

Food Animal Initiative Economic Development Study



Prepared By:

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College of Agriculture and Life Sciences
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February 2020

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February 2020

Please find attached to this letter a report entitled The North Carolina Food Animal Initiative: A Feasibility Study. This report was jointly commissioned by NC State's College of Agriculture and Life Sciences and the College of Veterinary Medicine to evaluate core competencies in the animal and poultry sciences, veterinary medicine and associated disciplines, and to study the feasibility of building upon our capabilities by establishing a Food Animal Initiative (FAI).

The N.C. Plant Sciences Initiative at NC State provides the FAI a public-private partnership model it could emulate as a means to enhance the university's historical areas of strength, address gaps in capacity and proficiency, and drive bold ideas and innovation to support and accelerate the state's largest agricultural sector - animal agriculture. This report will be the springboard for NC State to develop an interdisciplinary, multi-college initiative that will help cultivate scientific breakthroughs and produce well-trained future employees to meet the needs of North Carolina's livestock, poultry sectors, and allied industries.

It is our hope that this report provides a path forward for North Carolina to grow its number one industry. If you have questions and suggestions related to this report, please direct them to either one of us or to Celeste Brogdon at cdbrogdo@ncsu.edu.

Sincerely,

A handwritten signature in black ink that reads "Richard H. Linton".

Richard H. Linton, Ph.D., Dean
NC State University
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A handwritten signature in black ink that reads "David Paul Lunn".

D. Paul Lunn, PhD, MRCVS, Dip. ACVIM, Dean
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Executive Summary

Animal agriculture, including the production and processing of livestock and poultry, is among the largest industries in North Carolina. The industry's value chain in the state is diverse and integrated, spanning the production of inputs to livestock and poultry production (growth and processing of feed grains and oil seeds, nutritional supplements, veterinary medicine products, etc.), through on-farm livestock and poultry production, and onwards into the value-added processing and distribution of food animal based products. Impacting every county in the state, the animal agriculture value chain provides employment for tens of thousands of North Carolinians across both urban and rural environments and works to supply an assured and growing domestic and international market for high quality animal derived proteins and associated food products. The industry in the state also has unique characteristics, not least of which is that it operates robust integrated systems for swine, broilers, turkeys and layers. North Carolina State University (NC State) has a long-standing history of support for this industry through research, education and extension activities and has structured its work and programs to be responsive to the integrated nature of animal production and processing in the state. Indeed, NC State is the only university in the country that has a totally integrated system for all categories of food animals.

As global demand increases, food animal agriculture represents an industry with significant promise for sustained and expanding economic impacts in North Carolina. At its heart, agriculture is an advanced life sciences industry, driven by R&D and innovation across a range of life science, physical science and engineering disciplines. It is also a complex industry, requiring management of sophisticated supply chains, production within a dynamic and changing environment, dealing with pressures and challenges from biotic and abiotic threats, and is subject to fluctuations in international trade agreements, commodity prices and other economic factors. Because of this complexity, the U.S. has long-supported the agriculture sector and its value-chain activities through the dedicated support and work of Land-grant universities (LGUs) – research intensive universities with a specific focus on the performance of R&D, education, and extension services that are purpose designed to enhance agricultural industry outcomes and solve industry challenges. NC State stands among the preeminent LGUs in the nation, ranked 6th in agricultural research expenditures, 4th in veterinary sciences, and deeply resourced in associated STEM, business and social science disciplines. Because of the diversity of agricultural production in North Carolina and the variety of climatic/production zones in the state, NC State experiences a particularly rich environment for experimentation and the performance of advanced agbioscience research. That said, NC State facilities for research and education in food animal agriculture have experienced evident underinvestment, with 20 or more years of deferred maintenance now significantly impacting the relevance and capabilities of facilities to support research and education that is responsive to the needs and practices of industry. NC State's position in food animal agriculture is at a tipping point – placed well in terms of research and educational reputation and output but restrained in its ongoing relevance to opportunities and needs by less than optimal facilities and infrastructure.

The recent Plant Sciences Initiative (PSI) at NC State illustrates a path forward, comprising an initiative purpose-designed to leverage North Carolina strengths in plant-based agriculture. The PSI has realized extraordinary support and success in its development – driven by careful deliberations in terms of research and education focus areas, associated infrastructure investments, and investment in world-class faculty and transdisciplinary science resources. Similar, but smaller scale, investment has taken place in the NC State Food

Manufacturing Initiative (FMI) also. **Now the development of similar momentum is sought at NC State via a Food Animal Initiative (FAI) – a focused collaboration between the College of Veterinary Medicine (CVM) and the College of Agriculture and Life Sciences (CALS)** seeking to positively impact the trajectory of the largest sector of agriculture and value-added activity in North Carolina – food animal agriculture. To evaluate the opportunity, identify university core competencies to build upon, assess the needs and opportunities within North Carolina industry, and develop a preliminary action plan for the FAI, NC State retained the services of TEconomy Partners (TEconomy) comprising the same analysis and strategic planning team that performed the economic feasibility analysis and planning assessments for the PSI and FMI.

In performing this feasibility analysis for the FAI, TEconomy has performed a broad range of quantitative and qualitative analytics. The current status of animal agriculture and associated industries are assessed through industry targeting analysis, productivity analysis and additional metrics. In addition food animal research themes are evaluated in detail, together with NC State’s specific core competencies, using machine learning algorithms supplemented by on-campus interviews with faculty and reviews of previous surveys of faculty research capabilities and interests. TEconomy also reached-out to business leaders within the food animal industries value chain in North Carolina to assess their interests and thoughts regarding the FAI concept and what they would value in terms of potential research thrusts, education initiatives and related extension work. Learning from several other programs at universities in North America focused on food animal agriculture was also integrated into the project. The net result is an in-depth assessment of the food animal agriculture value chain in the state, the applied issues and needs that industry prioritizes, and the capacity of North Carolina State University to respond to these needs and other opportunities using research, education and extension activity focused through a dedicated Food Animal Initiative.

A. The Economic Imperative For North Carolina

North Carolina is among the national leaders in food animal agricultural production. Ranked 2nd in the nation in hog production, 3rd in the nation in broiler production and 2nd in turkeys, food animal agriculture is foundational to the overall economics of North Carolina’s statewide agricultural industry. Its impact is felt upstream and downstream of livestock and poultry production, with the majority of grain and soybeans grown in the state purchased as animal feed, and the presence of a significant livestock and poultry processing and value-added food products industry. The importance of the food animal sector to the state’s agricultural economy is highlighted by the fact that the most recent data from the National Agricultural Statistics Service (NASS) for North Carolina shows that 65.8% of North Carolina’s farm revenues are generated by animal agriculture (livestock, poultry and their products).

Having a statewide footprint, agriculture is exceptionally important as a fundamental driver for rural areas of the state, and it also directly impacts suburban and urban North Carolina through processing industries and a significant R&D sector. Using input/output analysis, TEconomy modeled the economic impact of the animal agriculture in the state¹, finding that just a one-percent increase in production in primary animal agriculture and in downstream value-added processing results in large-scale employment, income and economic output impacts (Table ES-1).

