure of excellence**. This does not mean, however, that other fields of research excellence may not be present within the institution. What it does mean is that these other research strengths are found in relatively limited pockets and so offer more limited opportunities upon which to build (but they very well may still contribute in some manner), or grow to become more significant.

[18] Council on Competitiveness, *Picking Up the Pace: The Commercial Challenge to American Innovation* (Washington, DC: Council on Competitiveness), pp. 9-10.

Several tests are generally used by Battelle to identify a core competency:

1. Is it a significant source of competitive differentiation? Does it provide the basis for a unique or prominent signature?

2. Does it comprise a critical mass of scientists and technologists?

3. Does it transcend a single business? Does it cover a range of businesses, both current and new, especially businesses inside the state?

4. Is it challenging for competitors to compete with and imitate?

5. Is there a line-of-sight to knowledge-transfer and commercialisation of innovations arising from this R&D focus?

C. Approach to Identifying Agbioscience Core Competencies and Clustering

Battelle identifies research core competencies using both quantitative and qualitative methods. Quantitative assessment uses statistical information on extramural grants, publications, and patent activitiesas well as application of Battelle's software tool OmniViz™ to identify research clusters.

Qualitative work includes interviews with key administrators, scientists, and researchers within the university, and also seeks the input of knowledgeable key external stakeholders (such as industry members interesting with the university, commodity group stakeholders, commercialization and economic development agencies, etc.).

The questions that the Battelle team explores in the core competency assessment focus on the following:

- In which fields of plant science and associated agbioscience disciplines has NC State received significant levels of funding, especially funding from "gold standard" external sources, such as federal agencies?
- In what plant science/agbioscience and technology fields does NC State demonstrate a substantive and influential record of publication?
- In what plant science/agbioscience and technology fields are patents and other intellectual property being generated by the University?
- What areas of research are connected to significant industry relationships, especially relationships with NC-based agbioscience companies?
- In what areas is there robust connectivity to advancing agricultural production in North Carolina research seeking to increase agricultural productivity and economic impacts in the state from agriculture?
- What areas of plant science/agbioscience does NC State self-identify as being established or emerging core competencies, and what is the institution's vision for signature focus areas of activity moving forward?
- Based on identified core competencies, what economic development opportunities can be identified for North Carolina?

In evaluating the answers to these questions, as elucidated by interviews and reference to the quantitative data, the Battelle team is able to provide insights into the plant science research base, and draw implications as to how these research strengths may best intersect with North Carolina's agbioscience corporations, agricultural industry, associated technological industries and economic base.

Battelle's quantitative assessment starts with an in-depth examination of areas of critical mass in plant science and associated agbioscience R&D. This quantitative review uses multiple data resources:

- OmniViz™ pattern recognition analysis of publication abstracts to identify distinct clusters of R&D activity
- Analysis of patent/IP generation statistics
- Presence of dedicated university centers or institutes designed to leverage institutionally identified areas of focus and excellence
- Links to established or emerging agbioscience companies or specific agricultural applications in North Carolina.

The Battelle OmniViz™ analysis uses real text cluster analysis of R&D activity as indicated by publications abstract and title data. Battelle uses the OmniViz™ pattern recognition software, to group publication abstracts based on the actual use of words in the abstracts and titles, allowing for free association based on the usage of words and phrases, rather than forcing clustering based on preselected key words. Thus, the analysis goes beyond predetermined, high level classifications, such as publication field. Instead, this process analyzes the text of the abstracts for each publication to identify how these key indicators connect or "cluster" around key themes.

Text clustering is a multistage process that involves transformation of individual text records into a numerical form that can then be processed by various clustering algorithms into distinct groupings that are represented in two dimensional space. This process is shown below in Figure 17.

Figure 17: Process Flow for Translating and Clustering Unstructured Text Data from Research Publications

The performance of the clustering analysis involves the following steps:

Step 1 Content Development: A data set is developed with sufficient descriptive content.

Step 2 Pattern Recognition: The analysis generated by OmniViz™ creates clusters in which publications, grants, and patents have apparent relationships and produce a series of words to describe and link these cluster areas.

Step 3 Interpretation and Grouping by Battelle Review: The identification of key themes and groupings that result from an OmniViz™ cluster analysis requires an experienced research team to review the cluster items and interpret and explain the types of technologies and specific activities that are represented.

The OmniViz™ cluster analysis performed for NC State uses a dataset containing 5,652 input records. The dataset comprised publication records (2009 through October 2014) classified in

plant sciences and associated agbioscience fields (see Appendix B) with at least one NC State-based author. These records, which include article title, abstract, key discipline classifications, and key words, were obtained from Thomson Reuters Web of Knowledge (using Battelle's Current Contents Connect subscription).

It should be noted that the OmniViz™ search captures only publications produced while authors were employed as faculty or staff of NC State. As such the analysis likely under-represents capabilities in some areas where there may have been major recent hires at the university (representing personnel whose previous publications would be categorized under their previous institution, and thus omitted). Similarly, the analysis may capture some capabilities that have since been diluted in North Carolina by specific researchers leaving the state for other research employment opportunities.

As shown in Figure 18, and summarized in a more simple form in Table 16, the OmniViz™ analysis identified 53 distinct clusters of activity by NC State University faculty and research scientists[19]. These clusters range in size from a high of 501 records in "Plant Growth, Metabolism and Production" to the smallest cluster with just four unique record in "peridoxase biochemistry". These 53 clusters are then further associated and interpreted by Battelle into 14 major THEMES (metaclusters of related clusters) which reflect important themes within the NC State data.

[19] These data represent publications in which at least one of the authors of the paper was located at North Carolina State University at the time of publication.

Figure 18: NCSU Omniviz Cluster Analysis

Cluster ID (0-59)	Number of Records	Major Theme	MetaCluster Focus Areas	% of Records with Bold Term	Key Terms											
					Color key is after the cluster data. **Bold** term is single largest term within the Major/Minor Topics.											
6	501	Plant Science	Horticulture and Plant Growing Methods	31%	plant	metabolism	**grow**	quality	temperature	production						
46	441	Plant Science	Genetic Profiling of Plants and Plant Diseases	78%	**gene**	trait	association	protein	plant	express	sequence	genetics				
50	433	Biochemistry	Biochemistry, Peptide/Protein Sequencing	72%	**protein**	peptide	bind	structure	express							
30	360	Soil Science	Soil Ecology and Plant Nutrition	46%	**water**	soil	nitrogen	management	quality	nourish	fertilize					
0	275	Entomology	Insect Adaptation, Evolution and Pop'n Genetics	57%	**evolve**	phylogeny	insect	adaptation	genetics	population	behave					
47	256	Plant Science	Plant Disease Resistance	78%	**resist**	marker	disease	wheat	gene	plant	leave	blight	population			
48	243	Artifact	Artifact	18%	**particle**											
26	228	Ecology	Forest Ecosystem Mgmt/Land Cover Modeling	70%	**forest**	carbon	pine	tree	soil	ecosystem	vegetation	biomass	tropic			
15	221	Veterinary	Veterinary Science - Small Animal Treatment	90%	**dog**	cat	disease	cancer	osteoarthritis	therapy	diagnose					
42	200	Cellular Biology	Plant and Animal Cellular Biology	94%	**cell**	protein	express	grow	in vitro							
39	198	Ecology	Wildlife Conservation	32%	**habitat**	bird	move	ecology	disperse	predation	population	conserve				
25	189	Ecology	Ecology	54%	**species**	diversity	community	richness	plant	ant	biodiversity	biology	pattern			
56	182	Plant Science	Weed Management and Herbicides	72%	**management**	crop	herbicide	weed	grow							
10	164	Veterinary	Veterinary Science - Small Animal Diseases	68%	**disease**	cat	vinsonii	dog	virus	bacteria	infect					
36	154	Animal Science	Swine Health and Production	56%	**pig**	diet	digest	wean	sow	grow	swine					
23	127	Polymer Science	Polymer Additives/Properties	77%	**polymer**	property	morphology	mix	film	behave	co-polymer					
5	126	Polymer Science	Polymer Fibers	70%	**fiber**	composite	polymer	nanofibers	nanoparticle	surface	electrospinning					
20	101	Animal Science	Fish Ecology and Diseases	84%	**fish**	bass	salmon	teleost	grow	trout						
41	87	Food Science	Food Chemistry (Fruit Focus)	63%	**acid**	anthocyanin	fruit	proanthocyanidins	anti-oxidant	activity						
43	81	Cellular Biology	Microbial Growth and Inhibitors	88%	**bacteria**	biofilm	library	disperse	inhibit	infect						
1	81	Biomaterials	Wood Core and Plant Matter Analysis	62%	**wood**	lignin	cellulose	property	spectroscopy	biomass						
28	77	Polymer Science	Carbon Nanotubes/Carbon fibers	95%	**carbon**	nanotube	nanofibers	activate	organic							
44	76	Cellular Biology	Plant and Animal Immunogenetics	76%	**receptor**	nucleus	neuron	express	activate	gene-expression						
14	67	Environmental Mgmt	Runoff and Storm Water Management	78%	**runoff**	stormwater	water	bioretention	wetland	nitrogen	remove	pollute	quality			
51	65	Veterinary	Veterinary Science - Horses	89%	**horse**	ultrasonic	surgery	foot								
12	64	Food Science	Dairy Foods	64%	**flavor**	whey	protein	cheese	compound	property	millk	concentrate				
18	60	Food Science	Food Additives, Allergens, and Safety	95%	**food**	safety	peanut	texture	process							
8	59	Biofuels	Bio-Ethanol Production	80%	**pretreat**	hydrolysis	corn	lignin	cellulose	ferment	biomass	bioethanol	saccharification	ethanol	enzyme	ethanol-prod
31	52	Analytical Methods	Simulation and Modeling	96%	**simulate**	rate	algorithm	flow	field	optimize						
29	46	Plant Science	Plant Drought Resistance	54%	**drought**	tolerate	deficit	water	stress	leaves	transpire	hydraulic	genotype	pressure	aquaporin	
55	39	Ecology	Marine/Aquatic Ecology	82%	**river**	reserve	oyster	reef	habitat	bay	estuary	marine				
33	35	Polymer Science	Biopolymers	77%	**polymerize**	transfer	polymer	particle	nanoparticle	radical	surface					
52	35	Artifact	Artifact	91%	**transport**											
34	30	Analytical Methods	Biometric Models	80%	**regress**	likely	association	variable	semiparametric	data						
58	28	Biochemistry	Organic Chemistry	61%	**synthesis**	porphyrin	reaction	therapy	molecule	construct	chemical					
40	28	Analytical Methods	Network Algorithm Applications	86%	**network**	algorithm	genetics									
7	27	Biofuels	Bio-based Oils/Compounds	85%	**oil**	deposit	fat	biodiesel	seed	line						
49	21	Automation	Automation-Actuator Control/Fault Detection	62%	**feedback**	actuate	non-linear	sense	optimize	stabilize						
37	21	Veterinary	Verterinary Science - Anaesthesia	57%	**drug**	analgesia	ablate	pain	post-operative	morphine						
22	19	Biochemistry	Mycotoxins and Producing Organisms	74%	**aflatoxin**	parasiticus	compatibility	vegetate	recombination	biosynthesis						
13	18	Chemistry	Battery Structures and Materials	100%	**battery**	lithium-ion	electrolyte	property	polymer	material	electrode	electrochemical				
57	15	Entomology	Flying Insects	67%	**morphology**	fly	diptera	pollinate								
2	13	Public Health	Child Obesity Studies	77%	**child**	index	food	beverage	obesity	nourish						
17	12	Environmental Mgmt	Waste Management	50%	landfill	diesel	vehicle	recirculation	municipality	bioreactor						
27	11	Economics	Agricultural/Forestry Economics	91%	**market**	trade	policy	industry	cost							
11	11	Entomology	Insect Colonies	73%	**microsatellite**	parthenogenesis	isoptera	colony	locus							
45	10	Plant Science	Herbicide/Pesticide Efficacy in Turf	70%	**turf**	pesticide	herbicide	toxicology	toxicity							
38	9	Ecology	Wildlife Surveys	89%	**probability**	survey	occupancy	negative	hear	detect	count					
32	8	Ecology	Environmental Education	100%	**educate**	learn	distance									
59	8	Physics	Nuclear Particle Detection	100%	**neutron**	decay										
35	7	Analytical Methods	Environmental Statistics	100%	**calibrate**	regress	quantile	optimize								
54	6	Plant Science	Tobacco Plants	100%	**var**	**nicotianae**	black	tobacco			Major Topics -- Significant and driving impact on cluster formation					
24	5	Food Safety	Viral Transmission/Food Safety	100%	**virus**	norovirus	hand				Minor Topics -- Ancillary impact on cluster formation					
3	4	Artifact	Artifact	100%	**canadensis**						Other Terms -- No impact on cluster formation. Provide context on the records within the cluste					
53	4	Biomaterials	Biological Gels and Hydrogels	100%	**gel**	property	gelation	mix	microstructure							
4	4	Artifact	Artifact	100%	**junction**											
21	4	Biochemistry	Biochemistry	75%	**peroxidase**											
19	2	Artifact	Artifact	100%	**recreation**											
9	2	Artifact		NA												
16	2	Artifact		NA												

Table 16: Major Theme Areas Evident in OmniViz Analysis

Major Theme	Number of Clusters	Number of Records
Plant Science (see breakout in Table 17)	7	1442
Ecology	7	671
Veterinary Science	4	471
Biochemistry	3	465
Polymers	4	365
Soil Science	1	360
Cellular Biology	3	357
Entomology	3	301
Animal Science	2	255
Food Sciences & Safety	4	216
Analytical Methods	4	117
Biofuels	2	86
Biomaterials	2	85
Environmental Management	2	79

Table 17: Clusters Under the "Plant Science" Major Theme: Breakout of Seven Clusters

Plant Science: Individual Clusters Under Major Theme	Number of Records
Plant Growth, Metabolism and Production	501
Genetics of Plants and Plant Diseases	441
Plant Disease Resistance	256
Weed Management and Herbicides	182
Plant Drought Resistance	46
Turf pesticides	10
Tobacco	6
Sum	1442

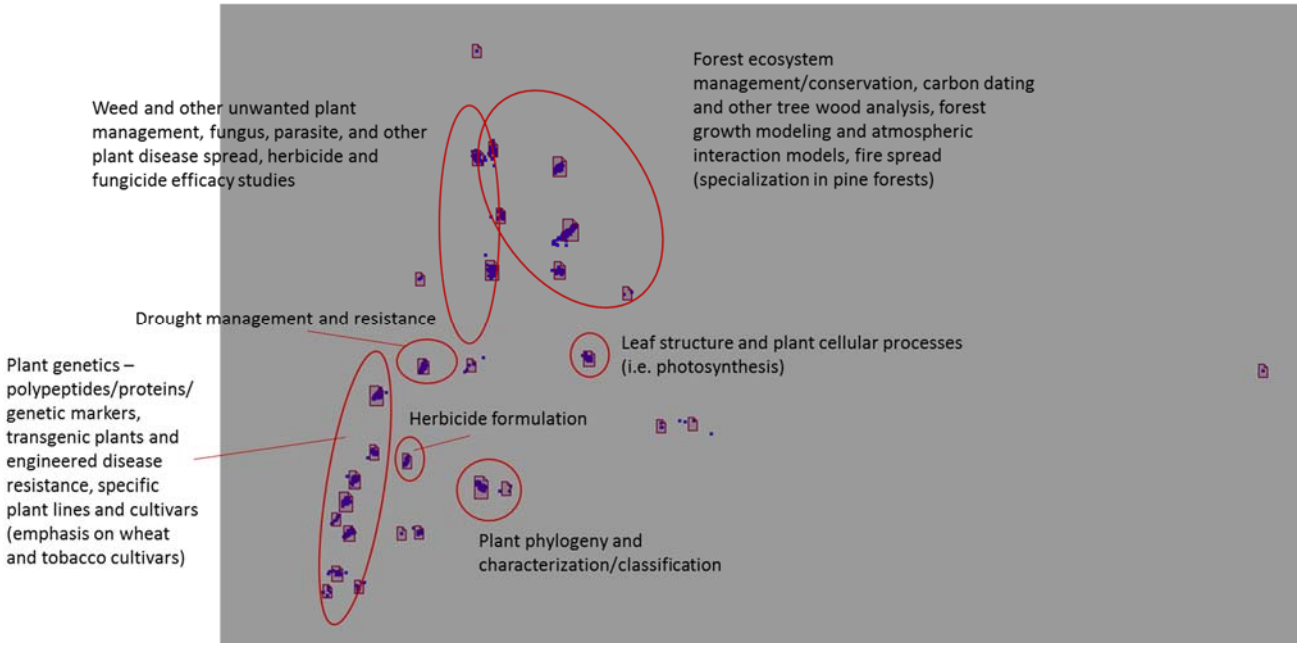
In addition to the above analysis of broad agbioscience and associated disciplines, Battelle also evaluated a smaller subset of 1,460 publications consisting of the core plant sciences research discipline area. This analysis subset **excluded** publications in areas of environmental science, animal science, veterinary medicine, etc. to concentrate tightly on basic and applied plant science research. The clustering analysis identified seven major capability themes in NCSU plant science research publications:

- Unwanted plant growth, fungus, parasite, and other plant disease management strategies and treatments
- Herbicide formulation and efficacy studies
- Drought resistant plant traits and genetic lines
- Plant genetic engineering, sequencing, and biomarker identification
- Forest ecosystem management and conservation and associated modeling and analysis techniques

- Plant phylogeny, characterization, and classification methods
- Plant leaf structure and related plant cellular processes.

The visualization of the clustered research publication records and identification of these theme areas is shown below in Figure 19.

Figure 19: Visualization of Clustering Analysis for NCSU Plant Science Research Publications 2009-2014



The identified clusters illustrate that NCSU's research capacity spans a quite broad spectrum of basic and applied plant science research capabilities. Plant disease and parasite management as well as herbicide formulation studies have strong ties to product focus areas for the local agbioscience industry in NC, and genetics capabilities for plant science applications serve as key enabling resources for these and other research areas.

The broader OmniViz analysis of the full 5,652 records included the much broader agbioscience definition, including additional fields closely related to plant science such as organic chemistry and animal science. The broader analysis revealed significant clusters in multiple other complementary research themes including:

- Biochemistry and protein compound engineering
- Biopolymers
- Cellular biology including animal and plant immunogenetics
- Microbial growth inhibiting compounds
- Biofuel refining and production
- Veterinary medicine.

These areas provide further support for existing plant science research capabilities and increase the capability for interdisciplinary research that can more rapidly advance the frequency of translational market applications of academic work.

D. Core Competencies: Summary Analysis

As noted above, in addition to the research publications analysis, Battelle also conducted interviews with university, industry and key external stakeholders to validate the quantitative assessment and to gain additional insights regarding research strengths, opportunities, challenges and future directions. The research team also accessed individual researcher and research team web pages and other accessible research resources to add further intelligence to the core competency considerations. Indeed, the Battelle team constructed a spreadsheet summary of the research focus areas of all faculty in CALS (with potential plant science connectivity) and in the College of Engineering and College of Sciences to be able to identify faculty capabilities and interests in detail.

Taking all of these information and data resources into account, resulted in the generation of the summary table of core competencies shown in Table 18, summarizing

- OmniViz publications cluster analysis
- Research funding data
- Patenting data
- Presence of dedicated university research centers or stated as a strategic thrust of research by the institution
- Notation regarding whether the competency was raised as such in interviews.