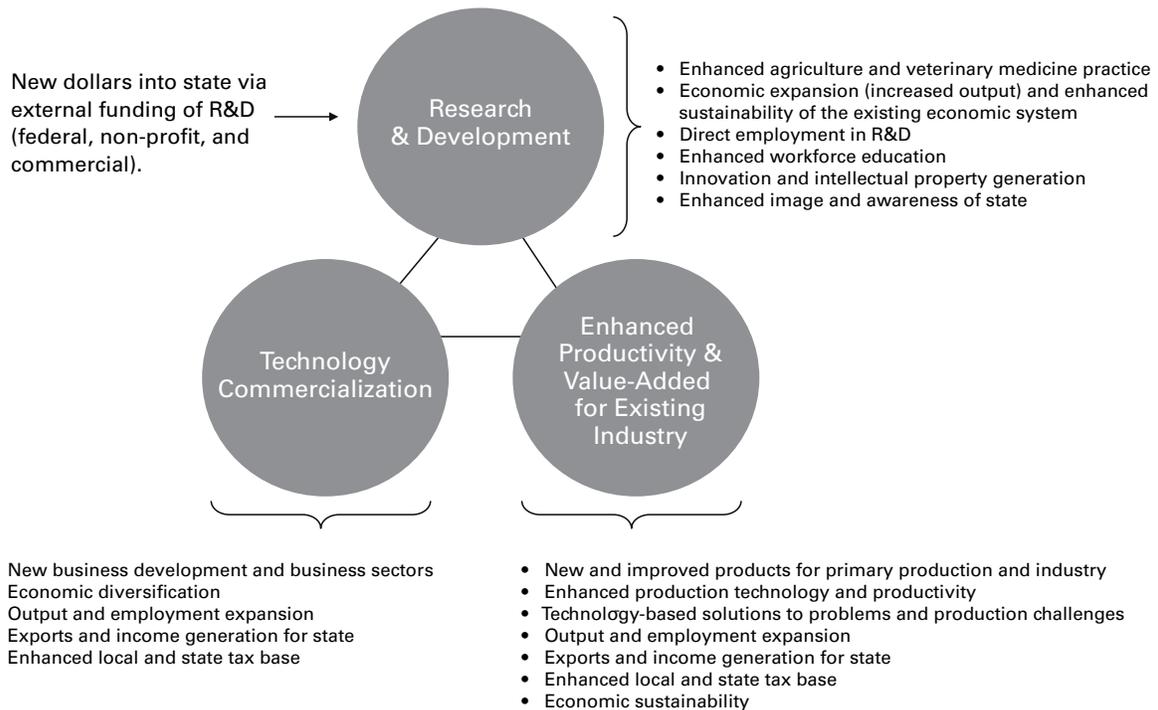
¹ For further detail on the input/output analysis see Appendix D. It should be noted that the food animal production and value-added processing numbers cannot be added together since part of the impacts in processing are derived from generation in increasing demand for local animal production. Adding the two rows would, therefore, lead to some double counting.

TABLE ES-1: ECONOMIC IMPACT OF A ONE-PERCENT INCREASE IN NORTH CAROLINA FOOD ANIMAL AGRICULTURE

	Impact on NC Employment	Impact on North Carolina Labor Income	Impact on North Carolina Economic Output
1% Increase in Food Animal Agricultural Production	685 additional jobs created	\$42 million in income for NC workers	\$149.5 million growth in state economic output
1% Increase in Processing of Food Animal Products	1,023 additional jobs created	\$54.1 million in income for NC workers	\$272.7 million growth in state economic output

As the impact data show, continuing to advance research, education and extension to meet the needs of the food animal agriculture industry in NC is not only necessary for helping the industry adapt to challenges and opportunities, but is also the source of significant economic development benefits. Investing in the R&D, education and extension ecosystem at NC State for food animal agriculture provides multiple pathways to North Carolina economic development as shown on Figure ES-1:

FIGURE ES-1: PATHWAYS TO FOOD ANIMAL AGBIOSCIENCE, VETERINARY SCIENCE AND TECHNOLOGY-BASED ECONOMIC DEVELOPMENT



Input received from industry representatives and other key stakeholder within North Carolina points to considerable support for a focused initiative at NC State that would enhance research, education and extension work in food animal agriculture. Chapter III of the report summarizes specific industry opinions, and the overall industry input received points to:

- A need for transdisciplinary approaches to complex issues in livestock and poultry agriculture
- A need for modern facilities at NC State able to duplicate the latest production environments for research and education relevance
- Support for a research focus on animal health, infectious diseases and food safety. These are viewed as crucial areas to emphasize, and broad enough in content to allow considerable transdisciplinary engagement and naturally support CVM/CALS collaborations (indeed in discussing other areas, such as nutrition, reproduction, welfare, genetics, etc. the discussion often circled to the impact of these on livestock health and disease resistance).
- Attention needs to be paid to agriculture communications and the use of science-based data and information to combat misunderstandings and disinformation that negatively impact the livestock and poultry sectors freedom to operate.

Why a Food Animal Initiative?

The grand challenges facing food animal agriculture increasingly call for transdisciplinary approaches and accommodation of multi-disciplinary research teams, together with an ability to integrate industry researchers into the process. NC State generally lacks the facilities for this activity in food animal agriculture and associated areas (although the CVM does have modern accommodations for industry co-location).

Modern food animal agriculture is increasingly deploying advanced and automated technologies across its production facilities and NC State's current research facilities and research farms lack the facilities to conduct research within relevant modern production environments. Similarly, the lack of representative production environments limits the ability to introduce students to the latest production practices and methods they will encounter when they enter the workforce. The development and testing of advanced technologies and the promise of digital agriculture advancements through sensors and data analytics needs facilities specifically designed or retrofitted to accommodate research, testing and piloting of new and experimental technologies.

Industry is deeply concerned with threats to animal health and food safety. While NC State has faculty expertise in livestock and poultry infectious diseases, veterinary medicine, and associated scientific disciplines, the University lacks sufficient facilities for conducting live animal research that requires Biosecurity Level 2 or 3 facilities. While CALS and CVM scientists are seeking to bring their skills together for transdisciplinary research in infectious disease and animal health, the lack of enough BSL facilities places a block on research advancement.

Advancements are needed in managing waste streams and realizing value from them, in terms of both primary on-farm production and in processing operations – with a desire for moving towards closed loop systems.

While North Carolina shows high levels of productivity in primary food animal production, the state has a comparatively undersized and underperforming processing industry profile. NC State's ability to improve the performance of the processing sector is hampered by a lack of investment in facilities and faculty R&D relating to meat processing and animal-based food product manufacturing. With global demand increasing substantially for high quality animal protein, there is a clear opportunity to advance the industry in North Carolina through enhanced research, education and extension activity in downstream processing. While the Food Manufacturing Initiative is addressing opportunities for increasing value-added to NC produced crops, a matching investment is needed on behalf of animal agriculture.

Animal agriculture research facilities have generally seen limited investment across the national research ecosystem, and North Carolina is presented with an opportunity to make a high-profile investment in facilities, programs and faculty that will propel the University to the forefront of a large global industry that has a substantial footprint in the University's home state.

Development of unique, state-of-the art food animal agriculture and veterinary medicine facilities will help attract the best and brightest talent in associated sciences to NC State.

Input received from stakeholders and from interviews with faculty and staff at NC State, suggests a topline vision for the FAI as shown in the sidebar:

The Food Animal Initiative is viewed by stakeholders, and supported by the core competency, industry needs and opportunity assessment as being a “must do”. Its importance to the state will be felt through:

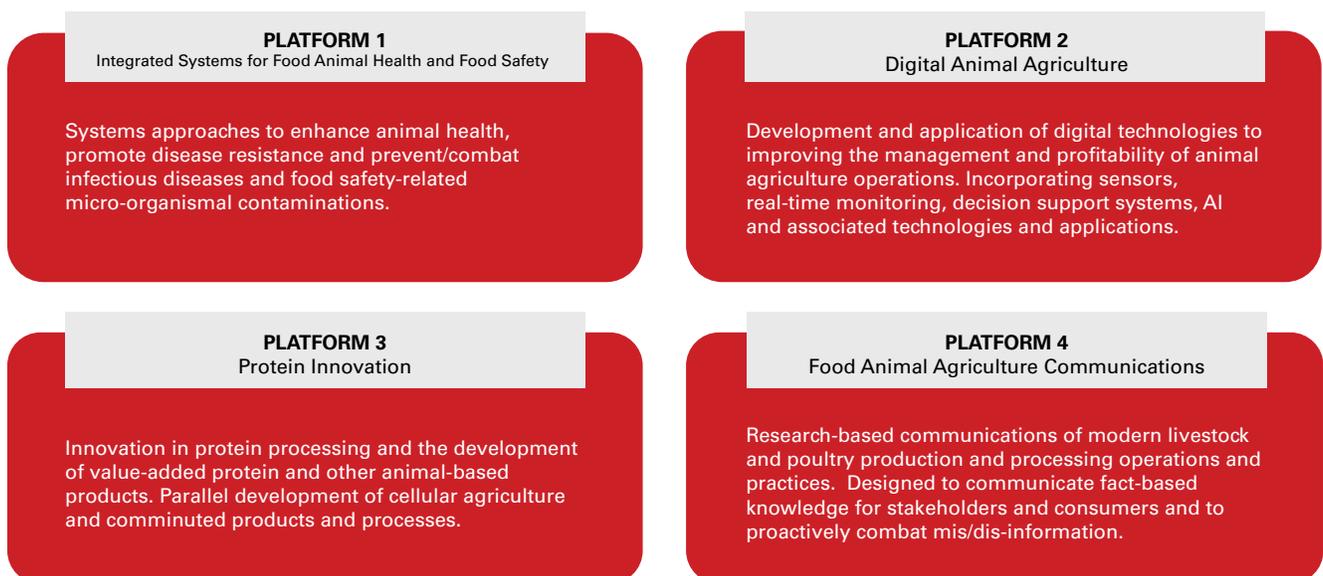
Topline Vision for the Food Animal Initiative:
 Develop a transdisciplinary, multi-college initiative that will propel NC State to the forefront of global food animal research based academic institutions and develop innovations and well-trained students to meet the needs of North Carolina’s livestock and poultry sectors and allied industries.

- Directly working to advance opportunities and address needs in a critical area of the North Carolina economy.
- Addressing major applied research needs that require the transdisciplinary capabilities that only an institution of the caliber of NC State can address.
- Raising the standard of facilities for animal agriculture research and education at NC State to best-in-class as opposed to the current status of barely adequate.
- Complementing and leveraging the signature NC State investments in CVM, the Plant Sciences Initiative and the Food Manufacturing Initiative.

B. What Focus Areas or “Development Platforms” Should a Food Animal Initiative Emphasize

TEconomy undertook detailed quantitative and qualitative assessment of sector needs and university core competencies. The work led to an in-depth understanding of where NC State has current strengths to build upon that are relevant to identified needs and opportunities across the food animal agriculture value-chain. Analysis led to a rating of potential topics, integrating input from university faculty, industry leaders and other key stakeholders. The key elements, or development platforms, for the FAI, became quite clear through this process – with the following development platforms recommended:

FIGURE ES-2: RECOMMENDED DEVELOPMENT PLATFORMS FOR THE FOOD ANIMAL INITIATIVE



(Each comprising research, education, and Extension activities)

Platform 1: Integrated Systems for Food Animal Health and Food Safety – a transdisciplinary approach to develop and quantify effective systematic solutions to improve animal health and address pathogen contamination. Will include research, education and extension activity in areas such as:

- Surveillance and monitoring systems in primary production and processing
- Diagnostics and rapid pathogen detection systems
- Immunology, vaccines and immunotherapeutics
- Nutritional impacts on animal health and livestock immune systems
- Microbiome and gut health effects on livestock health
- Housing, management, welfare and handling system impacts on livestock health
- Genetics and livestock improvement for health and pathogen resistance
- Health decision and practices that positively influence animal well being
- Operation of new BSL2 facilities, and potentially BSL 3.

Platform 2: Digital Animal Agriculture – focused on development and application of digital technology in livestock and poultry production and downstream processing operations. The platform leverages NC expertise in engineering, computer science, advanced analytics together with the domain specific expertise contained in CALS and CVM. Will include research, education and extension activity in areas such as:

- Sensors and networked systems
- Advanced analytics and AI
- Machine vision and recognition
- Agricultural engineering
- Animal health and well being
- Food processing.

*Infectious diseases and livestock health are what keep producers “up at night.” It is a broad area of concern, covering worries relating to emerging/re-emerging infectious diseases (including exotic infectious diseases), the challenge of reducing antibiotic use, pathogen contamination and food safety, etc. **Industry views this challenge as needing an “all of the above” approach now – envisioning a systems approach** that uses: vaccines and immunotherapeutics; study of the livestock microbiome to understand impact on health and ability to stave off disease; study of livestock genomics to identify resistance/health traits and markers; nutritional approaches to boosting the livestock immune system (including during pregnancy or in-the-egg); the use of precision/digital technologies to monitor animals and produce early ID of emerging symptoms, and use of precision technologies to combat risk of food safety challenges. This broad area of focus is seen as an excellent area for engagement of both CALS and CVM, plus engineering and other university capabilities.*

As discussed below, each of the platforms, including the Digital Animal Agriculture platform will benefit from development of NC State’s Lake Wheeler site into a modern research, education and demonstration farm, purpose designed to be fully instrumented and reconfigurable for demonstrating, testing and innovating livestock production systems. This will require livestock housing systems of a high industry standard, fully instrumented and networked to facilitate the development and use of precision animal agriculture technologies. This “Forefront Farm” should be structured to facilitate industry engagement and co-location of university-industry collaborative teams for joint participation in research programs. The Forefront Farm should also form the hub of a network for precision animal infrastructure installed at other major NC State livestock research facilities and at participating industry sites, serving to build a powerful data collection and analysis network for application to work across the platforms.

Platform 3: Protein Innovation – Potentially collocated with the envisioned Forefront Farm a platform in Protein Innovation would focus on R&D and training focused on value-added meat and animal protein product processing. Incorporating slaughter and processing operations, the platform and its Protein Innovation Center would allow innovation to be pursued in the safe processing of protein products, integration of sensing and digital technologies into a holistic livestock rearing through processing value-chain, and potential integration of emerging NC State capabilities (and industry interests) in cellular agriculture. This platform could also work on other value-added food animal products, but protein is viewed as a principal demand area based on growth in global population and food demand patterns.

Platform 4: Food Animal Agriculture Communications – Voiced by industry and faculty alike, there is strong recognition that freedom to operate in animal agriculture is under threat and subject to significant misinformation and disinformation challenges. TEconomy believes that these challenges should be addressed through a two part approach:

- Design of the recommended Forefront Farm to be visitor friendly (within the constraints imposed by biosecurity), representing a showplace and demonstration site for modern approaches to livestock agriculture and food animal welfare. Forefront Farm can be rapidly integrated into student curriculum, extension programs and public educational events in the state capital.
- Development of a small team at NC State focused on proactive communications with the public, policy makers and other key stakeholders regarding modern animal agriculture and focused on combatting mis/disinformation where identified. The team should connect to and support the existing Council for Agricultural Science and Technology (CAST), which is an existing science-based agricultural communications organization² and with other organizations and initiatives such as The Center for Food Integrity³. By leveraging existing organizations the Food Animal Initiative can work to meet the goals of combating mis/disinformation without having to undertake major research programs or substantial faculty recruitment in the area.