Table 18: Summary of NC State Plant Science and Associated Discipline Strength Areas by Key Criteria

	Evident NC State Research Clusters (OmniViz Analysis) 2009 to Oct. 2014	NC State Research Funding Awards (2008 through November 2014)	Patents NC Universities and Industry 2009 to Oct. 2014	Dedicated NC State Research Centers or Stated Thrusts	Interviews Validated as an Area of R&D Strength or Concentration
Research Strength Area	√√√ >500 publications √√ 200-499 publications √ 50-199 publications	√√√ >$50 million √√ $20-$50 million √ <$20 million	√√√ >200 patents √√ 100-2000 patents √ <100 patents	Yes or No (Comments)	(Comments)
Genetics and Plant Improvement	√√√ 501 Horticulture 441 Crop Genetics 256 Disease Resistance/ Genetics 46 Drought Tolerance	√√√ $36.1 million Crop Science $43.6 million Horticultural Science $10.6 million Genetics	√√√ 302 New plants or processes for obtaining them, plant reproduction by tissue culture techniques[20] 20 Horticulture	**YES** Center for Plant Breeding and Applied Genomics Floriculture Research Group Center for Turf Grass AMPLIFY Forage Research Group Specialty Crops Program	Diverse breeding, genetics and plant molecular biology programs in corn, cotton, peanuts, small gains, turfgrass, soybean, tobacco. With more than 35 core faculty actively developing new cultivars, germplasm and parental lines - has more plant breeders than any other U.S. university Robust programs in Horticulture with vegetables and ornamentals Tissue culture and molecular genetics for crop improvement using marker-assisted selection, gene isolation and transformation. Quantitative genetics, statistics and cytogenetics thrusts. Overall quantitative genetics capabilities highly cited by industry. Collection, evaluation and utilization of exotic germplasm

[20] Breakdown of largest (new plants/processes for obtaining them) category: 350 patents in flowering plant lines/products, 183 patents in processes for modifying plant genotypes, 39 patents in hybridization/artificial pollination, 25 patents in processes for producing mutations

	Evident NC State Research Clusters (OmniViz Analysis) 2009 to Oct. 2014	NC State Research Funding Awards (2008 through November 2014)	Patents NC Universities and Industry 2009 to Oct. 2014	Dedicated NC State Research Centers or Stated Thrusts	Interviews Validated as an Area of R&D Strength or Concentration
Plant Pathology	√√ 256 Disease Resistance/ Genetics 19 Mycology 10 Turf Protection	√√ $31.2 million Plant Pathology $29.4 million CIPM* $20.3 million Plant & Microbial Biology*	273 Pesticides, herbicides, biocides and plant growth regulators (formulations)*	YES Center for Integrated Fungal Research Center for Integrated Pest management*	Significant cluster of faculty performing fungal research (pathogens and genomics focus) Host-parasite interactions and genomics Microbial ecology and epidemiology Diagnostics and forecasting Engineering of resistance o geminiviruses.
Biochemistry	√√ 433 Biochemistry	√ $16.3 million Biochemistry		Biochemistry is responsible for multiple core facilities for CALS covering proteomics, gene regulation, crystallograph y, NMR, Mass spec and electron microscopy.	Primarily focused on mechanisms and basic science inquiry. Plant focus in gene regulation, transcription and proteomics. Considering some microbiome cluster hires and hires in epigenetics. Interdisciplinary work in biology and biochemistry of circadian rhythms.
Soil Science	√√ 360 Soil Ecology & Plant Nutrition	√ $14.2 million Soil Science	13 Planting, sowing and fertilizing	NCSU has sustained a soil science department where other universities have not (5 major depts. in nation)	Traditionally strong in soil chemistry and minerals, environmental chemicals and wetland soils. Diversity of NC soils advantageous for research. Strengths in soil physics Need to build capabilities sin soil microbiology. Targeting a faculty hire for soil metagenomics.

	Evident NC State Research Clusters (OmniViz Analysis) 2009 to Oct. 2014	NC State Research Funding Awards (2008 through November 2014)	Patents NC Universities and Industry 2009 to Oct. 2014	Dedicated NC State Research Centers or Stated Thrusts	Interviews Validated as an Area of R&D Strength or Concentration
Weed Management and Control	√ 182 Herbicides & Weed Management	√√ $29.4 million CIPM*	273 Pesticides, herbicides, biocides and plant growth regulators (formulations)*	YES Center for Integrated Pest Management*	Diverse work in weeds across field crops, horticulture and in applied ecology (e.g. riparian area weeds, aquatic weeds).
Cellular Biology	√√ 200 Cellular Biology	√√ $20.3 million Plant & Microbial Biology*			Interdisciplinary with research identified in both CALS and College of Sciences.
Forestry and Forest Ecosystems	√√ 228 Forest Ecosystems/ Management				Evident research thrust areas in: forest ecology, conservation and restoration; tree physiology, genetics and improvement; hydrology and watershed systems; and spatial analysis.
Entomology	√√ 275 Insect Adaptation/ Population Genetics 15 Flying Insects	√√ $31.0 million Entomology $29.4 million CIPM*	273 Pesticides, herbicides, biocides and plant growth regulators (formulations)*	YES Center for Integrated Pest Management*	Known for diversity of work across field crops, vegetables and fruits. Well regarded groups in urban entomology and in animal health entomology. Engaged with RTP companies, especially in pesticide testing. Would like to build further in genetic pest management and microbiome work.
Ecosystem Management and Ecology	√√ 198+199 Wildlife Conservatio n & Ecology	√√ $24.1 million Applied Ecology		YES Environmenta l Statistics Working Group Environment and Climate Observing Network	External interviewees noted that they see emphasis on ecology/applied ecology at NC State.

	Evident NC State Research Clusters (OmniViz Analysis) 2009 to Oct. 2014	NC State Research Funding Awards (2008 through November 2014)	Patents NC Universities and Industry 2009 to Oct. 2014	Dedicated NC State Research Centers or Stated Thrusts	Interviews Validated as an Area of R&D Strength or Concentration
Microbiology	√ 81 Microbial Growth & Inhibitors	√√ $20.3 million Plant & Microbial Biology*	273 Pesticides, herbicides, biocides and plant growth regulators (formulations)*	BTEC Facility (industrial microbiology) Masters of Microbial Biotech program	Identified by external stakeholders as a very high priority area for building focus especially in plant-microbe interactions. Potential RTP regional strength if combine NC State, UNC and Duke activities + industry. Microbiology within the Dept of Plant Biology and Microbiology primarily focused in biofuels, nutritional compounds and bioremediation + systems biology capabilities.
Biofuels and Industrial Biomass	√√ 81 Cellulosic Biomass 59 Bio-ethanol 35 Biopolymers 27 Bio-oils	√√ $25.5 million Biological & Agricultural Engineering		YES Focused extension program and research in Biological and Agricultural Engineering Department.	A defined focus within Biological and Agricultural Engineering at NCSU, building on significant capabilities in industrial biotechnology. Work in biodiesel and ethanol. Active extension emphasis area. Biofuels Center of NC and NC Bioenergy Research Initiative have awarded grants to horticulture, crop science and soil science departments in CALS at NC State.
Advanced Analytics	√ 117 Analytical Methods			YES Institute for Advanced Analytics (IAA) Bioinformatics cluster hire initiative	IAA operating an interdisciplinary institute focused on complex methods and tools for large-scale data modeling Major companies in NC to connect with, e.g. SAS, IBM Strong statistics group within CALS (inter-college). Applied mathematics strong in College of Science. Strong GIS/spatial analytics capabilities at university, plus a focus area for cluster hires/

Multiple additional areas of research focus were identified either through interviews or notation of the presence of a research center but were not readily available by referencing the Omniviz or publications analysis. These additional areas include:

- **Sustainable Agriculture.** NCSU and CALS have a long-standing program of research and extension activity in sustainable farming systems and community-based food systems. CALS has a dedicated center and research farm focused on this research theme, with the Center for Environmental Farming Systems.

- **Engineering at NCSU.** With almost 300 tenure track faculty, the College of Engineering at NCSU is both large and diverse. Several research focus areas within the College of Engineering have relevance to development of applications in agriculture, for example: biosensor development; biobased materials; remote sensing, machine learning and autonomous vehicle relevance to precision agriculture. The College is strong in materials science and materials engineering.

- **Textiles.** Presence of a world-leading program in textiles.

- **Physics and Chemistry** with robust thrusts in photonics and photovoltaics.

- **Veterinary Medicine.** Ranked number 3 in the nation by US News, the College of Veterinary Medicine has intensive programs in research and extension. Some key research areas of emphasis include comparative medicine and translational biology, chemical toxicology and pharmacokinetics, and marine sciences. Significant work is performed in support of the State's livestock industry, but there is also an evident research focus on companion animals and horses.

E. Field Research Assets

While the main NC State campus in Raleigh is certainly a key hub for NC State agbioscience research, it is far from being the only location of NC State's intensive basic and applied research in agricultural sciences. The North Carolina Agricultural Research Service has an annual research expenditure exceeding $120 million, with over 1,700 total personnel engaged in research and research support services. Among the key assets of this system is a highly distributed set of research stations and extension centers covering various agricultural environments across North Carolina. These geographically dispersed state assets include:

- 18 research stations (6 owned by NC State and 12 by the NC Department of Agriculture and Consumer Services)
- The Center for Environmental Farming Systems in Goldsboro, operated by NC State, the NC Department of Agriculture and Consumer Services, and NC A&T State University
- 10 field labs, with 6 close to the main campus in Raleigh and others at Butler, Aurora, Hillsborough and Wallace
- The Plants for Human Health Institute at the North Carolina Research Campus in Kannapolis.

Having such a geographically dispersed system of field research assets, in combination with North Carolina's diverse agronomic zones and associated characteristics, gives NC State capabilities for field research that are duplicated in very few other U.S. or global locations.

The research core competencies of NC State, in concert with evident industry R&D and agriculture thrusts in the state, are considered in the next chapter to identify specific platforms of opportunity for NC State to pursue with the Plant Sciences Initiative.

IV. Aligning NC State, Industry and Agricultural Opportunities for Plant Science-Based Economic Development in North Carolina: Platforms for Advancement

A. The Concept of Development Platforms

While NC State demonstrates a broad variety of competencies in, and related to, plant sciences (as seen in the previous chapter), it should be noted that not all research core competencies are created equal in terms of their overall scale, their associated commercialization potential or their line-of-sight to major markets thus, several factors need to be taken into account when moving from core competencies to actual development platforms (core interdisciplinary programmatic themes).

The state of North Carolina certainly anticipates tangible economic development benefits to be realized from investment in the Plant Sciences Initiative (PSI) and the proposed Plant Sciences Building (PSB) on the Centennial Campus. Similarly, other key stakeholders in North Carolina (including established and emerging agbioscience companies, agricultural producers and other participants in the agricultural value-chain) have expectations regarding the initiative and its delivery of discoveries, innovations and practice advancements that will have a tangible impact on industry and agriculture.

Ideally a **PLATFORM** for agbioscience-based development should meet several key threshold criteria:

- Be built on a cluster of competencies with a significant base of R&D and established clusters of faculty or centers to build upon.
- Contain a clustering of existing businesses and institutions with interests in similar R&D areas, products, markets, feedstocks, processes, supply chains or technologies.
- Represent a platform around which public/private partnerships may be developed to promote shared interests and encourage the development of a favorable operating environment for platform growth.
- Be associated with a significant potential market with strong growth prospects and an achievable line-of-sight for bringing new products and technologies to serve market demands.

B. Potential Platforms for Consideration

Taking into account the quantitative and qualitative analysis of NC State core competencies, the assessment of industry and agriculture in the state, in combination with the input of key stakeholders across the value-chain a number of areas were identified by Battelle as potential candidates for interdisciplinary thematic platform development within the Plant Sciences Initiative. Eight themes emerged as a potential fit between NC State competencies (established or emerging), industry interests, relevance to North Carolina agriculture and global food security, and line-of-sight to significant markets and opportunities, including:

- **Plant Engineering** encompassing the modification of plants to improve yield and other functional characteristics. This may be accomplished through traditional breeding,

marker assisted selection and/or genetic modification techniques that target improvement of intrinsic yield, tolerance to crop protection chemicals (e.g. herbicide tolerance traits), or resistance to pests and resistance to abiotic stress conditions.

- **Agri Symbiotics** focusing on advancing scientific understanding of the beneficial biological interactions between plants and other organisms (especially microbes, but also including fungi and invertebrates), and applications of knowledge of symbioses to advance agricultural yield.

- **Biologics for Crop Protection** including research into biologicals (active substances derived from natural sources such as plants, fungi or bacteria) or entire organisms that impart protection to plants from disease/loss-causing pathogens, fungi and pests, or to abiotic stress conditions.

- **Precision/Prescription Agriculture Technologies** -- Precision agriculture uses precise positioning and sensor technologies, in combination with data analytics, to evaluate crop development and the conditions of the production environment in real-time and to prescribe actions or the specific application and dosage of inputs to enhance yield.

- **Integrated Agronomic Systems** -- focusing on developing holistic understanding of agronomic systems and the development of integrative, multi-component yield enhancement approaches.

- **Plant Output Traits and Nutritional Phytochemistry** -- In addition to increasing yield, agricultural scientists may also focus on plant improvements focused on output traits such as the nutrition profile of a plant or positive sensory characteristics such as taste, smell or texture. Plants represent sophisticated chemical production organisms that may be engineered to produce substances that, in addition to nutrition applications, may also be used for applications as diverse as vaccine production, biopharmaceutical production, or the production of industrial chemicals.

- **Big data and analytical sciences** Experimentation and research in most areas of agbioscience, including most of the areas bulleted above, generate vast quantities of data. Elucidating meanings, functions and interactions embedded within millions or billions of genetic or phenotypic data points, for example, mandates not only having high-performance computational horsepower and data storage systems but also requires the presence of deep expertise in mathematical modeling and simulation, informatics and data analytics, advanced statistical analysis and the basic programing and analytics capabilities to support investigations. **Because of the ubiquitous requirement for big data analytics across other potential platforms, 'big data and analytical sciences" is perhaps better considered as a cross-cutting support requirement, rather than a freestanding platform of its own.**

- **Agbioscience Communications** -- Agriculture and the sciences that support it are complex and relatively poorly understood by the general public, elected officials and other external parties. A lack of understanding, or the presence of misinformation regarding agricultural practices and products, is not a benign condition because external parties influence policies, regulations, consumer demands, etc. that may have a powerful impact on agricultural practices and technology and innovation deployment. It is important that the practice of agriculture and the agbioscience that supports it be communicated effectively to external parties to assure rational, science-based decision making in the public sphere (either in terms of consumer decisions, or government actions).

While the above represent potential thematic platforms for consideration, in Battelle's experience there are too many. Typical science- and technology-based development initiatives will, at most, have three or four platforms to focus on ideally with synergies across the platforms

that will leverage shared resources and disciplinary capabilities. In meetings with the big agbioscience companies within North Carolina (most notably with BASF, Bayer CropScience, Syngenta and Novozymes) it was generally noted that to be "believable" the Plant Sciences Initiative will need to be focused to be excellent, and not try to be all things to all people. Battelle concurs with this input. The expressed needs and interests of a large variety of stakeholder groups were collected during Battelle interviews, and it is clear that there would be no way that an initiative can be adequately focused yet still meet all the needs of such diverse stakeholders.

Some tough choices have to be made in order to develop an initiative that:

- **Is focused enough** to have a critical mass of interdisciplinary expertise brought to bear to make significant progress on a relatively compact number of important basic and applied agbioscience questions
- **Advances the study of selected frontier areas of plant science** as identified by major external bodies (such as those identified in the decadal vision established by the American Society of Plant Biologists)
- **Presents a potential pathway towards the development of commercial technologies** and products that would be a fit to established and emerging clusters of corporate agbioscience capabilities in North Carolina yet, includes major work at the pre-competitive level allowing multiple corporate stakeholders to participate collaboratively
- **Makes significant progress in developing innovations and solutions relevant to the grand challenge of advancing global food security**
- AND, ideally, shows promise for **translation into potential applications in North Carolina agricultural production.**

Generating Job Growth for North Carolina

It should be noted that across the U.S. agricultural output has increased substantially in recent decades while employment in agricultural production has continued to decline. Overall this leads to the conclusion that while agricultural productivity will continue to grow, the primary production sector (farming) is unlikely to be a source of major job growth in individual U.S. states, including North Carolina.

The real promise for significant growth in high-paying jobs is contained within the advanced agbioscience sector the sector developing and producing the advanced technology-based inputs that farming will need to achieve global food security.

North Carolina has the opportunity to leverage its existing base of advanced agbioscience companies, in combination with a major investment in academic plant science (through the proposed Plant Sciences Initiative), and its diverse agronomic environment (for R&D field support) to become THE global leader in advanced agbioscience industry. While clichéd, the opportunity is real to make North Carolina the Silicon Valley of agbioscience.

NC State is already, as the 1862 land-grant University for the State, a provider of diverse R&D and extension support for North Carolina's agriculture sector. This University commitment to supporting the needs of the in-state agriculture sector is important to maintain and sustain however, it does not mean that mission has to be the primary focus of the new Plant Science Initiative. The larger opportunity for North Carolina is to make the state THE global leader in advanced agbioscience particularly in the R&D and production operations of agricultural technology companies. The global food challenge is such that an all but assured market exists for innovations, technologies and products that advance agricultural yield and other key characteristics of agricultural production.

Achieving incremental increases in North Carolina agriculture is a noble and valid goal, <u>and should indeed remain a core component of the operation of CALS</u> research, education and

extension activities. **Overall It is not, however, a big enough vision for the Plant Sciences Initiative. Rather the goal of the initiative should be to continue the successful advancement of North Carolina as the recognized hub of the advanced plant science sector, globally. It should work to add a core asset to the plant science mix in North Carolina that cements the State's position as a, if not the, global leader in advanced agbioscience providing a platform for continued growth in agbioscience-based economic development. It should fill the gaps created by aging agbioscience infrastructure at NC State, to propel the institution to the forefront of advanced agbioscience capabilities and collaborative infrastructure. It should also serve as a signature attractor for the best and brightest minds in plant sciences.**

To this end, Battelle recommends that the Plant Sciences Initiative be designed to address the "MUST HAVE" goals in the table below while, ideally being flexible enough to also leverage its infrastructure, assets and personnel to address the second column on the table.

MUST BE	WOULD BE BENEFICIAL IF
The PSI is focused enough to achieve truly "world-class" and, ideally, "world leader" status in three major thrust areas in modern plant science.	Has the flexibility to address long-term fundamental scientific investigations, while also bringing together flexible interdisciplinary teams to address shorter-term identified challenges and applied research projects for NC stakeholders where warranted.
Provides a line-of-sight to reinforcing and further developing North Carolina as a powerful global hub for advanced agbioscience corporations (achieving robust cluster-based economic development) and the leading location for new agbioscience business development.	Makes advancements in technologies and practices that may be applied to improve productivity and output in North Carolina agriculture.