Animal health and food safety are certainly viewed as a crucial area for the FAI to emphasize by industry. The review of NC State core competencies, across CALS, CVM and beyond, show that this is also a logical area where current and emerging strengths can be built upon collaboratively. Digital Animal Agriculture provides similar opportunities for collaborative research and education activity between CALS, CVM and other University colleges (such as the College of Engineering and the Poole College of Management). The Food Animal Initiative provides an opportunity to do something that is very hard for industry to do (if not impossible), but realistic in a large university setting, that of developing major transdisciplinary programs that integrate multiple fields of study and interest areas into a systems approach to major challenges in integrated food production and processing systems.

2 CAST is a nonprofit 501 (c)(3) organization composed of scientific societies and many individual, student, company, nonprofit, and associate society members. CAST's Board is composed of representatives of the scientific societies, commercial companies, and nonprofit or trade organizations, and a Board of Directors. CAST was established in 1972 as a result of a 1970 meeting sponsored by the National Academy of Sciences, National Research Council. The primary work of CAST is the publication of task force reports, commentary papers, special publications, and issue papers written by scientists from many disciplines. The CAST Board is responsible for the policies and procedures followed in developing, processing, and disseminating the documents produced. These publications and their distribution are fundamental activities that accomplish our mission to assemble, interpret, and communicate credible, balanced, science-based information to policymakers, the media, the private sector, and the public. The wide distribution of CAST publications to nonscientists enhances the education and understanding of the general public. CAST addresses issues of animal sciences, food sciences and agricultural technology, plant and soil sciences, and plant protection sciences with inputs from economists, social scientists, toxicologists or plant pathologists and entomologists, weed scientists, nematologists, and legal experts. CAST's mission statement is: "CAST, through its network of experts, assembles, interprets, and communicates credible, balanced, science-based information to policymakers, the media, the private sector, and the public." Its vision statement is: "A world where decision making related to agriculture and natural resources is based on credible information developed through reason, science, and consensus building." See: <http://www.cast-science.org/about/>

3 <http://www.foodintegrity.org/about/who-we-are-2/faq/what-programs-does-cfi-offer/>

The Plant Sciences Initiative is investing in a state of the art plant sciences research and education building on the Centennial Campus in Raleigh. The development of the new building is, in part, a response to recognition that agricultural science facilities at the University had become very much outdated and presented a serious constraint to the pursuit of advanced R&D in plant sciences. The same also holds true for facilities on the food animal R&D and training side of the equation. In some areas critical infrastructure that is needed to advance R&D in food animal agriculture is missing altogether (for example animal housing and research facilities with required biosecurity levels, and meat processing facilities), while other facilities and infrastructure are not to modern standards or are experiencing heavy maintenance requirements as they have been used beyond their anticipated life. Overall, the infrastructure and livestock/poultry facilities at NC State no longer are able to demonstrate best industry practices or support the types of advanced research needed to address major challenges in food animal agriculture.

If NC State wants to lead in advanced food animal agriculture research and training, and be able to maximize its positive impacts in North Carolina, it needs to build a food animal Forefront Farm to be able to demonstrate/duplicate current industry standards, and design it to be reconfigurable and fully instrumented to allow for experiments and testing programs. The 1,500 acre Lake Wheeler Road Field Laboratory (Figure ES-3), located in Raleigh, provides an extremely well-located site for development of the envisioned infrastructure, while other sites in the area, such as the Teaching Animal Unit of the College of Veterinary Medicine and CVM infectious diseases research barns and facilities should be considered components of the farm (i.e. it does not all need to be on a single site).

FIGURE ES-3: VIEW OF LAKE WHEELER ROAD FIELD LABORATORY



The Lake Wheeler site contains multiple existing facilities and assets that may be integral to systems approaches to animal agriculture and contains the developable space required for the development of new and renovated assets. Figure ES-4 Illustrates this:

FIGURE ES-4: ADDITIONAL AND EXISTING ASSETS FOR FOREFRONT FARM AT LAKE WHEELER



Note: The Teaching Animal Unit (TAU) and infectious diseases research facilities of the College of Veterinary Medicine also represent important components to integrate as non co-located assets for Forefront Farm.

As envisioned, Forefront Farm would form the central location for joint CALS, CVM (and other NC State colleges) interactions and collaborative education, research and extension activity in food animal agriculture, with direct relevance to three of the four platforms:

- Integrated Systems for Food Animal Health and Food Safety
- Digital Animal Agriculture
- Food Animal Agriculture Communications.

It is further recommended that development of a physical Protein Innovation Center take place and be collocated with the Forefront Farm, incorporating existing assets and adding new capabilities as illustrated on Figure ES-5.

FIGURE ES-5: ADDITIONAL AND EXISTING ASSETS FOR A PROTEIN INNOVATION CENTER

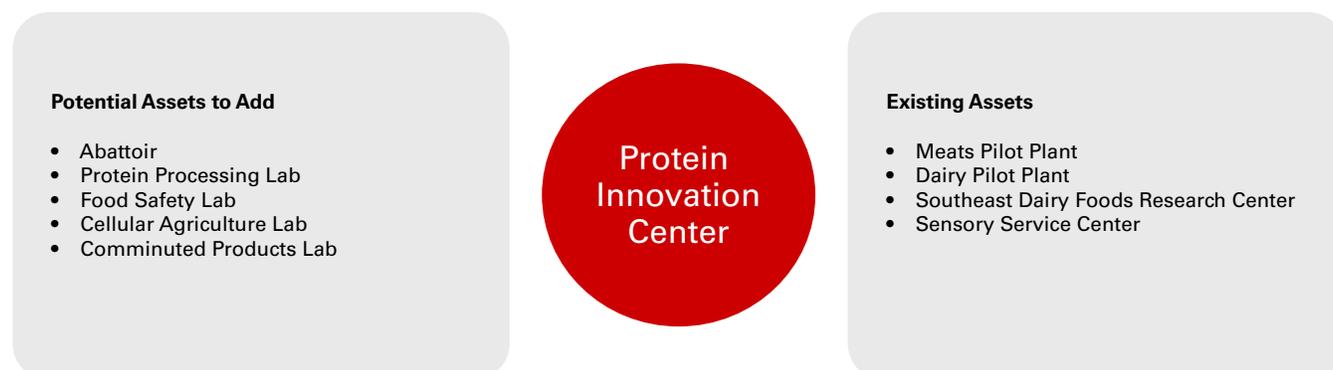
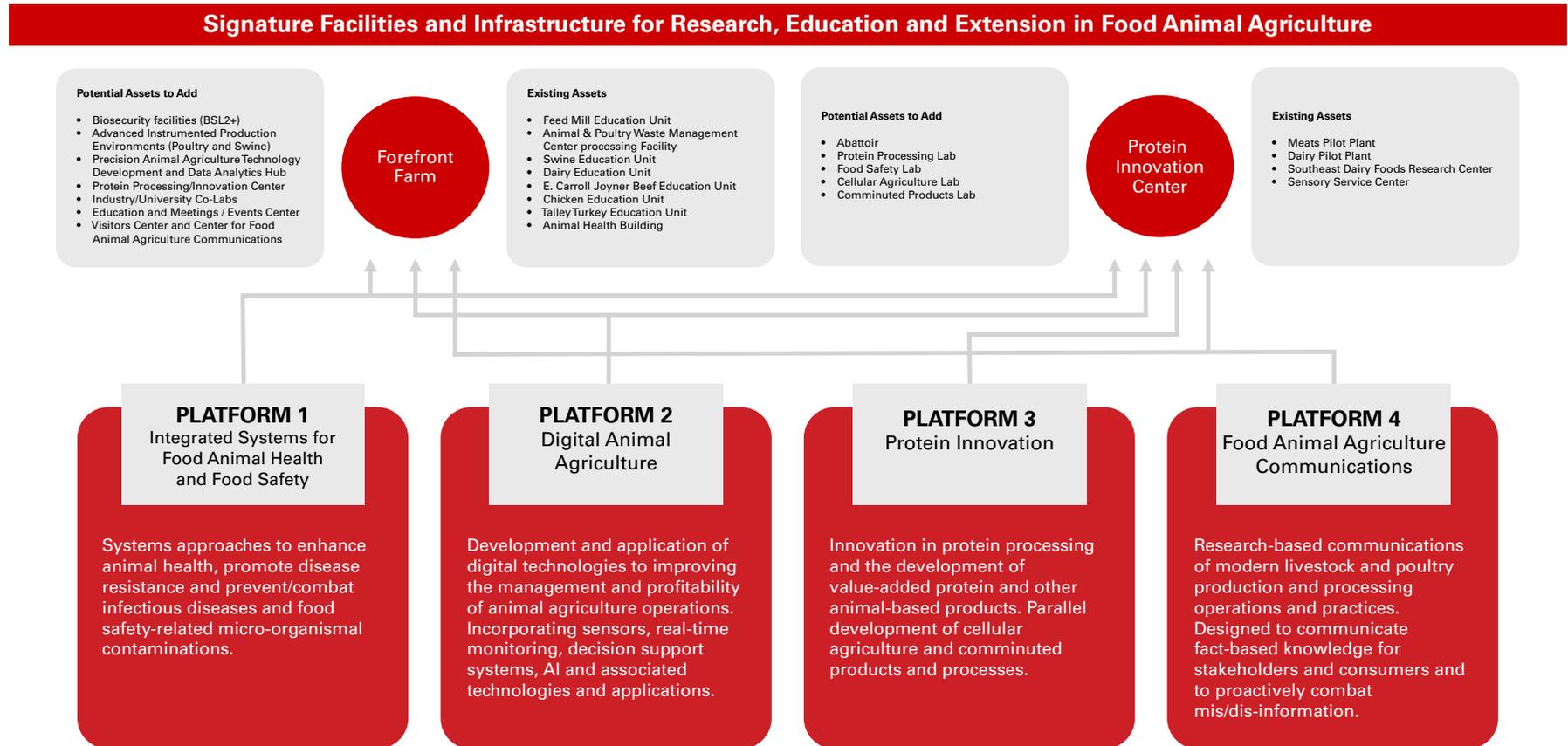


Figure ES-6 shows the recommended signature facilities and infrastructure investments (Forefront Farm and the Protein Innovation Center) and their relationship to, and critical support for, the four recommended development platforms.

FIGURE ES-6: FOOD ANIMAL INITIATIVE RECOMMENDED PLATFORMS AND SIGNATURE FACILITIES DEVELOPMENT



Rather than limiting activities in the Food Animal Initiative to just one or two main disciplines of fields, the four platforms proposed for the FAI provide the ability to integrate a substantial number of core competency areas identified across the University into focused initiatives directed at challenge-oriented needs and opportunities of relevance to both global challenges and issues of direct relevance to the North Carolina agricultural economy. Platforms 1, 2 and 4 also provide signature opportunities for CALS and CVM collaboration in areas that are of demonstrated concern and interest to industry and are structured to accomplish work in ways that industry would find highly difficult to do alone. This leverages the transdisciplinary strengths of a world class research university and the Forefront Farm concept focuses investment in assets and infrastructure to support innovative research, technology development, innovation piloting and demonstration. This also builds a unique environment for education and training across undergraduate, graduate and

professional fields. This recommended model also has the advantage of building connectivity to other major NC State initiatives:

- The Integrated Animal Health Management platform clearly brings CVM and CALS together around a highly relevant shared focus, and also provides opportunities to link to the PSI in relation to feed impacts on animal health and leverage the microbiomics capacity developing within the PSI.
- The Protein Processing platform connects the FAI and the Food Manufacturing Initiative, and gives the Food Manufacturing Initiative a base of operations in Raleigh at the proposed Forefront Farm
- The Forefront Farm provides opportunities for interfacing with the PSI in precision and digital technologies, and its Digital Animal Agriculture platform allows the powerful investment that NC State has made in engineering capabilities and data sciences to be leveraged.

C. Strategies and Actions to Advance the Food Animal Initiative

The development of the Food Animal Initiative is quite rightly being undertaken using an input process involving multiple stakeholders. A committee comprising CALS and CVM leadership is guiding the process and it is evident that care has been taken in providing an inclusive process that engages faculty, students, industry and other stakeholder groups. TEconomy puts forward the following five strategies (and 40 associated specific actions, outlined in Chapter VI) not as a rigid prescription, but rather as conceptual strategies and actions recommended for further discussion and consideration within the FAI planning process. This mirrors the successful planning and deliberations process used for the PSI.

The strategies and actions have been developed using a series of assumptions:

- The FAI seeks to be world-class signature program for NC State, equivalent in stature to the PSI
- The University will be successful in securing sufficient funds, potentially in the order of \$200+ million to build the infrastructure necessary to realize the Initiative’s vision
- Structures and policies will be put in place within CALS and CVM that require faculty collaborations and transdisciplinary research and education program engagement
- The FAI will have a strong orientation towards meeting the applied and prioritized needs of food animal production and processing industries of relevance to North Carolina and will be designed to facilitate industry/university collaborations.

Five primary strategies are proposed for the Food Animal Initiative:

Strategy 1	Develop a Farm of the Future or “Forefront Farm” as a high visibility, signature development that will provide the modern R&D, education and production environment infrastructure required to propel NC State to the forefront of food animal science and veterinary medicine.
Strategy 2	Build transdisciplinary teams and infrastructure to advance NC State food animal agriculture and veterinary sciences work in the primary development platforms.
Strategy 3	Recruit faculty to reinforce strengths, address skills gaps relevant to the platforms and create opportunities for collaborative research.
Strategy 4	Develop undergraduate, graduate and certificate programs that are focused in the three platforms and developed with input from industry.
Strategy 5	Develop a proactive Food Animal Agriculture Communications program.

As noted above, further detail, including a series of 40 recommended actions are profiled in Chapter VI. Benchmarking analysis performed by TEconomy reviewed several other North American initiatives and programs⁴ focused around food animal agriculture (see Appendix A), and it is found that none of these duplicate the comprehensiveness, infrastructure development and development-oriented platform focus envisioned for the NC Food Animal Initiative (although there are important lessons to be gained from them).