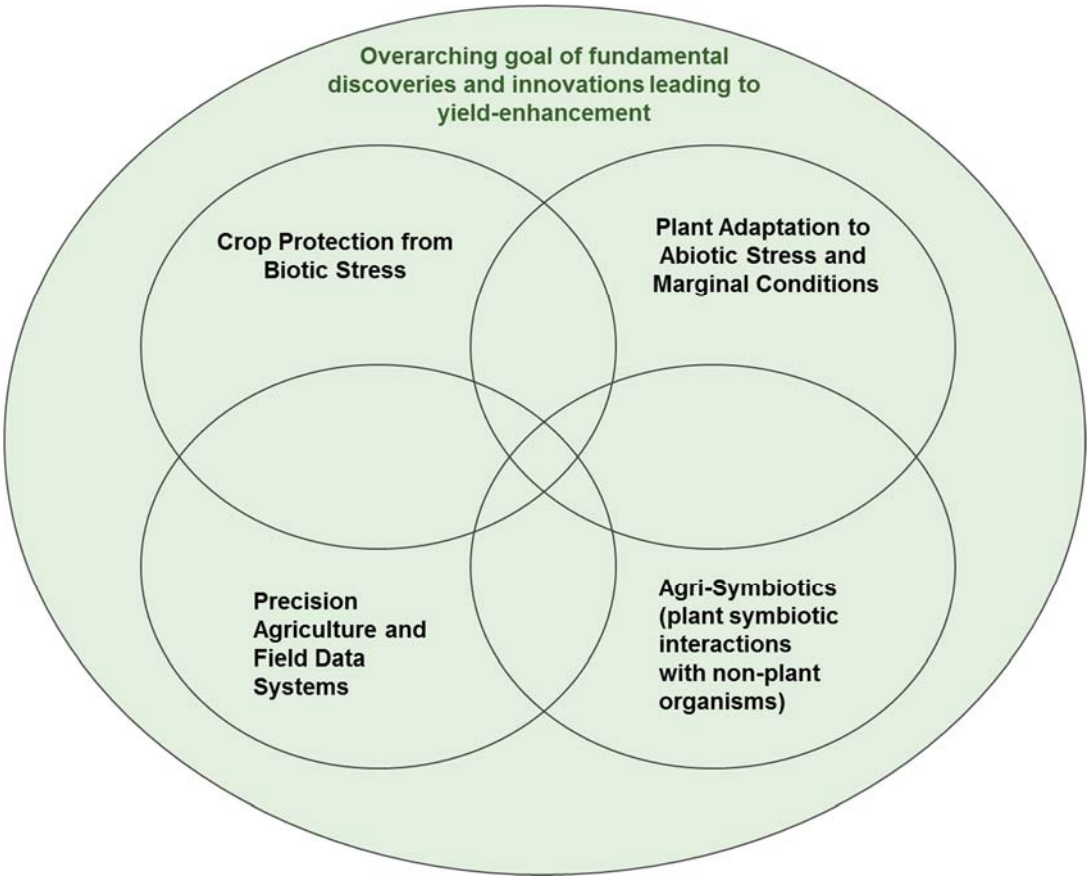
Battelle's review of opportunities leading to Plant Science development platforms for North Carolina includes:

- Consideration of grand challenges and frontier areas of plant science
- The existing and emerging core competencies in agbioscience contained within NC State, and surrounding complementary institutions
- Capabilities and assets at NC State, outside of CALS, that may be leveraged to advance interdisciplinary plant sciences
- Input from key stakeholder groups.

C. Recommended Platforms for the PSI/PSB

Taking these informational resources into consideration, Battelle concludes that the Plant Sciences Initiative should focus its efforts on a core, overarching theme of "agricultural yield increase" with an emphasis on four interdisciplinary thematic focus areas (platforms). The recommended platforms are shown on Figure 20 and further detailed in individual summary tables that follow.

Figure 20: Recommended Plant Sciences Initiative Development Platforms



Work within each of the four platforms should be focused on:

- Advancing fundamental science in each area
- Developing analytical tools, instrumentation and technologies that facilitate R&D in each area
- Developing collaborative partnerships with industry to facilitate the translation of discoveries and innovations into commercial solutions
- Translating knowledge and innovations into applications that benefit North Carolina agricultural producers as early adopters
- Producing graduate students and post-docs with significant "T" trained skills. Graduates who have achieved cross-disciplinary training across the platforms, and have received focused mentoring in a key faculty lab within one of the platforms.

Platform 1: Crop Protection from Biotic Stress

Description of Platform	In agriculture, biotic stress is stress to plants caused by pests (the collective term for microbes, weeds, insects, and other organisms that have a negative impact on plant health and yield). Preventing and controlling the impact and spread of pests is a key ongoing challenge for agbioscience. Globally, an average of 35% of crop yields are lost to pre-harvest pests.[21] A 2010 study in the State of Georgia, for example, estimated plant pathogen-related losses alone at 16.5%.[22] Addressing biotic stress agents is an ongoing battle for agronomists because of the capability of natural organisms to evolve resistance to pesticides, herbicides and control practices. Increasingly, integrated management practices are deployed as pest organisms develop resistance. Integrated practices include biological controls, chemical controls, cultivation practices and genetics (for breeding resistance into the crops themselves). Big issues in agriculture likely to be addressed by this platform may include: • Expanding basic knowledge of the genomics of pathogenic organisms, the mechanisms by which they cause plant diseases, and their ongoing molecular evolution. • Identification of crop traits associated with pest resistance and traits for tolerance of pesticides, herbicide and other crop protection chemicals. • Development of biological or chemical fungicides, herbicides and other pesticides for crop protection. • Improvement of integrated pest management strategies.
Relevance to NC Agbioscience Industry	Multiple companies in North Carolina are engaged in the development of crops incorporating disease and other pest resistance traits. Similarly, several of the large agbioscience corporations in North Carolina are active in R&D and production of agricultural chemicals and biologicals to combat plant pests. Companies relevant to this space include all the major agbio companies (Syngenta, Bayer CropScience, BASF, and Monsanto) plus Novozymes. Also potentially engaged would be agrichemical companies such as Arysta LifeScience, Cheminova USA and JABB of the Carolinas. Small companies such as Ecoblend LLC, MycoSynthetix, and TyraTech, for example, also operate in this space.
Relevance to NC Agricultural Production and Value-Chain	North Carolina, with its diverse agronomic conditions and crop profile sees its agricultural production susceptible to a wide-range of pests. Input received from commodity groups confirms their ongoing interest in NC State research focused on finding solutions for combatting established and emerging plant pests in the state.
Fit to NC State Core Competencies	79 NCSU faculty identified through review of faculty and department websites with research capabilities and interests in this research area (see Appendix C) Relevant OmniViz-identified research clusters include: • Crop genetic engineering for disease resistance (256 publications)

[21] Dehne HW, Oerke E, Schonbeck F, Weber A (2004). Crop production and crop protection: Estimated losses in major food and cash crops . Elsevier: Amsterdam.
[22] Georgia Plant Disease Loss Estimates, 2010. http://extension.uga.edu/publications/detail.cfm?number=AP102-3

	• Genetic profiling of plants and plant diseases (441 publications) • Weed management and herbicides (182 publications) • Insects pests adaptation, resistance and population genetics (275 publications) • Microbiology, microbial growth and growth inhibition (91 publications) • Mycotoxins and producing organisms (19 publications) • Pesticide efficacy (10 publications). Excellence in fungal research is centrally organized at NC State through the Center for Integrated Fungal Research (CIFR). CIFR is focused on "discovery and analysis of complete gene sets from major plant pathogenic and industrially important fungal species"; and "the understanding of genome organization, population biology and fungal evolution; whole genome reconstruction; and comparative and global functional analyses to decode the molecular basis of disease caused by fungal pathogens."[23] The Center contains a cluster of seven principal labs. The Department of Plant Pathology within CALS, incorporates CIFR, but also has notable multi-investigator research thrusts in: • Host-parasite interactions and genomics • Microbial ecology and epidemiology • Diagnosis, forecasting and disease management. The USDA Plant Science Research Unit, contained within NC State is active in research pertaining to diseases of corn, wheat and small grains. The Department of Entomology has quite diverse research foci. There is an evident focus on applied entomology for crop protection in field crops, fruits and vegetables, turf and ornamentals. Genetic pest management, insect genomics and molecular biology also feature in the Department's research thrusts. Work on weeds is primarily conducted within the CALS Crop Science Department and the Department of Horticultural Science. Diverse competencies are demonstrated across research in terms of herbicide tolerance and herbicide efficacy, and in alternative weed control technologies and strategies.
Fit to Decadal Vision for Plant Sciences	This platform is specifically relevant to the goal of defining "how plant species have naturally adapted to stressful or extreme environments, specifying biological mechanisms that can be harnessed for agriculture." Also related to goals to "link genome to performance during environmental change and biotic interactions" and to "understand the dynamics of plant communication, from the intracellular to the interorganismal scale."
Potential Products and Technologies	• Improved pesticides • Biological control products • Novel resistance traits for improvement of crops • Disease diagnostics and management tools • Control product application/precision-application systems • Integrated pest management and decision-support systems.

[23] NC State Department of Plant Pathology. http://plantpath.cals.ncsu.edu/research/center-for-integrated-fungal-research-cifr/

Key Departments in CALS	• Plant Pathology; Entomology; Applied Ecology; Biological and Ag Engineering; Crop Science; Horticultural Science; Molecular and Structural Biochemistry; Plant and Microbial Biology; Soil Science; Ag/Resource Economics, and Food, Bioprocessing and Nutrition Sciences. • Extension • Multiple NC State agricultural experiment field stations
Potential External- to-CALS Collaborations for Interdisciplinary Engagement	• College of Engineering for participation in engineering solutions for rapid diagnostics and pathogen detection. Also engineering would be relevant to potential engagement in application technologies for crop protection products. • Cross-college programs in information management, data analytics, statistics, mathematics and bioinformatics are highly relevant. • Potential linkages with other universities in North Carolina in areas of mycology and microbiology.

Platform 2: Plant Adaptation to Abiotic Stress and Marginal Conditions

Description of Platform	Both in North Carolina, and around the globe, significant agricultural land exists on the margins of sustainable agricultural productivity. Whether because of water, climate, soil fertility, salinity, occasional freeze pressures, or other factors, such land is under permanent or periodic abiotic stress conditions that limit agricultural crop yields. The pressures placed on agronomic land, in order to feed expanding populations, can lead to cascading problems with declining soil fertility, soil stability, water resource availability, etc. Similarly, the pressure to increase food production leads to more marginal lands being pressed into production. The potential impacts of global climate change will further influence agricultural land productivity and the likely frequency of abiotic and biotic plant stress events. Work in this platform to enhance plant yield in marginal environments is likely to have benefits along three principal pathways: 1) It will identify crops, crop cultivars and plant traits associated with enhanced performance in various conditions of abiotic stress providing opportunities for increasing agronomic yield on marginal lands. 2) It will identify traits associated with performance under stress conditions that may be incorporated into crop cultivars grown in high-productivity environments that may enable them to weather occasional unforeseen stress events, or provide for the development of new/improved crop cultivars using traits discovered for performance of crops on marginal land but that are also generally associated with resource use efficiency (e.g. requiring lower levels of water resource inputs, fertilizer applications, etc.) to perform at high yield levels 3) It will develop tools and technologies for measuring stress conditions and quantitative effects on plant phenotype and gene expression. In effect this platform will be able to address multiple major needs for current and future agriculture (especially under climate change conditions): • Drought tolerance and reduced water resource consumption • Frost and freeze tolerance • Salinity tolerance • Flood tolerance and other abiotic stress factors.
Relevance to NC Agbioscience Industry	Directly relevant to major agbioscience companies that produce commercial seed (e.g. Syngenta, Monsanto, Bayer CropScience, BASF, Benson Hill Biosystems) and to companies engaged in developing technologies for plant improvement, such as genome editing tools, automated phenotyping systems, etc.
Relevance to NC Agricultural Production and Value-Chain	North Carolina is in a “transition zone” for various crops existing at the southern extreme of northern crop ranges, and the northern extreme of southern crop ranges. North Carolina also contains diverse topography and soil types, providing a flexible testing environment for crops in marginal conditions. Innovations from this platform may be integrated into NC crops to improve yield or new crop varieties introduced to better handle abiotic stress conditions in specific NC growing environments.

Fit to NC State Core Competencies	35 NCSU faculty identified through review of faculty and department websites with research capabilities and interests in this research area (see Appendix C) Relevant OmniViz-identified research clusters include: • Plant drought resistance (46 publications) • Plant growth and development/plant physiology (501 publications) • Soil ecology and plant nutrition (360 papers) • Potentially also relevant: Forest ecosystem management and land cover (228 publications) Interviews identified long term strengths at NCSU in plant breeding (a diversified area of excellence with work across a broad range of food, feed, fiber and ornamental plants). Relevant NC State centers: • Center for Plant Breeding and Applied Genomics • AMPLIFY • USDA Ag Climate Science Center • NC State Weather and Climate Network • USGS SE Region Climate Research Center
Fit to Decadal Vision for Plant Sciences	This platform is specifically related to goals of defining "how plant species have naturally adapted to stressful or extreme environments, specifying biological mechanisms that can be harnessed for agriculture" and to "link genome to performance during environmental change." Developing systems for lab, greenhouse and field phenotyping will also facilitate the decadal vision goal to "expand plant phenotyping capabilities, particularly drawing upon advances in computation and robotics."
Potential Products and Technologies	• Novel commercializable traits for plant improvement. • Improved crops and crop cultivars. • Identification of new crops best suited to specific conditions. • Soil amendments and inoculants. • Automated field phenotyping equipment and analytical systems.
Key Departments in CALS	• Ag/Resource Economics; Applied Ecology; Biological and Ag Engineering; Crop Science; Horticultural Science; Molecular and Structural Biochemistry; Plant and Microbial Biology; Soil Science. • Extension. • Multiple NC State agricultural experiment field stations.
Potential External- to-CALS Collaborations for Interdisciplinary Engagement	• College of Engineering for participation in engineering solutions for automated phenotyping (requiring multi-disciplinary engagement in mechanical, electrical and computer engineering, sensors and biosensors, robotics, analytics, etc.). • Cross-college programs in information management, data analytics, statistics, mathematics and bioinformatics. • College of Science: Department of Marine, Earth and Atmospheric Sciences. • Duke University Benfey lab.

Both Platform 1 and Platform 2 intersect in building upon the considerable strengths of NC State in plant breeding and applied plant genomics. There is considerable breadth and depth of faculty

working in traditional breeding, marker assisted selection, trait identification and plant transformation. This is also an arena in which NC State has contributed in the technology development sphere in high throughput plant genotyping and marker-assisted technologies. An overarching opportunity (raised by faculty, industry and external stakeholder groups) is to cement a leadership position in linking lab genomics with field phenotyping data for trait identification and then to leverage university capabilities and regional industry capabilities in plant transformation to advance yield improvement based on adaptation to stress conditions. Advancing in the genotype-phenotype space lends itself strongly to interdisciplinary collaboration between CALS, the College of Engineering and the analytical sciences contained within the College of Sciences.

Platform 3: Precision Agriculture and Field-data Systems

Description of Platform	Precision and prescription agriculture uses precise positioning and sensor technologies, in combination with data analytics, to evaluate crop development, and the conditions of the production environment. This may be accomplished in real-time to guide actions including the specific dosage of inputs to enhance yield. As noted by the NC State Crop Science Department "site-specific management may be applied to such decisions as variety selection, weed and pest management, nutrient management, and irrigation."[24] Precision agriculture technologies provide the information and systems that allow producers to optimize the timing, amount, and placement of inputs (seed, fertilizer, pesticides, irrigation, etc.) for any given area of a field. This allows producers to maximize yield from the entire field at the lowest possible cost. A core technology used in precision agriculture is GPS-enhanced guidance and GIS. GPS location information is often augmented by correctional technologies (Wide Area Augmentation System (WAAS) or Real Time Kinematic technology (RTK), for example); to provide steering and application capabilities down to centimeter precision. Advancements in sensor technologies, wireless data transmission, remote sensing, unmanned/autonomous vehicles, robotics, imaging analysis, machine learning, high speed data analytics, etc. hold promise for the development of agricultural production equipment, and field research equipment, that can significantly increase agronomic yield. The gathering of field data for research, especially crop phenotype data, is an important challenge to be met providing opportunities for significant interdisciplinary collaborations between CALS and the College of Engineering. The current market for precision agriculture in the U.S. is estimated to be circa $1.5 billion. Some market researchers view it as a very fast moving market with expected compound annual growth of over 13% from 2013 to 2018, while others view the market growing at a more modest pace of under 7%. 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.[25] [26]

[24] http://www.cropsci.ncsu.edu/PA.asp
[25] 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.
[26] The key uncertainties to 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 in whether

Relevance to NC Agbioscience Industry	The large agbioscience companies present in North Carolina each have interests and programs in, or related to, precision agriculture. BASF, for example, has a specific partnership with John Deere, while a recent NCBC conference on precision agriculture attracted participation from BASF, Syngenta, Monsanto, Novozymes and other leading companies. To-date, North Carolina has not developed into a major hub for precision ag technology development, and small business development in this arena in North Carolina is limited. However, the presence of the RTP region universities, together with regional IT/computing companies, data analytics companies and agbioscience companies bodes well for an environment where strategic partnerships could evolve to advance this sector in the state.
Relevance to NC Agricultural Production and Value-Chain	Precision agriculture technologies will have direct application to improving productivity in North Carolina agriculture. In addition, precision field phenotyping and other precision field research tools will enable CALS scientists to improve identification and testing of traits and achieve enhancements in yield across NC crops.
Fit to NC State Core Competencies	60 NCSU faculty were identified through review of faculty and department websites with research capabilities and potential interests in this research area and associated technologies (see Appendix C). Potentially relevant OmniViz-identified research clusters: • Plant growth, metabolism and production (501 publications) • Water resources, run off and soils (67 publications) • Soil ecology and plant nutrients (360 publications) • Analytical methods and modeling (52 publications) This platform complements one of the NCSU cluster hiring focus areas in geospatial analytics. Here, NC State has been making strategic hires to develop unique interdisciplinary research and a Ph.D. program in "geospatial analytics to address the extensive research needs in both basic geospatial sciences and the corresponding computer science and mathematical modeling disciplines. These faculty additions will allow NC State to significantly expand its research initiatives in spatial analytics and algorithmic development and computation, mobile GIS, spatial data mining, and remote sensing."[27] AMPLIFY (Agrosphere Modeling for Producing Large Increases in Food Yield) is a new initiative at NC State focused on strategic public-private research partnership that brings together experts and key stakeholders from industry, academia and production to generate knowledge and develop, test and disseminate new approaches, technologies and analytic tools to advance high-yield sustainable agriculture. AMPLIFY partners will collectively plan, coordinate and conduct research with transdisciplinary teams of scientists from across NC State's campus, and then will test, refine and validate promising concepts at a technology-rich AMPLIFY flagship site in Kinston, at 17 additional research stations throughout North Carolina and at partner-growers' farming operations. There is obviously synergy between this initiative and a precision agriculture and field-data systems platform.

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 products 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.

[27] http://workthatmatters.ncsu.edu/geospatial-analytics/

	It should be noted that the College of Engineering at NC State contains significant expertise in research fields that may be applied to an interdisciplinary center in precision agriculture. This includes multiple faculty in Electrical and Computer Engineering, Computer Science, and Mechanical and Aerospace Engineering with expertise in: • Artificial intelligence, intelligent agents, computational intelligence and machine learning • Image analysis and computer vision • Robotics and mechatronics • Algorithm development for autonomous operation • Communications and signal processing • Unmanned aerial vehicles and remotely piloted vehicles. Relevant NC State centers: • AMPLIFY • Geospatial Analytics • USDA Ag Climate Science Center • NC State Weather and Climate Network • USGS SE Region Climate Research Center • Multiple centers and research focus areas within the College of Engineering.
Fit to Decadal Vision for Plant Sciences	Field data systems are a direct fit to the Decadal Vision to "expand plant phenotyping capabilities, in particular drawing on advances in computation and robotics." It is noted in the decadal vision that: "Linking traits to genome features requires large scale gathering of phenotype data. This, in turn, requires advancements in phenotype data gathering technologies hence the need to integrate engineers, robotics expertise, sensor and imaging experts, computer scientists, etc. Automated, robotic lab and field phenotype devices needed to achieve much denser coverage of plant data."
Potential Products and Technologies	• GIS, GPS and precision spatial positioning systems • Guidance systems • Variable rate application systems • Equipment mounted and field sensor systems • Remote sensing systems and aerial vehicles • Robotic/autonomous field phenotyping and data gathering systems • Data analysis tools and decision support systems • Engineering and design of low cost precision agriculture technologies for small farms.
Key Departments in CALS	• Biological and Agricultural Engineering; Applied Ecology; Crop Science; Horticultural Science; Entomology; Plant Pathology; Soil Science; Animal Science; Poultry Science; Ag and Resource Economics; Ag and Extension Education.