D. Conclusion

As envisioned herein, the Food Animal Initiative is proposed as a multi-college NC State initiative focused on advancing research addressing prioritized food animal industry challenges and education to meet the needs of livestock and poultry production and processing sectors. It is recommended that the Initiative feature a signature investment in a Forefront Farm and collocated Protein Innovation Center, providing the state-of-the-art infrastructure, research and training environments required to support ongoing work of CALS and CVM in food animal agriculture and veterinary sciences, and advance four specific platform-focused transdisciplinary development platforms in **Integrated Systems for Food Animal Health and Food Safety, Digital Animal Agriculture, Protein Innovation, and Food Animal Agriculture Communications.**

By working in these platform areas, the FAI will have high visibility in areas of substantial importance to North Carolina and national food animal sectors – addressing animal health and food safety (two issues at the forefront of challenges expressed by industry), enhanced production efficiencies through improved animal health, enhanced production efficiencies through the application of digital technologies and data science to food animal agriculture, and innovations to advance the value-added protein processing and food products manufacturing sector for the state. The FAI will also pay close attention to advancing fact-based communications on the realities of modern food animal agriculture, thereby working to secure freedom to operate for modern integrated food animal operations required to meet global food demand.

The FAI's unique infrastructure and platform focus will provide a competitive advantage for North Carolina in applications for external research funding, and serve as a signature attractor for joint R&D programs with industry, and a world-class hub for attracting and training high quality students who will be well prepared to lead future advancements in food animal agriculture and be highly attractive to employers in food animal production and processing industries.

⁴ Reviewed in the benchmarking analysis are: Kansas State University Beef Cattle Institute and Animal health Corridor; Michigan (Michigan State University Alliance for Animal Agriculture; University of Georgia, and the University of Saskatchewan Livestock and Forage Center of Excellence. There is significant intelligence and peer learning that may be derived via review of the benchmarking in Appendix A, which covers for each university: initiative background; primary thrusts/elements; origins; governance; industry collaboration; inter-college collaboration; facilities; incentives, and overall lessons learned.

I. Introduction

A. Global Food Demand – Livestock and Poultry

As of July 1, 2019, the world's human population stood at 7.7 billion.⁵ Population projections by the United Nations suggest that by 2030 the global population will rise to 8.6 billion, and by 2050 it may reach 9.8 billion.⁶ The phenomenon of rising population levels, now combined with rising global incomes, leads to a substantial increase in the demand for animal-derived foods because, as the World Health Organization (WHO) notes, "there is a strong positive relationship between the level of income and the consumption of animal protein."⁷

Meeting the increasing demand for high-value animal protein (from meat, milk and eggs) and associated food products is no small task. In recent years the world's livestock sector has experienced unprecedented growth, to an extent that WHO reports that "annual meat production is projected to increase from 218 million tonnes in 1997-1999 to 376 million tonnes by 2030."⁸ What these projections illustrate, is that while population may increase 10.8% by 2030 over current levels, demand for animal-based food products is likely to experience a rate of growth several times higher.

Increasing our production of food above current levels and meeting the large-scale demand increases projected for livestock products is a major challenge. Good agricultural land is already in production worldwide, and pressing other, more fragile and marginal lands into production, degrades the environment and the valuable ecosystem services and biodiversity provided by natural non-cultivated land. In effect, the awesome challenge for those in agricultural sciences and animal agriculture is to achieve increases in livestock production outputs sufficient to meet large-scale demand increase without significantly increasing the land footprint used in production.

A Perspective on The Challenge

It is difficult to envision a more challenging task than that of meeting rising global demand for animal protein. Consider that this needs to be accomplished ideally while:

- Maintaining present landmass used for primary livestock and poultry production.
- Increasing feed availability for expanding livestock populations while maintaining present landmass.
- Increasing the comfort, welfare, health, safety and wholesomeness of livestock throughout production and processing.
- Reducing the use of antibiotics and growth hormones in response to regulatory and consumer demands.

⁵ <https://www.worldometers.info/world-population/>

⁶ United Nations. World Population Forecast (2020-2050). UN Department of Economic and Social Affairs, Population Division. World Population Prospects: The 2017 Revision. (Medium-fertility variant). Reported at: <https://www.worldometers.info/world-population/>

⁷ World Health Organization. Global and regional food consumption patterns and trends – availability and changes in consumption of animal products. Accessed online at: https://www.who.int/nutrition/topics/3_foodconsumption/en/index4.html

⁸ Ibid. Note that 1 tonne (metric) = approximately 1.10 U.S. tons.

- Keeping the environmental emissions of livestock agriculture at, or ideally below, current levels.
- Operating in a natural environment, subject to changing and often unpredictable biotic and abiotic challenges (such as emerging diseases, pests, drought, floods, etc.).
- Maintaining competitiveness in the face of changing commodity prices, market conditions, consumer preferences, trade conditions, etc.
- Maintaining biosecurity in the face of rapid global transportation networks and the threat of deliberate and accidental food contamination events.
- Operating in an environment that is challenged (particularly in developed nations) by anti-animal agriculture activists, persistent mis/dis-information campaigns, and a general public that is commonly quite poorly informed regarding modern livestock production practices and systems.

In addition to the above challenge of feeding the world, animal agriculture is also part of a substantial value-chain that contributes non-food biomass to the production of value-added industrial products. Animal agriculture produces oils and fats used in a range of industrial processes, leather and fiber materials, and manure-based fertilization products and biofuels. On the frontiers of animal science, livestock species are also being used to produce biopharmaceuticals, vaccines, therapeutic tissues and as model systems for human biomedical science research. These industrial applications of animal agriculture production further factor into the food security equation and are significant in enabling development of a more sustainable, bio-based global economy.

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 represent the largest industry in the state.**

B. Animal Agriculture in North Carolina

Within North Carolina, agriculture is a particularly important statewide industry. Present in every county, agriculture is foundational to the state, regional and local economies with a production and processing profile that benefits both rural and urban North Carolina and all North Carolinians. The most recent State Agricultural Overview for North Carolina, produced by the United States Department of Agriculture (USDA) National Agricultural Statistics Service (NASS), highlights a total market value of North Carolina agricultural products sold at \$12.59 billion, with \$8.29 billion **(65.8%) generated by animal agriculture** (livestock, poultry and their products), and the remaining \$4.3 billion (34.2%) generated by the value of crops and horticultural

North Carolina Animal Agriculture Inventory (January 2019)

Chickens, Broilers = 873,600,000
Chickens, Layers = 14,600,000
Turkeys = 32,500,000
Hogs = 9,100,000
Cattle (including calves) = 800,000
Cattle, Cows, Beef = 367,000
Cattle, Cows, Milk = 43,000
Goats, Meat and Other = 49,000
Goats, Milk = 6,000
Sheep (including lambs) = 29,000

Source: USDA/NASS 2018 State Agriculture Overview for North Carolina.

products.⁹ With two-thirds of the value of agricultural production in North Carolina centered on food animals, it is not surprising that the state ranks 6th in this sector in the nation, whereas in crops it is ranked 18th.¹⁰

The importance of food animal agriculture to the overall agricultural production of the State is actually understated in the above statistics. A large proportion of the value of crops produced in North Carolina is realized through the sale of crops as feed inputs to livestock and poultry operations. Thus, much of the crop production activity in North Carolina is part of a vertically integrated animal agriculture value-chain. Other than tobacco, several of the leading crops produced in North Carolina in terms of production acreage and value of production are primarily grown as feed inputs for animal agriculture. Among these are \$408 million in corn, \$464 million in soybeans, and \$272 million in hay.¹¹

When looking across the entire agricultural value chain (from the development and production of inputs, through primary production, and onwards into the full-scope of value-added processing industries), agriculture, along with the related food manufacturing, forestry, and natural fiber industries are incredibly important to North Carolina's economy. Analysis by NC State University placed the value of agriculture and agribusiness (food, fiber, and forestry) at \$78 billion or nearly one-fifth of the state's GDP and found that this value-chain employed 642,000 of the state's 3.8 million employees (16.7% of all employment in the state) in 2012.¹² As noted above, animal agriculture is the largest of the primary production sectors and thus stands at the heart of this large scale value-chain for North Carolina.