Potential External- to-CALS Collaborations for Interdisciplinary Engagement	• College of Engineering, especially:
	  • Department of Electrical and Computer Engineering
	  • Department of Computer Science
	  • Department of Mechanical and Aerospace Engineering
	• Cross-college programs in information management, algorithm development, data analytics, statistics and bioinformatics.

Platform 4: Agri-Symbiotics

It should be noted that of the four recommended platforms, this platform represents the one in which NC State is currently lacking in sufficient faculty depth. To achieve its potential will require investments in new faculty hires. It is, however, seen as <u>a key area for collaborative industry-university research partnerships moving forward, and the agbioscience companies in North Carolina strongly encourage a focus on this platform within the NC State Plant Sciences Initiative</u>. This is also a platform in which UNC and Duke should be engaged for collaboration in the Initiative given their complementary strengths.

Description of Platform	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 fast-emerging field of inquiry with considerable "room to operate" and opportunities for pre-competitive collaborative research between academe and industry. It is inherently multi-disciplinary, 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. Big issues in agriculture likely to be addressed by this platform may include: • Expanding basic knowledge of plant-microbe interactions and the impact on plant growth, metabolism, nutrition uptake, disease and pest resistance, resistance to abiotic stress, etc. • The development of biological inputs for agriculture for the control of pests and diseases (biological control agents), providing an alternative to agricultural chemicals. • The development of inoculants, probiotics, seed coats and other technologies to enhance the yield potential of crops.
Relevance to NC Agbioscience Industry	Interviewees identified this to be an area of great interest for large agbioscience companies in NC (Bayer CropScience, Syngenta, BASF, etc.), a core thrust of Novozymes operations in NC, and an area that has spurred the development of start-up agbioscience companies, such as AgBiome and Mycorrhiza Biotech LLC.
Relevance to NC Agricultural Production and Value-Chain	With a focus on yield enhancement through biological inputs to production, this platform has the potential to develop affordable, sustainable biological products for application in diverse areas of North Carolina agriculture. Value may be added to crops through the development of yield enhancing technologies compatible with organic agriculture, and environmental benefits may be realized through reduced need for chemical fertilizers or chemical pesticides and herbicides.
Fit to NC State Core Competencies	37 NCSU faculty were identified through review of faculty and department websites with research capabilities and potential interests in this research area (see Appendix C). For the most part these faculty are focused on plant-pathogen relationships and effects on plant health, and there is much more limited capability currently within the university in beneficial plant-microbe interactions and fundamental inquiries regarding plant symbiotic relationships with other organisms.

	Relevant OmniViz-identified research clusters: • Microbiology, microbial growth and growth inhibition (91 publications) • Soil ecology and plant nutrition (360 publications)
Fit to Decadal Vision for Plant Sciences	This platform specifically relates to goals to "link genome to performance during environmental change and biotic interactions" and to "understand the dynamics of plant communication, from the intracellular to the interorganismal scale."
Potential Products and Technologies	• Novel traits for plant improvement that encourage formation of beneficial symbiotic relationships. • Custom microbial communities for application as seed coats or by other application modalities. • Biological control agents (sprays, inoculants, etc.) with highly targeted effects as insecticides, nematocides, fungicides, herbicides and as treatments for plant pathogens. • Soil amendments and improvement technologies. • Tools and technologies for improving beneficial plant symbioses with insects and nematodes. It should be noted that agents may result from work in this platform that may also be beneficial in animal/livestock agriculture for pathogen control, pest control, enhanced litter utilization, etc. It is also likely that discoveries resulting from this platform may be supportive of other biotechnology areas in North Carolina (medical, industrial and environmental).
Key Departments in CALS	• Ag/Resource Economics; Applied Ecology; Biological and Ag Engineering; Crop Science; Horticultural Science; Molecular and Structural Biochemistry; Plant and Microbial Biology; Entomology; Soil Science; Plant Pathology. • Extension. • Multiple NC State agricultural experiment field stations.
Potential External- to-CALS Collaborations for Interdisciplinary Engagement	• College of Engineering for participation in engineering solutions for the application of biological control agents and beneficial microbes and other agents via seed coat application, spraying, soil injection, etc. Also, could be engineering needs in rapid analysis of soil and plant microbiomes. • NC State BTEC facility in bio-manufacturing and process development for biological products. • Cross-college programs in information management, data analytics, statistics and bioinformatics. • College of Science: Department of Biological Sciences (with microbiology, genetics and zoology); plus Chemistry; Mathematics and Statistics. • UNC Chapel Hill (Dangle lab).

D. Cross-Platform Interdisciplinarity

By design, the platforms recommended by Battelle have some overlap with one another providing for not just interdisciplinarity within each platform, but also cross-platform interactions and supports. The four platforms each contribute to an overarching theme of **using science for generating discoveries and innovations that may be applied to agricultural yield enhancement.** Ideally, through this approach of selecting platforms that intersect with one another there is opportunity for the "whole to be greater than the sum of its parts" through encouraging holistic systematic thinking across approaches to yield improvement. There is also the opportunity for key existing faculty, and faculty recruits, to have cross-cutting capabilities in support of more than one platform. Similarly, certain instrumentation and key infrastructure assets may serve double-duty across platforms for example, genomics, plant transformation, phenotyping, data analytics, growth chambers and greenhouse facilities (among others).

By having a central unifying theme of agricultural yield enhancement, the Plant Sciences Initiative and Building will be able to evaluate potential faculty participation in interdisciplinary teams for potential contribution toward this overarching mission.

Platforms were also identified with an eye towards opportunities to embrace participants from both within and outside CALS. The proposed location of the PSB on the Centennial Campus, in relatively close proximity to the College of Engineering investments, should provide inherent advantages from cross-college interactions.

> "The overarching objective of the *Decadal Vision* is to build across disciplines including plant science, chemistry, engineering, and computational sciences to advance research through the continuum of observational to predictive to synthetic. Among the possibilities within reach are improving the agronomic properties of crop varieties through, for example, rapid deployment of resistance to emerging pathogens; designing plants for new functions; using native plants as "libraries" to harness their adaptive mechanisms and novel products for medicine and industry; and understanding the roles and regulation of plant genes in thousands of species."
>
> Am. Soc. Of Plant Biologists. "Unleashing a Decade of Innovation in Plant Sciences: A Vision for 2015-2025."

E. Other Opportunities for CALS and the PSI

CALS is a large college with a broad diversity of faculty and associated research capabilities. The above recommended platforms have been scoped based on evident core-competencies together with regional industry capabilities and line-of-site to market and, as noted above, support one another under a crop yield theme. There are other areas of interest at NCSU in agriculture that are important and notable but perhaps not a direct fit to the Plant Sciences Building vision at the present time. Chief among these additional opportunity areas are:

- **Functional nutrient expression for food and feed** (Output traits and associated breeding/plant improvement). In addition to increasing yield, agricultural scientists may also focus on plant improvements focused on output traits such as the nutrition profile of a plant or positive sensory characteristics such as taste, smell or texture. Plants represent sophisticated chemical production organisms that may be engineered to produce substances that in addition to nutrition applications may also be used for applications as diverse as vaccine production, biopharmaceutical production, or the production of industrial chemicals. NC has seen the emergence of company operations focused on the use of plants as production vehicles for biopharmaceuticals, vaccines and other chemicals of value (e.g. Medicago). There are certainly capabilities in the area of functional nutrient expression at NCSU and CALS, including the investment in the Food for Health initiative focused in Kannapolis. Work along this theme in North Carolina could have several benefits:

- Producing crops with enhanced functional characteristics may increase demand for, or the value of, specific niche crops.
- The existing investment in Kannapolis is focused on advanced nutrition and understanding the clinical benefits of plant-based compounds in human nutrition and health. The development of plant improvement for the production of identified clinically beneficial nutrition compounds would comprise support for an advanced nutrition value-chain in NC.
- The production of industrial or biopharmaceutical compounds may represent an alternative application for tobacco in NC.
- Value-added crops with enhanced functional characteristics in terms of health, nutrition or sensory characteristics.
- Feed crops with enhanced nutrition profiles to increase productivity in livestock agriculture.
- Production of valuable phytochemicals for industrial and biomedical applications.
- Potential for linkage to existing NC companies such as Medicago USA, Bent Creek Institute, SoyMeds, TechCrops International and Nova Synthetix.

- **Animal Science, Livestock Agriculture and Poultry Science**. In terms of overall economic output, animal agriculture constitutes the largest component of production agriculture in North Carolina. NC State is very active in work with the sector through CALS (especially within the Animal Science and Poultry Science Departments) and the College of Veterinary Medicine. Other CALS departments also lend support to the animal agriculture sector with faculty in the Department of Applied Ecology working on air and water quality in relation to livestock agriculture, faculty in Biological and Agricultural Engineering working on animal agriculture systems and technologies, and researchers in Crop Science examining opportunities for the introduction and improvement of feed grains and oil seed crops as livestock feed. Certainly a strong argument can be made for livestock feed and nutrition, gut microbiology, waste-as-fertilizer, etc. being considered a constituent element of a Plant Sciences Initiative focused on improving yield. Just within the Animal Science and Poultry Science departments at CALS, Battelle identified 22 faculty with primary research interests in feed and livestock nutrition.

- **Agbioscience Communications.** Agriculture and the sciences that support it are complex and relatively poorly understood by the general public, elected officials and other external parties. A lack of understanding, or the presence of misinformation regarding agricultural practices and products, is not a benign condition because external parties influence policies, regulations, consumer demands, etc. that may have a powerful impact on agricultural practices and technology and innovation deployment. It is important that the practice of agriculture, and the agbioscience that supports it, be communicated effectively to external parties to assure rational, science-based decision making in the public sphere (either in terms of consumer decisions, or government actions). NC State University has engaged in a cluster hire initiative called “Genetic Engineering and Society”, with Fred Gould in Entomology at CALS the cluster coordinator. This cluster has an opportunity to engage more broadly with CALS and extension, other departments on campus, such as Business, Political Science, Public Policy and Communications, etc. to address opportunities to enhance fact-based agriculture communication strategies and strategies for combating misinformation. By integrating science and social science expertise, NC State could make important contributions to public dialog regarding regulatory affairs, public policy and other factors that may be highly influential in terms of the ability to leverage technologies for yield enhancement and growth in food security. It should be noted that this area of “agriculture communications” was emphasized by NC agbioscience companies, commodity groups, and other key stakeholders as an important component to sustaining a positive operating environment for agriculture in the state moving forward, and for enhancing future market opportunities for agbioscience-based innovations and associated economic development.

Sustainable agriculture and the limitation of negative agriculture impacts on the environment and natural ecosystems is also an area of core competency that is readily apparent in reviewing CALS. Battelle considers these capabilities to be fully compatible for integration into the overall work of improving agricultural yield and the individual efforts to advance scientific research and development under each of the four recommended platforms.

V. The Plant Sciences Initiative at NC State: A Signature Investment Opportunity for Advancing State Economic Development

A. Why the Plant Sciences Initiative and its Associated Plant Sciences Building is a "Must Do" for North Carolina

North Carolina has an extremely compelling case to make for agbioscience-based economic development, especially in plant sciences. It is currently one of a limited number of global locations that has: a) a strong, recognizable cluster of major agbioscience multinational operations, including R&D centers, b) is experiencing growth in agbioscience start-up business enterprises, c) is home to a top 10 land-grant university in terms of total agbioscience research funding, d) has a diverse agronomic environment suited to the growth and development of multiple crops, e) provides a quality-of-life and location conducive to the attraction of skilled human capital, f) has an overall policy and regulatory framework that is still generally favorable to agbiotech and the introduction of associated innovations, g) has developed the infrastructure, business support services and workforce development programs required to underpin the growth of advanced biotechnology industry.

Because of these favorable characteristics there is an opportunity for North Carolina in agbioscience that is perhaps matched by only a handful of other places globally. There is an open window of opportunity for the State to invest in building upon the strong foundation already present in North Carolina to make the State the core global hub for plant-based agbioscience R&D and associated business growth. The Battelle Technology Partnership Practice (TPP) performs science- and technology-based economic development (TBED) projects across the world and has directed the evaluation and design of TBED programs in most U.S. states but in no location so far has Battelle TPP seen such a promising convergence of assets poised to take advantage of large-scale expanding markets as North Carolina has in plant science and associated agbioscience.

The PSI and proposed Centennial Campus building is a singular opportunity for North Carolina to grasp. Expanding upon the advantages of North Carolina, it is evident that the opportunity builds upon a unique convergence of capabilities, market opportunities and assets:

1. **Agbioscience addresses an assured, fast growing global market**: As noted in the introduction to this report, feeding an expanding global population and meeting global food demand, while preserving natural resources, is an intense challenge for humankind. Estimates are that global food production will need to increase 70% by 2050 to meet population and wealth-driven demand and this will have to be achieved without increasing agricultural land acreage and water consumption. Agbioscience advancements are absolutely key to meeting this global challenge. The anticipated growth in agbioscience markets is well illustrated by the latest projection for the agricultural biotechnology sector just released by BCC Research[28] which notes that agricultural biotech reached global sales of $27.8 billion in 2014, and is anticipated to expand dramatically by 2019 to reach $46.8 billion (a very strong CAGR of 11% over five years).

2. **North Carolina is increasingly a hub for global agbioscience companies, especially in plant science**. North Carolina has already established a critical mass of operations of

[28] BCC Research. November 2014. "Agricultural Biotechnology: Emerging Technology and Global Markets." Accessed via Battelle subscription to BCC reports.

globally prominent agbioscience corporations to build upon. Home to major R&D operations of Syngenta, Bayer CropScience and BASF, together with a significant presence of Monsanto and fast-growing operations of Novozymes, the state especially in the RTP region has established a clear global hub of industry activity. In recent years, the North Carolina Biotechnology Center reports that the industry has invested more than $200 million in major agbioscience research facilities in the state, and Battelle's interviews with companies lead to a conclusion that more investment should be anticipated. It should be noted that, without fail, each of the major agbioscience companies in North Carolina interviewed by Battelle stated that they see the Plant Science Initiative building and investment at Centennial as a "must do" project for the state an investment that will be highly beneficial to the long-term support, growth and development of the cluster in the state both in terms of scientific research, novel innovations and educational output. Having a robust base of major agbioscience companies in North Carolina brings the added benefit of providing a key element in a localized ecosystem that makes it likely that, as new agbioscience business grow, they will benefit from local collaboration opportunities and be more likely to remain in North Carolina if they are acquired by major agbioscience corporations. One of the challenging aspects of technology-based economic development has been creating "sticky" environments environments where the benefits of the location outweigh benefits of relocation. The critical mass of commercial agbioscience activity in North Carolina provides definite advantages for sticky business development, and also provides a pathway for retaining skilled students graduating with advanced agbioscience degrees from NC State, NC A&T and other universities.

3. **There is limited domestic and international competition (but it is growing).** While agbioscience addresses large-scale global issues and is anticipated to experience significant growth into the foreseeable future, it is an area that has received far less economic development attention, and associated investment in technology-based economic development (TBED), than health sciences, medical devices or a number of other tech clusters. It is thus a more open market space, with more freedom for North Carolina to cement an early global leadership position. That is not to say that other U.S. states and global regions are not thinking about agbioscience opportunities or beginning to actively target agbioscience as a strategic sector. Recently, for example, Indiana launched its *AgriNovus* initiative bringing Indiana agri-business together with the State, Purdue University and statewide stakeholders to advance Indiana as a global hub for agbioscience business development. Iowa has similarly been pushing an agbioscience development agenda, especially in the arena of biofuels and biobased industrial products, and is pulling together key stakeholders under its *Cultivation Corridor* initiative. Saskatoon, in Canada, has made significant investments in agbioscience infrastructure and attracted R&D operations from several companies to its technology park, and the University of Guelph in Canada is similarly targeting agbioscience opportunities. Internationally, Australia has seen the opportunity and invested in significant new university-based infrastructure in Melbourne (with the state-of-the-art $250 million AgriBio facility at La Trobe University), and major investments at the University of Adelaide. Europe too, despite a challenging regulatory and public opinion environment for modern agbioscience and biotechnology, has several significant hubs of activity in the UK, the Netherlands, Denmark and Germany. All told, however, the competition from other locations in agbioscience is far lower than it is in areas such as biopharmaceuticals or medical technologies. It is also a space that has a more relatively compact number of world-class research universities active in research. A key attribute for North Carolina is that it further reinforces, and is reinforced by, existing state commitment to the biotechnology sector in general. There is significant overlap in life science technologies and opportunities across the domains of biomedical, industrial, environmental and agricultural biotechnology and a plant sciences initiative helps to further reinforce the biotechnology cluster for which North Carolina is well recognized globally.

4. **There has been a comparative lack of investment in state-of-the-art U.S. academic agbioscience facilities. Development of the PSI will be a high profile event in global agbioscience.** While the United States has had a long-standing record of excellence in

agbiosciences, firmly rooted around our major land-grant universities, it is an area of academic research that has seen relatively little investment in state-of-the-art research infrastructure. As noted in a recent report by Pardee, Alston and Chan-Kang[29] the "U.S. public agricultural research infrastructure is antiquated", and this situation is certainly the case at NC State where the last major new building investment in CALS occurred in the 1950's. Generally, whereas in biomedical sciences the quality of facilities seen on leading university campuses is at a level seen in industry, the same is not true in agbiosciences where industry has built state-of-the art laboratories and automated greenhouses, while academic agbioscience space investments have languished. Industry in North Carolina noted the lack of modern infrastructure and facilities at NC State in CALS in comparison to the University's investment in state-of-the-art buildings for engineering and other disciplines at the Centennial Campus. The comparison of the modern agbioscience facilities available to agbiotech company researchers at RTP, compared to current infrastructure within CALS is stark. The general lack of investment in U.S. academic agbioscience facilities, of course represents an opportunity for North Carolina to gain significant visibility and attention by developing the proposed PSI building on the NC State Centennial Campus. Other than the non-profit Donald Danforth Plant Science Center in St. Louis, the proposed PSI building would stand without peer among U.S. academic institutions serving to show both the commitment of NC to the sector, and a powerful attractor for academic research talent and industry collaborators. **Several of the major agbioscience companies interviewed by Battelle noted that, were the PSI building to be developed as envisioned, they would likely station research teams and post-docs in the building, sponsor joint research programs with the university, and potentially support the endowment of faculty positions.** Again, in Battelle's experience, the expressed support of external stakeholders to seeing the new building developed at NC State is unprecedented.