C. Animal Agriculture as a Science- and Technology-Based Economic Development Opportunity

R&D in topics of importance and relevance to animal agriculture is not only valuable in terms of the enhanced production of food animal output and the growth in the economy that may result. **It is also an important pathway to the development and growth of advanced, science and technology-based industries that produce inputs, production and processing technologies used within the food animal agriculture value-chain.** Modern animal agriculture is an advanced life-science industry that uses a broad variety of innovative R&D technologies and skilled scientific talent to advance productivity, animal welfare, environmental sustainability, food safety, food quality and other positive production variables.

The diversity of livestock and poultry species, variability in production environments, variability in abiotic and biotic stressors, changing regulatory policies and consumer preferences, and a host of other factors, provide a rich environment for R&D-driven solutions to needs. **As such, animal agriculture provides opportunities not only for economic development rooted in primary animal production and processing activity but also for development of innovative R&D-based industries that supply into the food animal production value-chain.** Here there are a diverse range of needs and companies working to meet these needs, for products that address:

- Livestock reproduction and genetics
- Livestock and poultry health (diagnostics, vaccines, therapeutics, medical tech and devices)
- Animal nutrition (livestock and poultry feed, feed supplements and probiotics)
- Animal welfare and handling

9 USDA/NASS 2018 State Agriculture Overview for North Carolina. Statistics for production values are from the 2012 Census of Agriculture. Accessed online at: https://www.nass.usda.gov/Quick_Stats/Ag_Overview/stateOverview.php?state=NORTH%20CAROLINA

10 Ibid

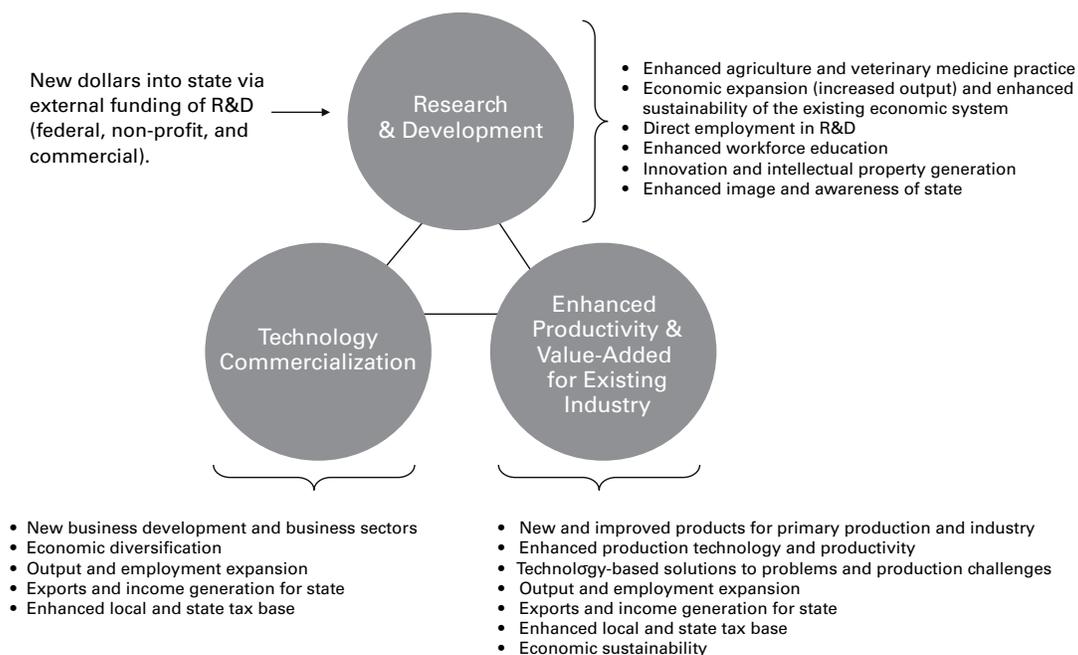
11 USDA/NASS 2018 State Agriculture Overview for North Carolina. 2018 crop production statistics.

12 North Carolina State University, College of Agriculture and Life Sciences, "Agriculture and Agribusiness: North Carolina's Number One Industry," Fact Sheet, 2013.

- Housing and environmental controls
- Waste management and nutrient recycling
- Processing and packaging technologies
- Food safety

With North Carolina’s rich history of technological innovation, NC State’s adjacency to industry within Research Triangle Park, and other life-science/R&D hubs in North Carolina (e.g. Kannapolis), **a Food Animal Initiative (FAI) may present a significant opportunity for advancing existing and new industries to meet the present and future needs of the food animal production chain.** The FAI may, therefore, be designed to solve challenges and improve the output and profitability of North Carolina animal agriculture operations, and to realize economic growth through the development and production of technologies used within food animal industries. The multiple pathways toward food animal agriculture based economic development are shown on Figure 1:

FIGURE 1: PATHWAYS TO FOOD ANIMAL AGBIOSCIENCE, VETERINARY SCIENCE AND TECHNOLOGY-BASED ECONOMIC DEVELOPMENT



As seen above, if a state achieves a robust position as a major global hub in R&D for the food animal agriculture 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 food animal agriculture industry companies, and industries that supply into the sector, to undertake R&D and production activities.
- Further growth of existing in-state animal agriculture and associated industries.
- Growth of new entrepreneurial businesses commercializing R&D outputs and innovations.
- 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 that may otherwise restrain sector growth and development.

D. North Carolina State University – Animal Agriculture Education, R&D and Extension

North Carolina State University (NC State) is one of the United States’ signature Land-grant universities (LGUs) and among the national leaders in agricultural research, ranking 6th in the nation in total research expenditures in agricultural sciences (Table 1).

TABLE 1: RESEARCH EXPENDITURES IN AGRICULTURAL SCIENCES – 2017 U.S. ACADEMIC INSTITUTION RANKINGS

Rank	State	Academic Institution, Campus Level	Year	Agricultural Sciences Research Expenditures (\$1000s)
1	Texas	Texas A&M University, College Station	2017	190,264
2	Florida	University of Florida	2017	162,494
3	California	University of California, Davis	2017	141,734
4	Michigan	Michigan State University	2017	130,732
5	Indiana	Purdue University, West Lafayette	2017	128,613
6	North Carolina	North Carolina State University	2017	113,295
7	Washington	Washington State University	2017	98,094
8	New York	Cornell University	2017	97,306
9	Mississippi	Mississippi State University	2017	89,253
10	Georgia	University of Georgia	2017	88,456

Source: National Science Foundation, National Center for Science and Engineering Statistics, Higher Education Research and Development (HERD) Survey, FY2017 Data

NC State has a long-standing tradition of research and extension activity in animal agriculture, with expertise maintained in the College of Agriculture and Life Sciences (CALS) and the College of Veterinary Medicine (CVM). Because of the wide variety of livestock and poultry species produced in the state, NC State has to maintain a particularly broad suite of capabilities within both CALS and CVM in order to provide excellence in educational coverage and a relevant program of research and extension activity. This need is evident in CALS structure, for example, with the college being unusual among agriculture colleges in the U.S. in sustaining both an Animal Sciences Department and a separate Poultry Science Department (one of only six such departments at U.S. universities).