5. **Potential to attract leading minds in agbioscience.** R&D is an inherently human capital driven endeavor, and the attraction of innovative minds to a state is key to building a cluster of innovation activity. Given the relative lack of investment by other universities in state-of-the-art agbioscience research facilities, the proposed PSI building at NC State is likely to prove a powerful attraction vehicle for recruiting leading agbioscientists. This has proved to be the case at universities investing in modern biomedical research labs, and there is no reason to think the situation will be different in agbioscience. Indeed, the uniqueness of the NC State PSI building concept will likely be even more powerful than the more ubiquitous biomedical facilities. Having modern labs, research instrumentation, growth chambers and greenhouse facilitates, collaborative space, business incubation facilities, etc. will not only be attractive to faculty but also conducive to attracting the best and brightest graduate students and post-docs. Having the assets to attract skilled human capital is particularly important for ag-research when noting that "at least half of all U.S. ag researchers are over 55" and that "investing in people is an urgent priority."[30] It should also be noted that the traditional rather siloed department/single-discipline based education of plant scientists, and agricultural scientists in general, is seen as antiquated and increasingly "not fit for purpose" by industry leaders. Modern agbiosciences is increasingly "systems based" requiring more holistic understanding of agricultural systems and the role of individual technologies and actions within the system. Agbioscience companies noted to Battelle that they are looking for graduates who not only received specialized mentorship and training in a mentor's lab, but have also been engaged in interdisciplinary plant-science work that exposes them to an understanding of agronomy, soil science, plant physiology, plant pathology, plant breeding and a range of technologies and applications. The development of the envisioned PSI building as an interdisciplinary plant sciences hub, in combination with CALS planned reorganization of plant sciences out of siloes, directly supports the stated preferences of industry. **There is the potential through this initiative, for NC State to become the go-to**

[29] Philip G. Pardey, Julian M. Alston, and Conie Chan-Kang. April 2013. "Public Food and Agricultural Research in the United States: The Rise and Decline of Public Investments, and Policies for Renewal." AGree, Food & Ag Policy.
[30] Ibid

place for accessing graduates who have received the specific type of cross-discipline training that the agbioscience sector desires. Industry representatives interviewed by Battelle expressed a keen desire to be engaged in the development of an interdisciplinary plant science curriculum at NC State that will leverage the new building to be the leading institution in modern plant science "T" training.

6. **Place matters for facilitating collaborations and interdisciplinary research.** There is growing recognition of the benefits associated with interdisciplinary science and team science in addressing major scientific and technological challenges. Indeed there is growing acknowledgement that modern social and physical challenges, and some of the biggest questions in science, demand solutions that are beyond the remit and capabilities of any single discipline. While university policies and procedures can play a role in encouraging collaborations (for example , via the use of research seed funding for interdisciplinary proposals, and promotion and tenure policies that support collaborative work) there is also a strong argument to be made in regards to the importance of co-location and specialized facilities as engines of collaborative engagement. As noted by Harris and Holley[31], "by emphasizing interdisciplinary efforts through physical, structural, and cultural symbols, the university affirms the importance of such work to the institutional mission. Physical symbols serve as frames of reference for members of the organization, and embodiment of often abstract components of the institution's strategic plan or mission statement." **In other words, the construction of an interdisciplinary building to house interdisciplinary activity is key to developing an interdisciplinary culture** it communicates commitment to interdisciplinarity in a way that words or policies alone cannot. Harris and Holley conclude that "the first major implication of our findings is the need for collaborative teams to be housed in a single structure regardless of existing organizational structures. Physical proximity is a key element in creating an environment of communication an open exchange of ideas".[32]

> "'The growth of interdisciplinarity as a guiding principal for academic programs, institutional organization, and research requires concurrent changes in institutional space planning and facilities use. The traditional physical and social spaces of the university, frequently identified by departments, do not allow for the engagement of individuals from multiple disciplines. The construction of interdisciplinary facilities acknowledges that the discrete spaces of the university are restricted in their ability to foster interdisciplinary collaboration."
>
> Michael Harris and Karri Holley. *"Constructing the Interdisciplinary Ivory Tower."* Society for College and University Planning, 2008.

7. **The PSB will leverage existing investments on the Centennial Campus.** The planned location for the Plant Science Initiative building is adjacent to the BTEC facility on the Centennial Campus. With biotechnology being a key component of modern agbioscience, this adjacency to BTEC will no doubt be beneficial. Also important is the proximity at Centennial of the NC State College of Engineering, providing enhanced opportunities for interaction between CALS plant scientists and engineers in areas such as precision/prescription agriculture, precision phenotyping technologies, advanced bio- and chemo-sensors, etc.

[31] Michael Harris and Karri Holley. "Constructing the Interdisciplinary Ivory Tower." Society for College and University Planning, 2008.
[32] Michael Harris and Karri Holley. "Constructing the Interdisciplinary Ivory Tower." Society for College and University Planning, 2008.

8. **Opportunity to develop business incubation facilities inside the new building.** It is important that the new plant sciences building be developed to facilitate not only traditional academic research but also applied research and development focused towards the commercialization of innovations. Entrepreneurial business development is challenging in agbioscience because of the tendency for emerging companies to need access to expensive specialized instrumentation and development facilities (such as climate controlled growth chambers and greenhouse facilities). There is potential with the new plant sciences building to integrate some business incubation space for start-up entrepreneurial endeavors and for this activity to be integrated with the planned agbioscience accelerator investments planned by Alexandria Real Estate Equities at RTP. There is an ideal opportunity here for a synergistic relationship whereby the pre-seed and seed stage of business formation occurs at the building on the Centennial Campus and emerging firms achieving traction can then move to larger space at the Alexandria accelerator where access to growth capital and specialized business development services may be further facilitated. Such a relationship would allow the plant sciences building to limit the amount of space it has to dedicate to business start-ups, yet still be an important part of the entrepreneurial business development pipeline. The likelihood that some large agbioscience industry players will also co-locate labs and research programs within the plant sciences building will also be beneficial for industry start-ups, providing entrepreneurs the opportunity to interact with the knowledge-base contained within multinational agbioscience corporations (which in turn may be potential investors in the start-up companies). The proposed plant sciences building will, therefore, play an important role in the development of a robust agbioscience business development ecosystem serving to connect business leaders, researchers, graduate students and entrepreneurs in a collaborative environment supportive of early stage business incubation.

Universities and Interdisciplinarity

The University of Pennsylvania: "In order to remain at the cutting edge, Penn's faculty must have flexible and modern research facilities. The University must create an environment that breaks down the real or psychological barriers of school-based spaces…Our new facilities mustand dohave an interdisciplinary focus, enabling researchers to work as teams." (University strategic plan).

University of North Carolina at Chapel Hill: "Most critical to Carolina's interdisciplinary goals for excellence is the development of …[new] facilities. (Academic plan)

Harvard University: "Harvard seeks to enable scientists from diverse disciplines…to share new kinds of spaces and collaborate on common problems." (Harvard Allston Campus Plan).

University of Pittsburgh: "Our most pressing task is to heighten our intellectual environment so that it is fully alive to the expression and the materialization of bold new ideas." (Long-range master plan).

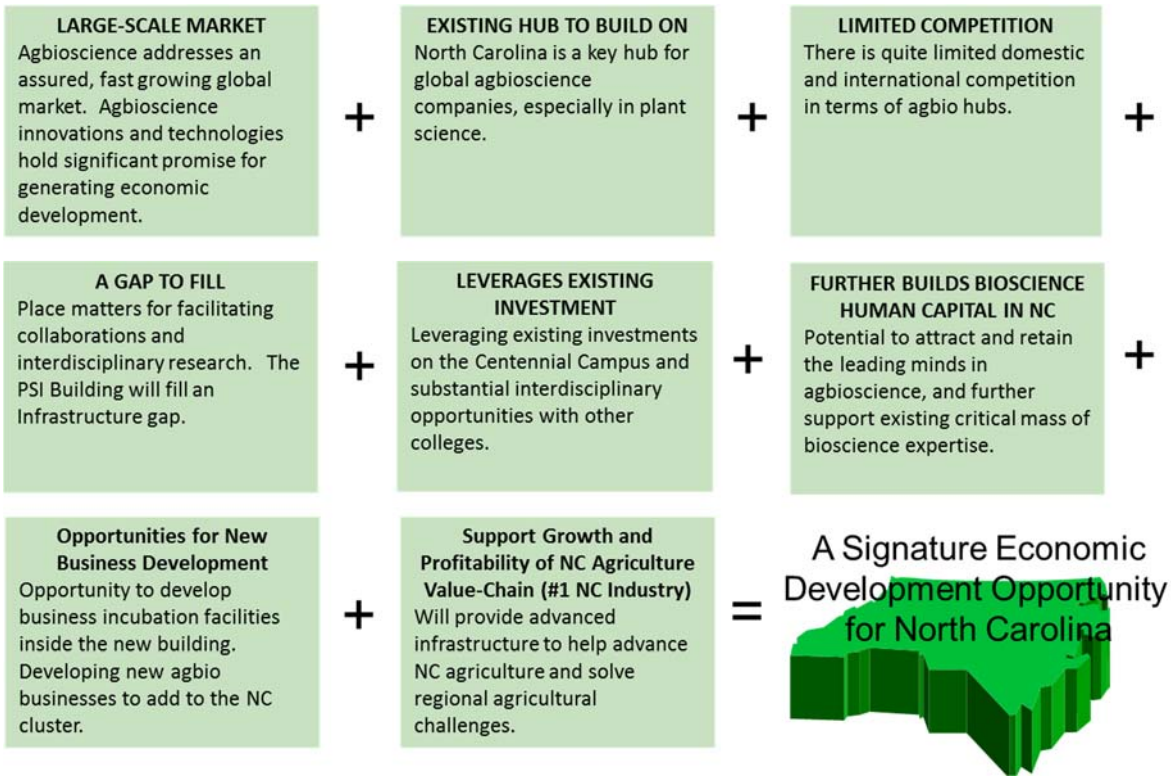
Cornell University: "The institution will be defined by a trend toward interdisciplinary collaboration, a trend that is likely to become more pronounced." (University Master Plan).

Reported in Michael Harris and Karri Holley. *"Constructing the Interdisciplinary Ivory Tower."* Society for College and University Planning, 2008.

9. **The Plant Sciences Building will provide supporting infrastructure to help advance NC agriculture.** Having state-of-the-art scientific research infrastructure and instrumentation available to interdisciplinary teams of scientists is also crucially important to NC State's traditional land-grant university role in supporting NC agricultural producers. A number of key issues facing agricultural producers (such as the expanding challenge of herbicide resistant weeds, emerging diseases and pests, etc.) lend themselves to multi-disciplinary solutions engaging expertise in plant pathology, entomology, crop science, soil science, horticulture, etc. to develop integrated approaches to challenge management. Modern economic

development is not just about creating new jobs, it is also concerned with maintaining existing jobs and industry competitiveness in the face of domestic and international competition. The new plant sciences building, and the platforms suggested as key thematic areas for NC State therein, hold significant promise for the rapid deployment of cross-disciplinary teams to address emerging issues for North Carolina producers. The overarching theme of increasing agricultural yield factors directly into supporting North Carolina farmers and the agricultural-value chain in the state.

Figure 21: The Plant Sciences Initiative Equation: Leveraging Unique Advantages for NC Economic Development



As can be seen in Figure 21 above, North Carolina has a compelling case to make as a global agbioscience leader. It is not, however, a perfect case. The key gap in the North Carolina offering pertains to the quality of infrastructure at NC State University for advanced agbioscience research and the fact that industry currently views the institution as "good" but not "great" (in part because of infrastructure deficiencies, and in part because of gaps in faculty expertise and unfilled faculty positions or a lack of communication of faculty expertise).

Locations that have tended to become the leading growth poles in technologies have shared the characteristic of having a world-class university presence in that technology field think Stanford and Silicon Valley, MIT and Harvard in Boston, Cambridge University and the British biotech cluster. As science and technology becomes more complex, the requirements for educated workers more critical, and open-innovation more central to technology industry strategies the presence of a world-class university, with world class infrastructure, to support an industry cluster becomes more and more important. North Carolina has proven that industry growth can be attracted by quality research universities with Research Triangle Park standing as a testament to the vision of marketing a region based on the presence of three anchoring world-class research universities. **The one part of the equation that is quite obviously lacking is high-quality advanced agbioscience academic infrastructure, especially in terms of space to**

accommodate the interdisciplinary teams that are so important to advancing discovery and innovation across complex challenges.

For NC State there is a need for agbioscience investment on three primary fronts:

- **Improvement in infrastructure to advance clusters of expertise and interdisciplinary science** and to better connect capabilities with regional agbioscience industry. To be accomplished through the proposed Plant Science Initiative building on the Centennial Campus.

- **Investment in faculty and graduate student positions directed towards filling gaps in current capabilities** and assuring that NC State achieves the global leadership position in the final platforms determined as interdisciplinary thrusts for the Initiative.

- **Investment in seed funding for facilitating interdisciplinary team formation** and to provide the start-up funds that may then be leveraged to attract significant extramural funding.

Put simply there is a need for collaborative research space, people and seed funding.

B. Investing for Success

As noted above, research acknowledges the significant importance of dedicated space to advancing interdisciplinary research especially research tackling such multi-dimensional challenges as agriculture and global food security. North Carolina has a current and significant opportunity to cement its position as the "go to" hub for global agbioscience, and associated industry growth, but key stakeholders (in academe, industry, agricultural production and economic development) agree that NC State University lacks the type of state-of-the-art interdisciplinary building and associated infrastructure required fully leverage the opportunity.

Currently, in the U.S., only St. Louis (with the Donald Danforth Plant Sciences Center) has really stepped forward with investment in the type of research infrastructure needed for advancing interdisciplinary agbioscience. James Carrington, the director of the Danforth Center, is on record noting that:

> ***"We (St. Louis) are a hub… but were not the only hub. All the way down the value-chain starting with seed and then all the way through agriculture, agricultural product processing, distribution and food manufacturing. If you look at some of the other hubs like Research Triangle Park in North Carolina, they are very much a hub for seed companies and other technologies. And they're a very formidable hub, but it is a little less integrated than St. Louis, And it's less of an innovation culture."***[33]

Clearly, St. Louis, one of the other leading global agbioscience hubs, sees North Carolina as formidable competition to their vision to be the global leader in agbioscience. They have invested in world-class independent research institute/academic facilities, to advance agbiosciences research and collaborations with industry, whereas North Carolina has not…yet.

NC State University has advanced a concept for filling the gap for developing, on the Centennial Campus, a $180 million advanced interdisciplinary Plant Sciences Building. The stated vision for the building (conceptually illustrated in Figure 22) is "to create the premier plant sciences

[33] Jason Rosenbaum. October 2013. "For Carrington, the future of plant sciences is digital and data based". St. Louis Beacon.

Infrastructure in the U.S." As envisioned, the Plant Sciences Building would be a world-class facility that that will:

- *"Foster the spirit of multi-disciplinary research to solve global challenges*
- *Create unique partnerships among universities, industry & government*
- *Maximize efficiencies for integrating our core missions of research, teaching, and outreach programs*
- *Be the premier destination for plant sciences in the world*
- *Allow NC to have a unique competitive advantage locally to globally*
- *Leverage our unique assets to create the Silicon Valley of Plant Sciences."*

With a total building area of 190,000 sq. ft. the envisioned Plant Sciences Building will provide space for the faculty offices and research labs of up to 65 faculty. It will accommodate the faculty and their associated research teams (post-docs, students and staff) together with core scientific infrastructure required to support several major interdisciplinary research thrusts. The building conceptualization was undertaken prior to Battelle's recommendation for specific platform-based research thrusts, but as preliminarily scoped the envisioned building meets the parameters needed to support these platform foci. As can be seen in Figure 23, NC State quite rightly envisions having space in the building dedicated to corporate partnerships and the presence of specific research teams from industry. Discussion between Battelle and the major agbioscience companies operating in North Carolina, and outside, indicate that there is solid interest in such co-location opportunities among several of the major agbioscience corporations. Similarly interest was expressed in providing support for key faculty endowments and for graduate student support in interdisciplinary areas that align with industry interests (which the four recommended platforms do).

Figure 22: Conceptual Design of the Plant Sciences Building at the NC State Centennial Campus

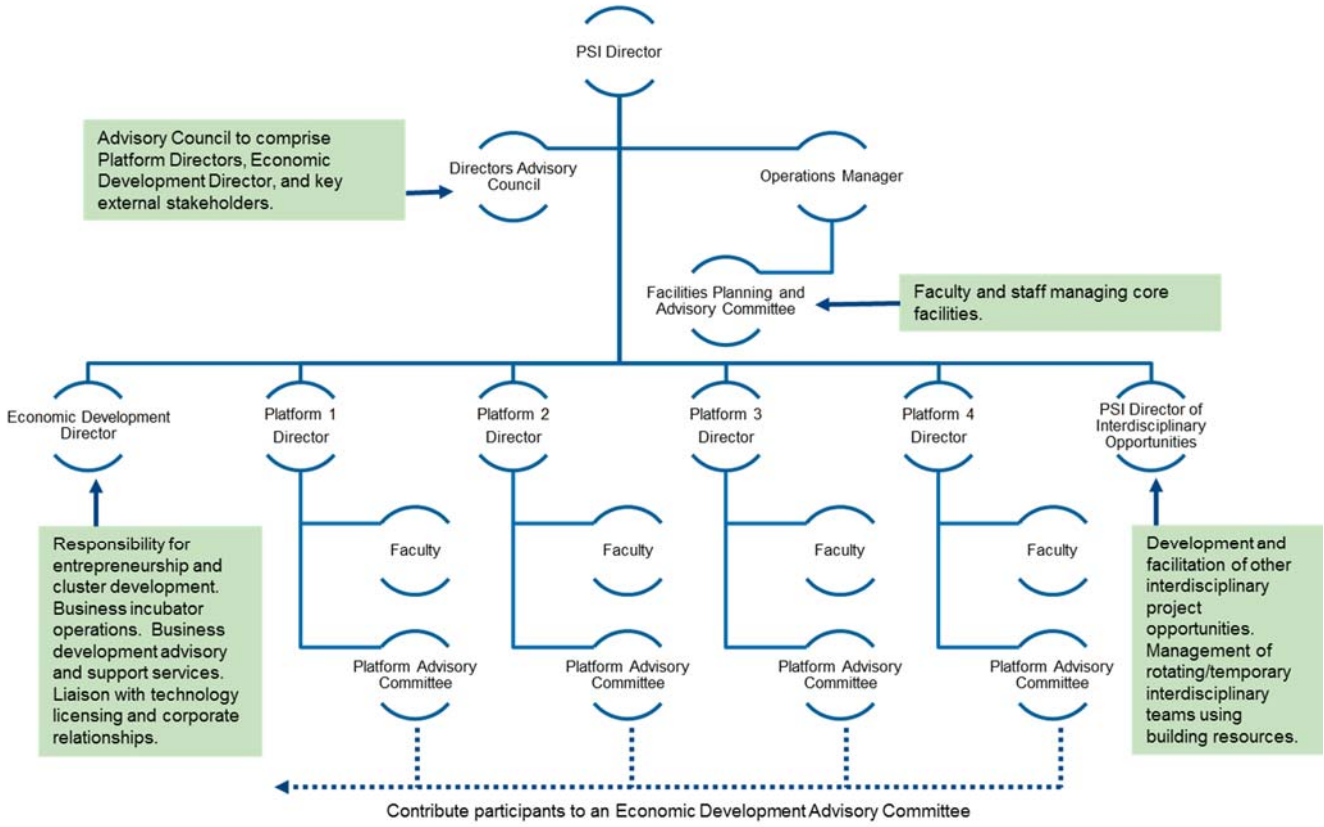
Figure 23: Conceptual Space Allocation for the Plant Sciences Building

The Plant Sciences Building design is just conceptual at this stage and will, of course, need to be refined in consultation with the leaders of the intended platforms, current "owners" of core instrumentation, and key external stakeholders. Not just within NC State academe, but also within regional agbioscience industry, there is considerable depth of expertise in advanced agbiosciences research and there has been large-scale investment recently in major agbio research facilities at RTP and elsewhere in the State. It will be important to integrate the leaders of these recently developed facilities to gain advice regarding the PSB.

C. Organizing for Success

Battelle will be examining governance options for the PSB in more detail in a separate Phase II report specifically focused on governance options. However, input gathered by faculty, external stakeholders and via benchmarking/literature review of other interdisciplinary academic building structures, provides the ability to make preliminary recommendations regarding potential organization of the interdisciplinary Plant Sciences Initiative and the associated PSB. Figure 24 provides a basic starting point for discussion of organization, and is structured partly in reference to the existing organization deployed at the interdisciplinary Bindley Biosciences Center at Purdue University.

Figure 24: Conceptual Organizational Structure for PSI/PSB



Some of the key attributes to note in this preliminary recommended structure include:

- **A High Profile Initiative Director.** Almost without fail, parties interviewed by Battelle in the course of the evaluation project noted the critical importance of hiring the right person to direct the initiative. Some interviewees felt that while platform directors should come from academe, the Initiative may benefit from recruiting a PSI Director with significant industry R&D experience and credentials. Either way (whether from industry or academe), it will be important to have director with the gravitas to impress and engage academic, corporate and ag production stakeholders while also providing leadership that inspires high performance in each platform and assures that significant advancement is made on the overarching goal of major discoveries and innovations that will improve agricultural yields. It was noted that the right director would ideally bring existing connections to major research funding streams and be supportive of academic research commercialization, business development and technology transfer.

- **Director's Advisory Council**. With multiple key stakeholders engaged in North Carolina providing support and engagement with the PSI, it will be important for the Director to have an Advisory Council to provide both guidance to decision making and support and assistance in development and implementation of strategy. Battelle would recommend a quite inclusive Advisory Council comprising, for example:
    - The Dean of the College of Agriculture and Life Sciences
    - The Dean of the College of Engineering
    - The NC Commissioner of Agriculture

- The Director of the North Carolina Agricultural Research Service
- Director of NC Cooperative Extension
- Senior research leader representation from Bayer CropScience, BASF, Novozymes, Monsanto and Syngenta
- A senior executive from at least two entrepreneurial agbioscience companies in NC
- Head of the AgBio[sphere] program at the North Carolina Biotechnology Center
- Head of the North Carolina Farm Bureau
- Head of USDA/ARS research program in North Carolina
- Research Director for the North Carolina Department of Agriculture.

- **Operations Manager:** This position would have primary responsibility for the PSB building finance, operations, oversight of core infrastructure, and for staff/systems engaged in coordinating and scheduling access to building and research resources. The Operations Manager should have their own **Facilities Planning and Advisory Committee** comprising faculty with responsibilities covering main elements of the core instrumentation and infrastructure contained in the PSB and crucial to its successful interdisciplinary programs.

- **Platform Directors:** Each of the four platforms needs a Director to manage interdisciplinary team development, financial planning, staffing, resource access and guide overarching research activity. Given that the teams under each Platform Director will be deliberately inter/multidisciplinary each Director will need to have the academic status and credentials that empowers them to guide complex projects with multiple stakeholders and engaged disciplines. It is likely that the success of the PSI and PSB will very much depend on the persons holding these positions, and it would be ideal if these could each be very well regarded academics in their own right, committed to interdisciplinary research advancement, and to commercial partnerships and innovation commercialization. It is recommended that both internal and external stakeholders likely to be engaged in each platform be involved in identifying potential leaders for consideration. These Director positions are absolutely critical to gaining credibility and early traction with partners and potential research funders.

- **Platform Advisory Committees.** Each platform should have an Advisory Committee comprised of research scientists (including faculty and scientists at external organizations including industry, the USDA, foundations, or other stakeholder organizations). The goal of each of these committees will be to assist in the review and development of potential platform research foci, provide oversight and problem solving in specific areas, and assist with connecting the platform to other leading external groups working in the field.

- **PSI Director of Interdisciplinary Opportunities (DIO).** While the four platforms will be very important drivers of the work of the PSB, as pointed out in this report, there are other areas of opportunity for interdisciplinary plant science and agbioscience engagement at NC State. It is likely that the facilities, instrumentation and expertise contained within the PSB may be extended beyond the four main platforms to support short-term or longer-term strategic programs of niche importance to external stakeholders and NC agricultural producers. The PSI-DIO would have responsibility for reviewing opportunities for furthering interdisciplinary plant science and for leveraging PSI infrastructure to facilitate novel interdisciplinary programs of research and development to address the most promising issues or those of most importance to the regional agricultural value-chain.

- **Economic Development Director.** Performing good science and making important discoveries on the frontiers of advanced agbioscience represent core goals of the PSI, but similarly the PSI is being developed with an eye towards a significant focus on generating significant agbioscience-based economic development and job growth in North Carolina. This economic development may stem from enhancements to existing production agriculture (sustaining and growing agricultural productivity) and through the

commercialization of innovations by existing, newly recruited or start-up North Carolina agbioscience company operations. Agbioscience is a highly specialized business sector, sharing much in common with biomedical sciences in terms of the impact of the regulatory environment on business development, long time-horizons from product conception to launch, and large-scale capital requirements to move products along the commercialization pipeline. The complexity of the agbioscience-business development ecosystem is such that it will behoove the PSI to have a dedicated Economic Development Director, and staff, who will focus on assuring translation of discoveries to benefit North Carolina and in particular coordinating PSI approaches to the in-state commercialization of innovations. In this regard the Economic Development Director will coordinate support programs, business incubation space, business capital access, and other PSI/University activities designed to optimize the entrepreneurial environment for plant-science business start-ups.

D. Other Key Considerations for the PSI and PSB

Battelle's review of the proposed Plant Sciences Initiative and associated building plan leads to several additional conclusions regarding programs and asset development that may need to be built or enhanced at NC State, or in collaboration with external stakeholder organizations (such as the NCBC or Alexandria), in order to maximize prospects for robust economic impacts in the state. Some of the most significant areas to address in finalizing the PSI/PSB will include:

- Funding for new faculty hires.
- Funding to support graduate student positions.
- Research seed funding to jump-start platform research programs (this might include use of the existing Research Innovation Seed Fund Program at NC State, or a dedicated extension to the program for plant science projects).
- Early stage proof of concept and pre-seed funding for innovation commercialization.
- Funding for IP protection and technology transfer operations.
- State engagement in assuring a supportive regulatory environment.

VI. Potential Economic Impacts of the NC State Plant Sciences Initiative for North Carolina

The plant sciences technology industry in North Carolina provides jobs for many employees across a variety of industries which represent a significant portion of state economic activity. Measuring this economic impact and the effect of projected future changes to employment levels in the state can serve as way of understanding the implications of strategic decisions to grow the industry through focused initiatives.

A. Overview of Economic Impact Analysis

Analysis of the economic footprint of an industry relies on tying employment in industry sectors to the economic output they produce. Output is defined as the dollar value of goods and services produced by a company, and summing output across all companies in an industry yields total industry output. The footprint of an entire industry in terms of its output is common known as the industry's economic impact, and can be categorized within the context of the state's larger economic output to determine the importance in driving overall state economic activity.

The economic impact analysis for North Carolina plant sciences technology industry makes use of a custom economic input/output (I/O) model that quantifies the interrelationships between economic sectors in the state economy. I/O data matrices track the flow of commodities to industries from producers and institutional consumers within the state. The data also show expenditure and consumption activities by workers, owners of capital, and imports. These trade flows built into the model permit estimating the impacts of one sector on all other sectors with which it interacts.

The measured economic impacts of a plant science technology company consist of three types:

- Direct effect: The dollar valuation of all goods and services provided as output by a company
- Indirect effect: The valuation of all of the inter-industry transactions between a company and other companies that supply the materials or services required to produce output
- Induced effect: The valuation of household income supported by the company through expenditures its employees make at other local industries.

Together, these three impacts comprise total economic impact. I/O analysis thus models the flow of funds that originate from direct plant science technology industry expenditures in the economy and the ongoing ripple (multiplier) effect of these expenditures. In other words, economic impact models are based on the concept of the "multiplier"i.e., every dollar spent in the economy is re-spent one or more times in the local economy, thereby generating additional economic activity and impact. I/O analysis represents the generally accepted standard for measurement of economic impacts.

The current estimated impacts of the plant science industry were calculated using 2012 North Carolina-specific I/O models generated by the IMPLAN Group (one of two major developers of nationally and regionally-specific I/O tables and analytical systems). The analysis builds upon a foundation of employment data included within the IMPLAN input/output model that is built primarily from the U.S. Bureau of Labor Statistics' Quarterly Census of Employment and Wages (QCEW, tied to unemployment insurance reporting). These data provide detailed intelligence on the number of establishments, monthly employment, and quarterly wages, by North American Industry Classification System (NAICS) industry, by county geography, by ownership sector, and for the entire U.S. The IMPLAN model employment data is further enhanced by U.S. Bureau of

Economic Analysis data to account for sole proprietorships and other very small firms that fall outside of the QCEW data collection protocols.

For this analysis, a customized model was developed to quantify the direct, indirect and induced impacts of the plant science technology industry in the state. The model incorporates detailed subsectors of the plant science industry and their interrelationships with more than 430 other individual sectors that cover the entire state economy. With these data, the analysis is able to show not only the overall impact on the state economy, but impacts on specific sub-sectors of the economy that are strongly dependent on economic activity generated by the plant sciences sector.

The following data are output from each model: ***employment*** (combined number of full and part-time workers), ***personal income*** (measures cash, benefits and non-cash payments received by individuals in the economy), ***value added*** (the difference between an industry's or an establishment's total output and the cost of its intermediate inputs), ***economic output*** (the dollar value of sales, goods, and services produced in an economy, is sometimes referred to as business volume, and represents the typical measure expressed as "economic impact" in a standard economic impact study), ***state and local tax revenue*** (including sales, income, and property taxes), and ***federal tax revenue*** (including sales and income taxes, and both corporate and employee contributions to Social Security).[34]

B. Current Impact of the Plant Sciences Technology Sector and Recent Employment Trends

Employment totals by industry for 2010 through 2013 from the North Carolina Biotech Center's company database were used to examine the economic impact of plant science-related employment in North Carolina. **Note that for this analysis, plant science industries were defined as biotechnology companies involved in plant sciences and excluded agricultural production, processing, and manufacturing industries. Results thus represent a conservative analysis of the footprint of all plant science-related economic activity occurring in the state.**

To convert the NAICS industry data for use in the state IMPLAN models, a functional modeling approach is used. This approach, although very similar to the way in which employment is classified into NAICS industries, provides a more accurate estimation of the impacts versus treating the employees each as contributing some "average" impact given the overall composition of a given industry segment. For example, one company's spending in the plant science technology segment may involve primarily fertilizer manufacturing but for another be more centered on plant biology research. To distinguish between the functional employment occurring in each North Carolina industry, each company establishment's employment was mapped to a primary aggregated IMPLAN sector using the company NAICS code. Table 19 below shows the 5 IMPLAN sectors used in the analysis of the NC plant science technology industry and the total functional employment in 2010 and 2013 mapped to each one.

[34] The estimation of tax revenue is subject to significant variability due to ever-changing rate structures, the use of available exemptions, and the accounting of potential income, if any, subject to taxation. These figures should be viewed with some measure of caution throughout this analysis.

Table 19: North Carolina Employment by IMPLAN Sector in Plant Science Technology Companies

IMPLAN Sector	2010 NC Employees	2013 NC Employees	Employment Change 2010-2013
126 Other basic organic chemical manufacturing	493	542	49
130 Fertilizer manufacturing	0	5	5
131 Pesticide and other agricultural chemical manufacturing	1,787	1,613	-174
141 All other chemical product and preparation manufacturing	0	18	18
376 Scientific research and development services	3,624	4,319	695
Total	5,904	6,497	593

Using the IMPLAN sector mappings for plant science technology industry employment, the economic impact analysis results for the North Carolina plant science technology industry's economic footprint in 2013 are shown below in Table 20.

Table 20: Economic Impact Results for 2013 NC Plant Science Technology Industry Employment

Impact Type	Employment	Labor Income ($M)	Value Added ($M)	Output ($M)
Direct Effect	6,497	$800	$1,980	$5,290
Indirect Effect	9,783	$621	$985	$1,818
Induced Effect	8,877	$370	$704	$1,113
Total Impact	25,157	$1,790	$3,669	$8,221
Multipliers	2.87	1.24	0.85	0.55

The plant science technology industry in North Carolina employed an estimated 6,497 individuals in 2013 who generated a further 18,660 full or part time jobs through indirect and induced effects to support a total of 25,157 jobs in the state. Business revenues from the plant science technology industry added approximately $5.2 billion in business volume to the state economy and contributed an additional $2.9 billion in business volume through indirect and induced business spending to support a total economic output footprint of $8.2 billion dollars.

The effect that direct industry spending and employment has on economic activity across all other industries in the state is known as the industry's multiplier. One employee in the plant science industry in 2012 supported approximately 2.87 additional employees in other industry sectors, and every $1 in spending from the plant science industry generated $0.55 in additional industry spending across all other industry sectors in the state.

As seen in Table 20 above, total net employment in the plant-related technology industries in North Carolina increased from 2010 to 2013 by 593 employees, driven largely by employment growth in research and testing firms related to plant science applications.

C. Projections for Future Plant Science Technology Industry Employment Impact and Growth

Future changes to employment in key technology industries can have a large impact on the overall economic footprint of the sector, and variability in future economic conditions creates a range of possible growth scenarios that North Carolina could experience. In order to assess the potential impact of employment changes on economic output of the industry, the impacts of two

potential employment level scenarios were evaluated in terms of their effect on plant science technology industry output by 2024. These scenarios correspond to varying perspectives on the future of economic conditions in the state, ranging from expected growth projections from employment statistics agencies to increased employment levels driven by establishment of a dedicated plant academic research facility.

Several sources of projections on employment growth trends across industries exist. The U.S. Bureau of Labor Statistics (BLS) publishes detailed 10 year employment growth projections at the industry level, and state employment statistics agencies often publish their own similar forecasts that are customized to account for state-specific conditions and expectations about future economic conditions. For the expected growth scenario, this analysis utilizes 10 year employment projections published by the North Carolina Department of Commerce's Labor and Economic Analysis Division (LEAD). These projections are refined annually based on observed statewide economic trends in order to guide expectations about future levels of employment and output. Projections at the 3-digit NAICS code level regarding the cumulative annual growth rate (CAGR) of employment in various industries were used to estimate levels of employment in plant sciences industries in 2024. The CAGR represents the estimated percentage change in employment totals for an industry each year, compounded annually, and assumed to be observed every year until 2024. Using CAGR projections at the individual industry level, the net NC LEAD projected CAGR across all industries through 2024 is 1.8%.

A scenario was also defined for an alternative growth trend under which higher employment is attained after construction and opening of a new plant sciences support and academic research facility at NC State. The establishment of a dedicated plant sciences facility to support plant technology research as well attract new employees to the state was assumed to result in higher than expected growth rates for the industry. For this scenario, it was assumed that the existence of the PSI/PSB at NC State could result in 1,000 additional employees working in the NC plant sciences technology industry by 2024 (approximately 143 additional jobs per year, for seven years following completion of construction), equivalent to exceeding NC LEAD CAGR projections by 1.1%, resulting in a net total CAGR through 2024 of 2.9% across all plant-related technology industries. The scenario rates and projected 2024 employment totals in the plant sciences industry are shown below in Table 21.

Table 21: Assumptions of 10 Year Employment Projection Scenarios for NC's Plant Science Technology Industry

Projection Scenario	Assumed Net Cumulative Annual Growth Rate (across all industries)	Projected 2024 Total Plant Science Related Technology Employment
Attain 10 Year Projected Growth Rates from NC LEAD	1.8%	7,924
Attain Higher Growth Rates Than Expected Due to Establishment of Dedicated Plant Science Facility	2.9%	8,924

The IMPLAN model for North Carolina was used to evaluate the implications of these projected employment trends by 2024 to determine the potential economic output gains and losses that might be observed for the state economy.

NC LEAD Projected Scenario

NC LEAD projects total employment in plant science related biotechnology industries to grow by 1,427 employees through 2024. Economic impact results for this scenario are shown below in Table 22:

Table 22: Economic Impact Results for 2024 NC LEAD Projected Plant Science Technology Industry Employment

Impact Type	Employment	Labor Income ($M)	Value Added ($M)	Output ($M)
Direct Effect	7,924	$956	$2,246	$5,935
Indirect Effect	11,142	$698	$1,110	$2,041
Induced Effect	10,331	$430	$819	$1,295
Total Impact	29,397	$2,084	$4,175	$9,271

The total impact of projected growth in economic output to the state's economy by 2024 is estimated to be approximately $9.2 billion. NC LEAD's 10 year employment projections for specific NAICS industries align fairly closely with overall U.S. projections published by BLS.

Plant Science Facility Establishment Scenario

Given the construction of the proposed Plant Sciences Building and the operations of the Plant Science Initiative to further existing research efforts and catalyze industry development, the total employment in plant science related technology is projected to grow from 2013 levels by an estimated 2,427 employees bringing the total state employment attributable to the industry cluster above 31,000 employees. Economic impact results for this scenario are shown below in Table 23:

Table 23: Economic Impact Results for 2024 Projected NC Plant Science Technology Industry Employment Under Facility Establishment Scenario

Impact Type	Employment	Labor Income ($M)	Value Added ($M)	Output ($M)
Direct Effect	8,924	$1,056	$2,361	$6,132
Indirect Effect	11,714	$725	$1,153	$2,111
Induced Effect	11,124	$463	$882	$1,394
Total Impact	31,762	$2,244	$4,396	$9,637

If even slight increases in employment over projected trends are achieved through establishment of the Plant Sciences Initiative and Plant Sciences Building, the benefits are quite large for North Carolina's economy. Reaching this scenario's employment gains would result in an increase of over $1.4 billion in economic activity for the state from 2013 levels, representing an additional $366 million in gains over projected levels of 2024 employment.

Economic Impacts of Construction of the Plant Science Building

In addition to the employment gains from increased translational research activity and industry involvement, the actual construction of a dedicated Plant Sciences Building would produce economic output for the North Carolina economy due to revenues received by construction companies and their employees.

Using an anticipated $180 million budget for the construction of a new plant sciences facility, the IMPLAN model was used to analyze the economic impact of this additional spending by NCSU in the state's nonresidential construction industry[35]. Results from the impact analysis are shown below in Table 24:

[35] IMPLAN sector 34: Construction of new nonresidential commercial or health care structures was used for the industry assumed to receive the majority of funds used to construct the facility

Table 24: Economic Impact Results for Estimated Construction Cost of Plant Science Facility

Impact Type	Employment	Labor Income ($M)	Value Added ($M)	Output ($M)
Direct Effect	1,251	$62,525	$71,755	$184,687
Indirect Effect	445	$24,347	$40,054	$72,579
Induced Effect	541	$22,507	$42,857	$67,762
Total Impact	2,237	$109,378	$154,667	$325,029

Construction of the plant sciences facility would directly support 1,251 jobs in the state's nonresidential construction industry as well as an additional 986 in-state employees through indirect and induced effects generated by the project. The project would support over $184.6 million in direct economic output for the state economy which would generate an estimated additional $140.3 million in economic activity in other industries.

APPENDICES

A. Benchmarking Reports
B. OmniViz Categories
C. Listing of Identified Faculty

Appendix A: Benchmarking Reports

1. Iowa State Plant Sciences Institute

Summary

The Plant Sciences Institute[36] (PSI) at Iowa State University is one of three university-wide institutes supervised by the Vice President for Research. Highly virtual and headquartered in a lab building far off the center of mass of agricultural research on campus, the PSI supports a core of permanent faculty and eight "centers" of various organizational type scattered across campus. Through these centers, the PSI involves as many as 200 faculty from 30 departments across six college of the university. The PSI is currently engaged in a major reorganization that will not change funding for permanent faculty but will redirect support from internal competitive grant and fellowship programs to a cross-university competition for long-term support of faculty committed to a "predictive phenomics" approach to plant sciences. This change is modeled on the Howard Hughes Medical Institute dictum of "support people, not projects."

History and Motivation

In a university announcement made at the time of founding in 1999, the mission of the institute was described as:

> *"providing an environment that promotes excellence in plant sciences through multidisciplinary collaboration; fostering quality research, including graduate and postdoctoral research; providing a forum for national and international symposia and scientific exchange; encouraging collaboration among industry, ISU, other universities, visiting scientists, and the State of Iowa; aiding wise application of developing knowledge about plants; and providing excellent scientists for employment in the private and public sector organizations related to plant science."*

The PSI was set up to fund faculty recruitments and the establishment of a confederation of "centers" around which recruited and retained faculty would build research agendas, promote collaboration, and in some cases provide service on chargeback basis to other faculty. At the outset, the PSI took responsibility for two existing centers (Center for Crop Utilization Research and the Seed Science Center) and supervised the formation of six new centers (Center for Designer Crops; Center for Plant Genomics; Center for Plant Responses to Environmental Stresses; Center for Plant Transformation and Gene Expression; Raymond F. Baker Center for Plant Breeding; Lawrence H. Baker Center for Bioinformatics and Biological Statistics). Most but not all of these centers were managed by the core faculty whose salaries were underwritten by the PSI budget.

[36] See http://plantsciences.iastate.edu. Battelle also acknowledges with thanks a telephone interview conducted with Institute business manager Deanne Brill on October 17, 2014.

Program evolution

Over time, the PSI has experimented with several ways to stimulate collaboration and define a unique expertise for Iowa State. In order to develop an identity and focus among its constituent centers, the PSI added thematic research initiatives genomics, biopharmaceuticals, biorenewables, and crop protection and then developed an internal competitive regrant program for faculty and a graduate fellowship program. Results are described as generally good, but still very focused around the core faculty and the supported centers (that roster has changed slightly over time). In the opinion of the PSI's new (and second permanent) director, Prof. Patrick Schnable, the time had come for change that embraced a wider scope of faculty participation.

According to a video presentation made by Dr. Schnable earlier in 2014, the PSI will return to its roots in the mid-1990s, when Prof. James Cornette, now an emeritus professor of mathematics, began a series of seminars designed to connect life scientists on campus to applied mathematicians, statisticians, and computer scientists. One week the life scientists would present their outstanding data problems; the next week the methodologists would present proposed approaches. The free-flowing format was popular on campus and led to a series of important, externally funded collaborations that allowed Iowa State to make well recognized advances in plant genomics. It was a search for support for this new kind of collaboration that led Iowa State to propose the interdisciplinary PSI to the legislature in the first place.

Seeking to recapture this spirit, Dr. Schnable has proposed a new, simplified mission statement: the PSI will be "dedicated to enhancing Iowa State University's international prominence in the plant sciences." In Dr. Schnable's analysis, the national focus is now shifting from plant genomics to "predictive phenomics" developing large and heterogeneous data sets that yield specific predictions on how genome and environment interact to produce actual crop outcomes. In his view, Iowa State is entering predictive phenomics earlier in its evolution as a field than it entered plant genomics, and has correspondingly higher chance to distinguish itself. He further believes that the university's advantage will not be in automated greenhouses, where others including in Germany are already in the lead, but in its large and highly accessible experimental fields. The challenge is to cheaply and intensively automate data-gathering in these fields, one which will involve not only plant scientists but also data scientists and engineers.

To promote this collaboration, the PSI will re-orient the portion of its budget currently dedicated to the regrant program and graduate student fellowships to a program modeled on the Howard Hughes Medical Institute dictum "fund people, not projects." He aims to provide long-term, stable funding of $100,000 to $200,000 annually to a core of faculty committed to these aims.

Governance

The PSI was envisioned from the outset as involving faculty not only from the College of Agriculture, but also from the Colleges of Engineering and Liberal Arts and Sciences, both of which were instrumental in the bioinformatics collaborations that spurred creation of the PSI. Accordingly, it needed an interdisciplinary reporting structure. At its inception, the PSI reported to the university Provost.

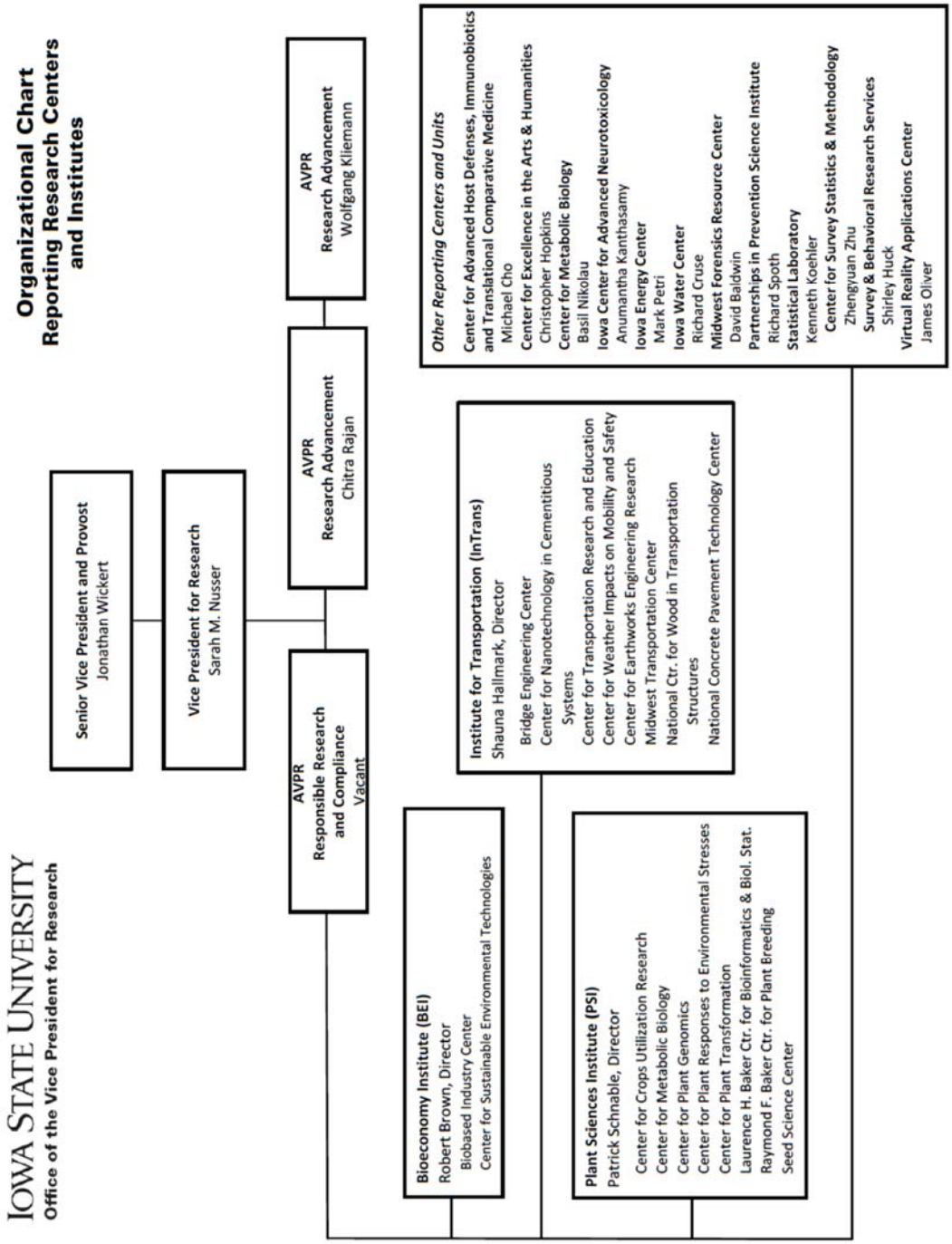
In 2007, the reporting line was moved to the Vice President for Research, which also directly supervises two other university-wide initiatives, the Bioeconomy Institute and the Institute for Transportation (see organization chart on the following page), as well as the integrative Office of Biotechnology.

Nominally, the PSI maintains a governing council including the directors of all the subsidiary "centers," at large faculty members, and the associate VP for research and director of technology

transfer and intellectual property. However, PSI staff report that this mechanism has been de-emphasized.

Over time, the roster of “centers” supported by the Institute has changed. At present they are:

- Center for Plant Genomics (directed by the Institute director), situated in the Co-Laboratory itself
- Laurence H. Baker Center for Bioinformatics and Biological Statistics, a research center and provider of hardware and software support to the PSI, situated in general “Office and Laboratory” building;
- Center for Plant Transformation, a research entity for plant transformation and gene expression, also embracing a core facility, (both situated in Agronomy Hall)
- Raymond F. Baker Center for Plant Breeding (also situated in Agronomy Hall), and various field sites and test farms, and collaborating with the USDA-ARS Corn Insects and Crop Genetics Research Unit in the Genetics Laboratory building
- Center for Plant Responses to Environmental Stresses (virtual)
- Seed Science Center (situated in the its own Seed Science building, locus of the seed testing program and other research, teaching and extension activities)
- Center for Crops Utilization Research (a value-added center situated in the Food Sciences and Human Nutrition building)


IOWA STATE UNIVERSITY
Office of the Vice President for Research
Organizational Chart
Reporting Research Centers and Institutes
Senior Vice President and Provost
Jonathan Wickert
Vice President for Research
Sarah M. Nusser
AVPR
Responsible Research and Compliance
Vacant
AVPR
Research Advancement
Chitra Rajan
AVPR
Research Advancement
Wolfgang Kliemann
Bioeconomy Institute (BEI)
Robert Brown, Director
Biobased Industry Center
Center for Sustainable Environmental Technologies
Institute for Transportation (InTrans)
Shauna Hallmark, Director
Bridge Engineering Center
Center for Nanotechnology in Cementitious Systems
Center for Transportation Research and Education
Center for Weather Impacts on Mobility and Safety
Center for Earthworks Engineering Research
Midwest Transportation Center
National Ctr. for Wood in Transportation Structures
National Concrete Pavement Technology Center
Plant Sciences Institute (PSI)
Patrick Schnable, Director
Center for Crops Utilization Research
Center for Metabolic Biology
Center for Plant Genomics
Center for Plant Responses to Environmental Stresses
Center for Plant Transformation
Laurence H. Baker Ctr. for Bioinformatics & Biol. Stat.
Raymond F. Baker Ctr. for Plant Breeding
Seed Science Center
Other Reporting Centers and Units
Center for Advanced Host Defenses, Immunobiotics and Translational Comparative Medicine
Michael Cho
Center for Excellence in the Arts & Humanities
Christopher Hopkins
Center for Metabolic Biology
Basil Nikolau
Iowa Center for Advanced Neurotoxicology
Anumantha Kanthasamy
Iowa Energy Center
Mark Petri
Iowa Water Center
Richard Cruse
Midwest Forensics Resource Center
David Baldwin
Partnerships in Prevention Science Institute
Richard Spoth
Statistical Laboratory
Kenneth Koehler
Center for Survey Statistics & Methodology
Zhengyuan Zhu
Survey & Behavioral Research Services
Shirley Huck
Virtual Reality Applications Center
James Oliver

Facilities

The PSI is now headquartered in the Roy J. Carver Co-Lab, a $27 million, $45,000 square-foot laboratory structure built in 2003 with a $3 million keystone contribution given by the family foundation of Mr. Carver, a Muscatine industrialist and Iowa State alumnus who has supported a range of university activities. A leading contribution also came from Pioneer Hi-Bred. The building is situated at the northwest corner of the campus, somewhat removed from the university's other agricultural sciences buildings. Although most of the PSI constituent "centers" and most PSI-supported faculty are based elsewhere on campus, the Co-Lab was designed to accommodate the following uses:

- Laboratory suites for four senior faculty who were at the time already closely affiliated with the PSI, and their graduate student/postdoc teams;
- Additional suites dedicated to recruitment of three additional senior faculty, for a total of seven large faculty-led teams in the building;
- A Genomics Laboratory created by the Pioneer Hi-Bred donation
- A Proteomics Laboratory
- An Innovations Development Facility targeting industrial collaboration, and itself comprising two elements:
    - A Public/Private partnership program aimed at existing companies
    - An incubator (distinct from the university's main incubator at its research park) aimed at faculty-driven startups
- Environmentally controlled growth chambers
- A greenhouse added on at a later date.

According to university facilities office documentation, the PSI appears to control about 30,000 square feet of usable space, with small residual spaces allocated to the DOE Ames Laboratory, a physical science facility based on campus. Because of the building's financing, it does not pay a facilities charge to the university on this space.

The Carver Co-Lab. Source: Iowa State website.

Industry participation

The PSI considers its strongest industrial support to come from the state corn and soybean commodity groups. Both are represented on an external Advisory Board also comprising representatives from the agbiotech sector (e.g., Syngenta), the state Secretary of Agriculture, and president of the state Farm Bureau Federation.

Experience with the Innovations Development Facility in the Carver Co-Lab has been uneven. Some startup companies have left Iowa in search of financing, and others have gone inactive. At present the most active incubator tenant is Data2Bio, a bioinformatics company in which Prof. Schnable is managing partner.

Other funders

The PSI reports that centers and faculty it supports leverage about $20 million to $30 million a year in external research sponsorship. The strongest agency funders for PSI projects have been USDA and NSF. Other than the capital grant from the Roy Carver Foundation to create the Co-Lab, the PSI does not indicate major philanthropic support.

Financing

The initial proposal called for investment of $400 million over 10 years, a quarter of that from state appropriations, a quarter from private fund-raising, and the remaining 50% from increased sponsored research.

Within two years of inception, the state budget for the PSI had grown from a $200,000 startup contribution to an annual appropriation in the range of $5 million, around which it fluctuated for nearly a decade before dropping to about $4.5 million.

FY	99	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14
Tot	.2	2.2	4.7	5.0	5.0	5.0	5.0	5.0	5.1	5.2	5.2	4.6	4.4	4.3	4.3	4.5

State funding for PSI by fiscal year after all adjustments ($ millions rounded). Source: PSI.

Fairly early in the PSI's history, the appropriation's status as a line item in the state budget became perceived as a liability, and funding was shifted to become an administrative allocation within the university's overall state budget.

In order to implement the change in emphasis planned by Dr. Schnable, budgets currently committed to the six centers and the competitive grant program are being reallocated to the new vision for PSI Faculty Scholars, which will reach $2.4 million annually by FY 16, according to data provided by the PSI. Amounts dedicated to "permanent faculty" salaries remain unchanged at $1.2 million, and administrative accounts are stable.

Lessons Learned

The PSI administrative staff believes:

- in retrospect it may have been a mistake to commit the institute budget in part to permanent faculty salaries, a substantial share of the overall state appropriation allocated to PSI;
- sharing of funding responsibility with academic departments opens up unproductive debates over which entities should get credit for expanded external research sponsorship and indirect costs;
- to assure broadest possible faculty participation, there should be full transparency on how discretionary funds are allocated, and an initiative must avoid any sense that only favored insiders are funded.

2. Purdue University Plant Sciences Initiative

Summary

The Purdue Plant Sciences Research and Education Pipeline the formal name for what is informally known as the Plant Sciences initiative[37] is a very new, trustee-level initiative. It includes a cluster-hiring initiative crossing several departments in the College of Agriculture; creation of a virtual Center for Molecular Agriculture; investment in existing plant-transformation facilities and teaching labs in several agriculture buildings on the main campus; and construction of a new "phenotyping platform" and seed-management facility at the Beck Agricultural Center, a center for agronomy research, education and industry outreach that is situated a few miles northwest of campus. The initiative also envisions a thrust in commercialization and student participation.

Note: Although the Purdue Discovery Park has caught the attention of research leaders at NC State University as a model for major new facilities dedicated to interdisciplinary research, the Discovery Park does not currently appear central to the Plant Sciences Initiative. According to Prof. Karen Plaut, the associate dean for research and faculty affairs at the College of Agriculture, faculty teams in the new Center for Molecular Agriculture may eventually make use of one or more of the specialized facilities at the Discovery Park, but this has not yet been determined. It is possible, for example, that some participating faculty will have as much interest in the Birk Nanotechnology Center as in the Bindley Bioscience Center.

History and Motivation

The Plant Sciences initiative was proposed by the College about a year ago in response to a short-turnaround request by university President Mitch Daniels for "big ideas" that could be brought before the trustees for endorsement and funding. Of 50 proposals received, ultimately two were funded that involved investment in research capacity: one in drug discovery and the other in plant sciences.

The Plant Sciences proposal was premised on earlier discussions with faculty, but because of the short turnaround and broad scope, it was not written by plant science specialists themselves, but rather by generalists in the college research administration. The general goal was to enhance the college's position in research for the future by capitalizing on strengths in both basic biology and applied plant research. Specific objectives included replacing retiring faculty in plant biology while also investing in phenotyping as the area in which external research support was considered most likely to grow over the next two decades.

Specific components include:

- Over the next two years, 10 new faculty lines in plant biology with emphasis on skills in plant biotechnology and synthetic biology, to be hired across the Departments of Agronomy; Botany and Plant Pathology; and Horticulture and Landscape Architecture;

[37] See https://ag.purdue.edu/plantsciences/pages/default.aspx. Battelle also acknowledges with thanks an interview on Nov. 7, 2014, with Prof. Karen Plaut, associate dean for research and faculty affairs at the College of Agriculture.

- Creation of a virtual Center for Molecular Agriculture, joining together these new hires with existing faculty to pursue research opportunities in basic biology;
- Establishment of a new phenotyping and seed management facility to serve applied scientists, professionalizing the management of seed strains in order to facilitate industrial outreach and technology commercialization;
- Fellowships for undergraduate research and a pre-college summer institute to recruit students; and
- Emphasis on commercialization, integrating with the campus-wide Purdue Foundry that provides guidance to campus innovators among faculty and students.

Governance

Because the Plant Sciences proposal had been written with limited faculty input, the first step in broadening "ownership" was to hold a series of town halls with more than 100 faculty from both the College of Agriculture and other interested units across the university. There is no formal dean's council or other governance mechanism to link to other colleges such as Engineering, in part because agricultural applications represent such a small share of research in these other units (e.g., Engineering is currently hiring 100 new faculty members). Connections are made one-to-one with interested faculty in whatever college.

Because it was created in response to a presidential call for proposals, the Plant Sciences initiative is monitored closely by the president, provost, and dean of agriculture. There has been one major annual update for the trustees, with a second scheduled shortly, and bimonthly progress reports are made to university leadership.

Facilities

The new construction at the Beck Agricultural Center will be a 25,000 square-foot building for automated phenotyping and centralized seed processing, which formerly was distributed across faculty labs. It will include group space for phenomics tool development by various faculty teams, a student hub, a sensor room, a threshing and shelling room. There will be a handful of offices for the director and administrative functions, but no major space for faculty offices. The site has already been extensively wired with high-bandwidth communication back to the main campus. The project has not yet gone to bid, but according to capital planning documents available on the Purdue website, the university has requested $10 million in state appropriations, to be matched by another $10 million from other sources, during the 2015-2017 budget biennium.

Financing

The exact level of investment committed by the trustees is not publicly disclosed, but is believed to be greater than $20 million, a combination of investment in facilities, new lines, and startup operational expenses for the Center for Molecular Agriculture.

Lessons Learned

Dr. Plaut observes:

- The college does not believe in providing primary space for faculty in new center buildings, because once a faculty member's affiliation with a center ends, the home department may not have kept space available for their return. Accordingly, new space is incremental only, targeted for new teams enabled by successful grant proposals.
- As the commercialization component was thought out more fully, the importance of professionalized seed management became clearer: to get new plant breeds beyond the "valley of death," it is important to be able to provide enough seed under proper conditions for industry partners to grow out much more than the typical academic experimental plot.

3. University of Florida Plant Improvement Program

Summary

The University of Florida Plant Innovation Program (PIP)[38] is an entirely virtual, faculty-driven, interdisciplinary initiative whose goal is to refine and use sensory analysis to better understand what aspects of fruits, vegetables and flowers people like best, so these attributes can be bred or genetically engineered. The PIP is built bottom-up on what director Prof. Dave Clark describes as "renegade" or "guerilla" principles and is not recognized by the university as an official center or institute.

In essence, the PIP represents an agreement among certain faculty to meet, to self-organize responses to grant opportunities, and to some extent cross-subsidize each other's' laboratories when the need and occasion arises. The PIP does leverage the work of two officially recognized university-wide units, the Center for Smell & Taste and the Clinical and Translational Science Institute, both of which report to the Vice President for Research. However, the PIP itself has no ongoing budgetary support (or discretionary seed grants) from either the UF Institute of Food & Agricultural Sciences (IFAS) or the university itself. It has "only a Web page," Prof. Clark says.

History and Motivation

The PIP began with the informal collaboration of three faculty members, director Dave Clark, who specializes in ornamental flowers, tomato expert Harry Klee, and Linda Bartoshuk, a perceptual psychologist coiner of the term "supertaster" who had recently been recruited from Yale. The three convinced the then-senior VP for Agriculture and Natural Resources to allocate a small amount of funding (mid-six figures) to a faculty retention package and to bless the effort.

Soon groups of faculty were meeting and self-organized into four or five different sub-groups that pursue various federal and corporate funding opportunities. The PIP now lists approximately 30 faculty crossing half a dozen departments in at least four colleges, both at the main campus in Gainesville and at the IFAS research and education sites distributed across the state:

- In the IFAS, faculty from the Departments of Horticultural Sciences; Environmental Horticulture; Food Science and Human Nutrition; and the Gulf Coast Research and Education Center;
- In the College of Liberal Arts and Sciences, faculty from the Department of Psychology;
- In the Dental School, faculty affiliated with the Center for Smell & Taste, itself a university-wide center;
- In the College of Medicine (Department of Medicine), faculty affiliated with the Clinical and Translational Science Institute, which itself crosses multiple colleges;
- In the College of Business, faculty from the Department of Marketing;

[38] See http://hort.ifas.ufl.edu/pip/index.shtml. Battelle also acknowledges with thanks an interview on November 4, 2014, with Prof. Dave Clark, the PIP director.

- In the USDA Agricultural Research Service branch on campus, research staff in chemistry and biochemistry and panel analysis.

Director Clark notes that the informal structure allows PIP to convene subgroups to pursue opportunity on very short notice. These faculty all have viable labs and do not need the PIP to thrive. However, the synergy that holds the PIP together is that the fundamental scientists in the group have a desire to get their innovations into practice, while the applied breeders control royalty flows from existing plant cultivars that allow them to cross-subsidize activities such as preparing proposals for larger grant support from the government or industry, or to gather data that support patent applications being pursued by the university Office of Technology Licensing. In effect, PIP stands in for a "gap fund" of a kind that is not currently provided by the university.

Program evolution

In its effort to attract NIH funding for perceptual studies, the PIP emphasizes the health benefits of breeding fruits and vegetables that people actually prefer to eat. The obvious next step for NIH proposals is to also breed for health benefits.

Senior research administration in IFAS has since turned over several times, and the PIP has been largely on its own. Discussions to make PIP formal within the IFAS have not advanced because the PIP faculty prefer its loosely structured style. However, the director believes the PIP has caught the attention of senior university administration because of the amount of favorable press for the university garnered through PIP's annual "Flavors of Florida" fund-raiser showcasing new varieties.

Governance

Prof. Clark disclaims much in the way of formal governance structure, but the PIP website lists him along with four other faculty all of them now in Departments of the Institute of Food & Agricultural Sciences, although one was initially recruited to UF by the Dental School as an "executive council" for the program.

External advisors do not meet formally, but comprise a group that has expressed interest in the PIP and provide an external "reality check" on current projects. These include faculty from other universities (Northeastern, UC Davis); research scientists in corporations (Monsanto, whose CTO was due on campus in late 2014); foundation staff (Bill & Melinda Gates Foundation); and several individuals representing entrepreneurial interests.

Facilities

The PIP has no facilities, and has not requested the construction of any.

Financing

Discretionary funds for the PIP are generated by voluntarily contribution of royalties controlled by faculty working in applied plant breeding. One high-profile example is Prof. Clark's "Gator [Orange] Glory" Coleus, which is now used exclusively at functions of the UF Office of the President and given out at football stadium skyboxes. The Office of the President pays royalties like any other exclusively licensed user, through the Florida Foundation Seed Producers, Inc., a captive licensing arm of the IFAS. These funds have been allocated to the Flavors of Florida event.

The PIP is not seeking to raise funds for facilities or endowed chairs, but its long-term goal is to use royalties or other sources to create a "perpetual research trust" that sustains the basic

connecting work of the PIP, with as few strings as possible attached to the revenue stream. The vision is to use such funding flow to solicit and develop new ideas from faculty. One model discussed is a three-way match: one-third from a perpetual fund at the University of Florida Foundation, one-third from the IFAS, and one-third contributed by participating faculty labs.

Other funders

Among the funders who have supported PIP-initiated faculty projects are the USDA Florida Block Grant; the NIH; Coca Cola.

Lessons Learned

Prof. Clark notes:

- Programs like PIP need to be led by faculty who are primarily connectors people who may not be motivated by being the absolute best in one narrow topic, but know a lot about many different things and can assemble a team that can “translate” among the language of specialists;
- It is necessary not only to assemble teams but to give them some kind of motivation for success, which in a university setting usually means some discretionary funding for their laboratories;
- Above all, the project needs a champion willing to risk his or her whole career on it and with the energy and drive to get it done.

4. Donald Danforth Plant Science Center (St. Louis, Mo.)

Overview

NOTE: The information contained herein on the Donald Danforth Plant Science Center comes from a previously released Battelle report that is available for public download on the Web.

The Donald Danforth Plant Science Center[39] is an independent nonprofit research institute with ambitions for impact on hunger, health, and sustainability. It was founded through local philanthropic and corporate support as part of a regional economic-development initiative, and its mission embodies both global and local goals. The Danforth Center occupies a modern, custom-built structure on 40 acres across the road from the corporate and R&D headquarters of Monsanto in suburban St. Louis County. Its plans include development of additional acreage on the site as a three-building research park, separate and distinct from a larger research-park initiative six miles east, in midtown St. Louis, adjacent to the region's medical district.

The center has grown steadily since its founding in 1998 to annual operating revenues of about $25 million. As of this year, its endowment stands close to $200 million thanks to substantial additional contributions received from the Danforth Foundation as it liquidated over the last decade (see below). The Danforth Center is organized around the laboratories of principal investigators (currently 20), supported by about 200 additional staff, including visiting scholars, postdoctoral and graduate students, graduate students, and both technical and non-technical support staff. The center's mission, which has evolved over time, is now encompassed in three broad goals:

Feed the hungry and improve human health

Preserve and renew our environment

Enhance the St. Louis region as a world center for plant sciences

The center's current president is James Carrington, Ph.D., a bioinformatician who studies RNA mechanisms, and the board chair is William H. Danforth, M.D., retired chancellor of Washington University in St. Louis and founding donor through his family's foundation.

Startup Phase

History and Motivation

The Danforth Center was established by the Danforth Foundation, an independent foundation capitalized by stock in the Ralston Purina Company (merged long afterward into Nestlé, in 2001).

[39] For background see http://www.danforthcenter.org .

Donald Danforth was the son of the company founder, long-time chairman of the company, creator of the Danforth Foundation, and a passionate advocate for ending global hunger. At the time of the center's establishment, the Danforth Foundation board was chaired by Donald's son and the founder's grandson, former Washington University Chancellor William Danforth, and vice-chaired by another son, former United States Senator John Danforth.

The idea for the Center emerged in the late 1990s in discussions among civic leadership, the Danforth Foundation, and executive leadership of the locally based Monsanto Company, which was enduring a turbulent decade. The company's troubles[40] were seen as threatening the future of one of St. Louis's leading corporate citizens and therefore the region's entire economic destiny. As a consequence of these discussions, the Danforth Foundation re-oriented its grant-making away from a national program of education reform toward one of regional economic revival.

The Danforth Foundation underwrote a 10-year regional economic strategy, focused on exploiting the region's comparative advantages in the plant and life sciences. As part of this strategy, the Foundation funded staff for a Coalition for Plant and Life Sciences, and began making major gifts for strategically targeted R&D capacity: to various biomedical and plant-science departments in Washington University, and a founding commitment to the Danforth Center. The endowments of the Danforth Foundation and Washington University also collaborated with the members of the McDonnell family (inheritors of the McDonnell aircraft fortune) to make investments in venture-capital limited partnerships and source early-stage deals in plant and life sciences.

As part of this wave of activities, the Danforth Center was envisioned as a connector among several regional sources of plant-science leadership: Washington University, the Missouri Botanical Garden, the University of Missouri at Columbia, and Monsanto. It was intended to strengthen Monsanto's connection to the region and to increase the community's understanding of the potential around plant and life sciences. The Danforth Foundation endorsed all these goals but wished also to honor the commitment of Donald Danforth to application of new knowledge to alleviation of global hunger through crop improvement.

In order to achieve those goals, the center was positioned somewhere between the basic mission of an academic institution and the applied motivations of private enterprise. Its goal was always to convert research findings into actual change in agricultural practice, partnering with farmers and institutions worldwide.

Startup Financing

The Monsanto board and its philanthropic partners set a go/no target of $100 million in firm commitments that they would need in order to launch the Center, although they ultimately succeeded in raising more. The final set of commitments achieved by 1998 included:

$60 million from the Danforth Foundation;

[40] Monsanto was well into a transition from a traditional pesticide manufacturer into a biotech giant, when some of its earliest genetically modified crops ran into political opposition, depressing the stock price and making Monsanto vulnerable to a merger engineered by the then-independent Pharmacia-Upjohn, which was interested mainly in Monsanto's G.D. Searle subsidiary, and ran Monsanto's operations from Chicago. Eventually, the agbiotech operations were spun back out into a new company named Monsanto. Control returned to St. Louis, where the main agbiotech assets had remained all along.

- $25 million in tax credits from the State of Missouri (this is typically the way this state funds such public-purpose projects);
- 40 acres of Monsanto-owned land, valued at $11.4 million;
- $50 million in grants from the Monsanto Fund, a corporate foundation, and agreement to fund $30 million in research in future years.

These funds financed the design and construction of a 170,000 square-foot facility (carried on the audited financial statements at $72.4 million before accumulated depreciation); fit-out of laboratory, core services, and greenhouse/growth chamber equipment (which had reached $12.6 million in total as of 2010); establishment of an initial endowment; and early recruitment and operations.

Initial Leadership

The center founders quickly identified as their founding leader Dr. Roger Beachy, a plant scientist known for his work on virus-resistant tobacco and other crops. Dr. Beachy had at one time been on the faculty of Washington University, and so was known to Dr. Danforth. He was recruited in 1999 from what was then his position with the Scripps Institute in La Jolla, Calif., and was given wide latitude to set the initial research directions and recruitment targets for development of the Center.

Simultaneous with Dr. Beachy's recruitment, Sam Fiorello joined the Danforth Center as CEO, transferring from the executive ranks of the Monsanto Company, and has been there ever since. In 2009, Dr. Beachy left to assume leadership of the USDA's newly created National Institute of Food and Agriculture, and was replaced by Dr. Carrington. Dr. Beachy completed his public service in Washington in 2011 but continues to serve the Danforth Center as vice chair of its board.

Current Operations

Research Profile

Dr. Beachy's earliest commitments were to (1) basic research in biotic and abiotic stresses in plants and (2) applied research that attempts to take findings in model systems and apply them in the field, especially internationally. These latter tasks would not typically be recognized as important in a university environment, or worthy of direct corporate investment. Dr. Beachy focused his efforts on recruiting PIs whose work seemed to align with these broad interests, and who shared his commitment to a culture of open collaboration with university, industry and non-governmental organizations internationally. Eventually the research program has settled into several broad buckets, supported by a set of underlying academic disciplines and core laboratory services:

(Columns are independent of each other)

Topical programs (short list)	Underlying disciplines	Core lab facilities

Biofuels Biofortification Disease resistance Pesticide/fertilizer reduction Biosafety/regulation Enabling technologies Translational plant science	Plant biology & genetics Cell & root biology Biochemistry Chemistry Phytochemistry Computational/structural biology Plant immunology Plant physiology Plant pathology	Proteomics Mass spectrometry Integrated microscopy X-ray crystallography Plant tissue culture/ transformation

Academic Partner Relationships

Originally a broad set of institutions with strong agricultural programs including several out of state universities (e.g., Illinois and Purdue) were given board seats, but the strongest interaction has always been with the local academic partners. Most center PIs have joint faculty appointments (full academic rank but non-salaried) at Washington University or the University of Missouri at Columbia, which allows them to take graduate students into their laboratories. This has proved a key factor in successful recruitment.

Bench-to-bench interaction continues to occur between the center and academic institutions nationwide, but Purdue has withdrawn from formal affiliation with the governance of the Center. In projects involving specialized field trials, especially internationally, it is not uncommon for the center to subcontract funds to institutions that are not involved in its governance at all.

Talent Recruitment

Center staff includes a mixture of full (4), associate (8) and assistant (8) members, at different levels in their careers. As part of standard recruitment packages, the center pays the initial salary of new investigators and asks them over time to finance about one-third of that salary through direct charges to external grants and contracts. Any additional funds in the package can be used in any way the PI wishes, from equipment acquisition to set aside as a rainy-day fund.

There is no tenure. Assistant members are offered three-year contracts and associate and full members five years at a time. Incumbents are judged on a range of measures including their performance at attracting grants and contracts, their skills at collaboration and technology management, etc. Some PIs have moved on to other positions at the end of their terms.

Subsequent Growth and Sustainability

Since the initial founding, the center has looked for operating growth and stability to major, multiyear grant awards, both from the federal government (NSF, USDA, NIH and Department of Energy) and from private philanthropies like the Howard Buffet Foundation, the Monsanto Fund, and the Bill and Melinda Gates Foundation, all of which have strongly backed field trials in Africa of biofortified and virus-resistant cassava strains. There is also an active annual giving program aimed at wealthy individuals and generally modest corporate giving.

To date, 90% of the center's endowment has come from local sources. In 2003, the Danforth Foundation announced that it would wind down its affairs, expending all remaining assets on the plant and life science initiatives it had already started. In 2011, the Foundation made a liquidating distribution of nearly $75 million to the Danforth Center, bringing its total current endowment to nearly $165 million.

In 2007, the Taylor family, owners of St. Louis-based Enterprise Rent-A-Car, made a $35 million gift to endow an Institute for Renewable Fuels within the center. This financed the recruitment of Dr. Thomas Brutnell from Cornell's Boyce Thompson Institute and led to major research awards from the U.S. DOE.

The $24 million operating budget is derived 60% from either federal or industrial grants or contracts, and about one-third from philanthropic gifts, with the small balance from endowment earnings.

Future growth

The center is reported to be hoping to secure a major gift for international partnerships, and begin a new development campaign to help build a new wing and both endowment and expandable funds to support recruitment of additional PIs. For the first time, the center expects to reach outside the region for major gifts

Industry Relations

Existing Industry and Research Partnerships

Danforth Center management views its job as building relationships with key individuals on corporate research teams, so that they visit the center often and exchange information with center PIs about goals, priorities, and current activities. Then, when a proposal is submitted for a research contract, it builds on clear understanding of each party's interests and capabilities.

Typically senior center management will reach out to the target company's senior R&D executives, and invite them for a visit where they receive presentations by all 20 PI labs. The center follows up to ask how best to push the interaction down to the level of bench-to-bench collaboration: which corporate scientists to link up to which center PIs. Then, senior management at the center monitors the relationship in order to encourage progress but stays out of detailed management of the research projects. Such arrangements now exist with Bayer, Dow AgroSciences, BASF, Syngenta and other major companies. Companies represented on the center's board like Monsanto enjoy no advantages over other corporate partners. The center has until now not tried to raise substantial endowment funds from agricultural companies, preferring to develop research contracts and partnerships as a priority, and to develop an identity distinct from its roots in Monsanto.

In partnership with the research-park developer Wexford, the Center is developing unused acreage from the original Monsanto donation into a Bio-Research & Development Growth Park (spelled BRDG-Park and pronounced BRIDGE Park) that will ultimately comprise three buildings

totaling 450,000 square feet.[41] The center very much desires large agricultural companies based elsewhere to take space in the park, so they can use the center's core facilities and develop relationships. At present, three of Building One's 17 tenants have such close connections.

Emerging Industry and IP Management

The Danforth Center has been an active player in the Coalition for Plant and Life Sciences, and supports the regional agenda to develop startup companies around knowledge generated in local institutions. Building 1 houses Nidus Partners, created originally as a plant-science incubator that was staffed and paid for by Monsanto, but now operating as a privately owned virtual accelerator[42]. The Center also sponsors an annual Ag Innovation Showcase, which serves as a "pitch event" for agbiotech ventures and venture capitalists nationwide and showcases the St. Louis region.

The center asserts ownership to discoveries made under federal research sponsorship, but emphasizes an open-door policy on collaboration. The Danforth Center presently contracts its IP management to the Global Patent Group, a group of private-sector patent practitioners who are based in the BRDG-Park.

The Center has available limited discretionary funds, which in a university context might be called a "gap fund," to help PIs define fundable projects that will translate findings into field trials, but does not maintain any capacity for equity investment. Instead, it leverages the capability of BioGenerator,[43] a nonprofit accelerator, an important component of the region's plant and life science strategy and equipped with funds to make pre-seed and seed-stage equity investments. BioGenerator maintains its own incubator facility in Midtown St. Louis, and was a key factor in the region's success at obtaining a regional innovation cluster award from the federal government's multi-agency i6 Challenge program.[44]

Three years ago the center announced the formation of the spin-off Agrius BioForms LLC , a joint venture with GeoSynFuels in which the center holds a 49% interest, with the mission of commercializing certain biofuels research supported by USDA. On current financial statements, no value is assigned to the JV.

Appendix B

Thompson-Reuters Categories Used for Identification of records for OmniViz Analysis

AGRICULTURAL CHEMISTRY
AGRICULTURE AGRONOMY
AI ROBOTICS AUTOMATIC CONTROL

[41] See http://brdg-park.com. According to the Danforth Center's financial statements, a long-term ground lease issued to a Wexford affiliate generates $1.158 per rental square foot, yielding $127,000 a year on Building One, which is not a very significant component of the Center's operating budget.
[42] See http://niduspartners.com.
[43] See http://www.biogenerator.org/index.shtml.
[44] See http://www.eda.gov/challenges/i6/ and http://www.biogenerator.org/i6/index.shtml .

ANIMAL PLANT SCIENCE
ANIMAL SCIENCES
AQUATIC SCIENCES
BIOCHEMISTRY BIOPHYSICS
BIOLOGY
BIOTECHNOLOGY APPLIED MICROBIOLOGY
CELL DEVELOPMENTAL BIOLOGY
ENDOCRINOLOGY METABOLISM NUTRITION
ENDOCRINOLOGY NUTRITION METABOLISM
ENTOMOLOGY PEST CONTROL
ENVIRONMENT ECOLOGY
ENVIRONMENTAL ENGINEERING ENERGY
EXPERIMENTAL BIOLOGY
FOOD SCIENCE NUTRITION
IMMUNOLOGY
INSTRUMENTATION MEASUREMENT
MICROBIOLOGY
MOLECULAR BIOLOGY GENETICS
MULTIDISCIPLINARY
OPTICS ACOUSTICS
OPTICS LASER RESEARCH TECHNOLOGY
ORGANIC CHEMISTRY POLYMER SCIENCE
PLANT SCIENCES
SIGNAL PROCESSING CIRCUITS SYSTEMS
SPECTROSCOPY INSTRUMENTATION ANALYTICAL SCIENCES
VETERINARY MEDICINE ANIMAL HEALTH

Appendix C

Identified Faculty Research Foci and Potential Platform Linkages

The listing of faculty has been provided to CALS in a computer spreadsheet.

Acknowledgments

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