While both CALS and CVM rank highly among their respective institutional peers in the nation, sustain a high level of graduate output and a substantial volume of research, the quality of college infrastructure has generally not kept pace. Like so many LGU’s across the nation, physical infrastructure

(especially university farms, livestock housing and associated research infrastructure) have fallen significantly behind what is state-of-the-art in industry. The extent of the infrastructural shortfall has reached a level whereby it is significantly constraining the conduct of applied research and educational training that is relevant to the needs and practices of industry. It is a situation similar to that observed at the outset of the Plant Sciences Initiative and Food Manufacturing Initiative (see below), where significant gaps in capabilities exist that need to be addressed in order to fully realize the opportunities and needs being presented to NC State by stakeholders and industry. NC State likely has a powerful suite of capabilities and core competencies (in research, extension and education) to organize around, but, to-date, has not put together a formal initiative to cement its position as a global leader in food animal agriculture.

E. Conceptualizing a Food Animal Initiative for North Carolina

In recent years, NC State has undertaken two major agricultural sciences initiatives focused on advancing academic and research excellence at the institution and advancing positive impacts for key sectors of the North Carolina agriculture and agribusiness economy. The Plant Sciences Initiative (PSI) and the Food Manufacturing Initiative (FMI) have both achieved early success in developing a shared vision for scientific advancement along strategic pathways and securing funding for required infrastructure and talent additions. Both initiatives are working to advance the North Carolina economy through joint work with industry and a focus on scientific approaches to agricultural issues of relevance to North Carolina agriculture and associated value-chain industries. The North Carolina State Legislature, the University, Golden Leaf Foundation and multiple other key stakeholders and donors, recognizing the power and promise of NC State in these sectors, have stepped forward to fund these major initiatives.

While both of the existing initiatives have relevance to advancing the food animal sector in North Carolina (for example, improving feed production and nutritional content in the case of the PSI, and advancing value-added food processing industries in the case of the FMI) it is well recognized by NC State that the size and importance of animal agriculture in the state mandate development of a third, focused, food animal specific initiative. Responsible for more than two-thirds of direct economic activity in North Carolina agriculture, livestock and poultry production certainly warrant development of a detailed and sector-specific series of strategies for advancement. Recognizing the need, stakeholders at NC State, led by the Deans of CALS and the CVM, have held a series of visioning and planning meetings (incorporating both university-based participants and outside

Topline Vision for the Food Animal Initiative: Develop a transdisciplinary, multi-college initiative that will propel NC State to the forefront of global food animal research based academic institutions and develop innovations and well-trained students to meet the needs of North Carolina's livestock and poultry sectors and allied industries.

stakeholders) to help conceptualize a Food Animal Initiative (FAI). Through these meetings a preliminary series of goals and potential focus areas for the FAI have emerged. Based upon review of notes and deliberations from these prior meetings, TEconomy summarizes these as:

FAI Goals

- Be transdisciplinary and inclusive of scientists and students across multiple NC State colleges, including (but not limited to) CALS and CVM.
- Educate a highly effective and skilled workforce of professionals to advance food animal agriculture and meet current and emerging industry needs.
- Enhance NC State food animal research facilities and infrastructure to meet and exceed the best practices of the industry and allow for experimentation and testing of concepts and technologies to advance animal agriculture.
- Become a valued and trusted hub for communicating the practices of modern food animal agriculture, and proactively combatting misperceptions and disinformation among the general public, legislators and other key parties.
- Produce innovations, discoveries and recommendations that enhance the productivity and safety of global food animal operations.
- Sustain the productivity, profitability and safety of food animal agriculture operations and reduce associated environmental impacts.

F. About this Study and Report

The Battelle Technology Partnership Practice (Battelle TPP) was previously retained by NC State to conduct economic feasibility, core competency assessment, identification of recommended development platforms (research foci), and to develop a preliminary strategy and implementation plan for both the PSI and FMI programs. In October of 2015, the complete staff of Battelle TPP transitioned out of the Battelle Memorial Institute to become an independent organization, TEconomy Partners, LLC. (TEconomy). TEconomy continues a more than 25-year history of research and strategic planning activity to advance economies through science and technology based economic development.

Ongoing work with NC State, performed as TEconomy, led to NC State approaching TEconomy for performance of an independent, third-party study to help guide the development of the proposed Food Animal Initiative (FAI) The scope-of-work for the Feasibility Analysis, Economic Assessment and Strategic Planning Services for the Food Animal Initiative was designed to provide:

- An economic analysis of North Carolina's current status in livestock and poultry production;
- A needs assessment gathering input from producers regarding priority needs, challenges and opportunities that they would like to see an initiative address;
- Quantitative and qualitative R&D core competency assessment of NC State in relevant disciplines;
- Analysis of current R&D frontier areas in livestock and poultry science, animal science and related areas of veterinary medicine against which NC State capabilities can be compared;
- Compilation of intelligence regarding the supporting infrastructure required to advance NC State as a leading hub for food animal research and innovation (including collaborative innovation with industry) and areas where the initiative may benefit from new faculty hires;
- A benchmarking of leading competitive initiatives in North America;
- Development of a strategy and action plan for advancing the Food Animal Initiative; and
- Projections of the economic impact of the current industry in North Carolina and potential enhanced benefits likely to be derived through the Initiative's development.

The result is an independent “deep-dive” into NC State’s capabilities to advance a Food Animal Initiative, and a preliminary plan of action designed to leverage capabilities, address identified gaps, and develop an Initiative that will meet the current and future needs of NC’s animal agriculture industries. The plan seeks to propel NC State to the forefront of global institutions focused on food animal agriculture research, veterinary medicine, associated innovations, education and extension activity.

II. Animal Agriculture in North Carolina— Production Profile and Associated Industries

A. The Importance of the Food Animal Industry in North Carolina

As detailed in the previous chapter, within North Carolina agriculture is a particularly important statewide industry. Present in every county, agriculture is foundational to the state, regional and local economies with a production and processing profile that benefits both rural and urban North Carolina and all North Carolinians. With two-thirds of the value of agricultural production in North Carolina centered on food animals, the livestock and poultry sectors underpin the strengths and impacts of agriculture in the state.

B. Strengths in North Carolina Food Animal Industries – Results of Industry Targeting Analysis

Clearly food animal agriculture is structurally important to the statewide economy, supporting a large-scale value chain. In evaluating the potential for an NC State Food Animal Initiative, and guiding its strategic application to address needs and opportunities in the state, it is necessary to understand the structure of the food animal value chain and gain insight into which subsectors are performing well, which subsectors show emerging strengths, and which subsectors may be lagging or seeing performance challenges. Industry Targeting Analysis (ITA) is an analysis method that forms a foundation for this insight.

Industry Targeting Analysis was performed to determine which food animal industry subsectors have had the strongest employment trends and which subsectors provide future opportunities for growth. The goal of industry targeting analysis is to provide a deeper understanding of industry employment composition by assessing change over time and interpreting recent employment trends in comparison to the national employment ecosystem. Establishment and employment data used in the analysis are sourced from the U.S. Bureau of Labor Statistics, Census of Employment and Wages survey. These data are then enhanced by IMPLAN (and TEconomy) to provide estimates for data that do not meet federal disclosure guidelines.

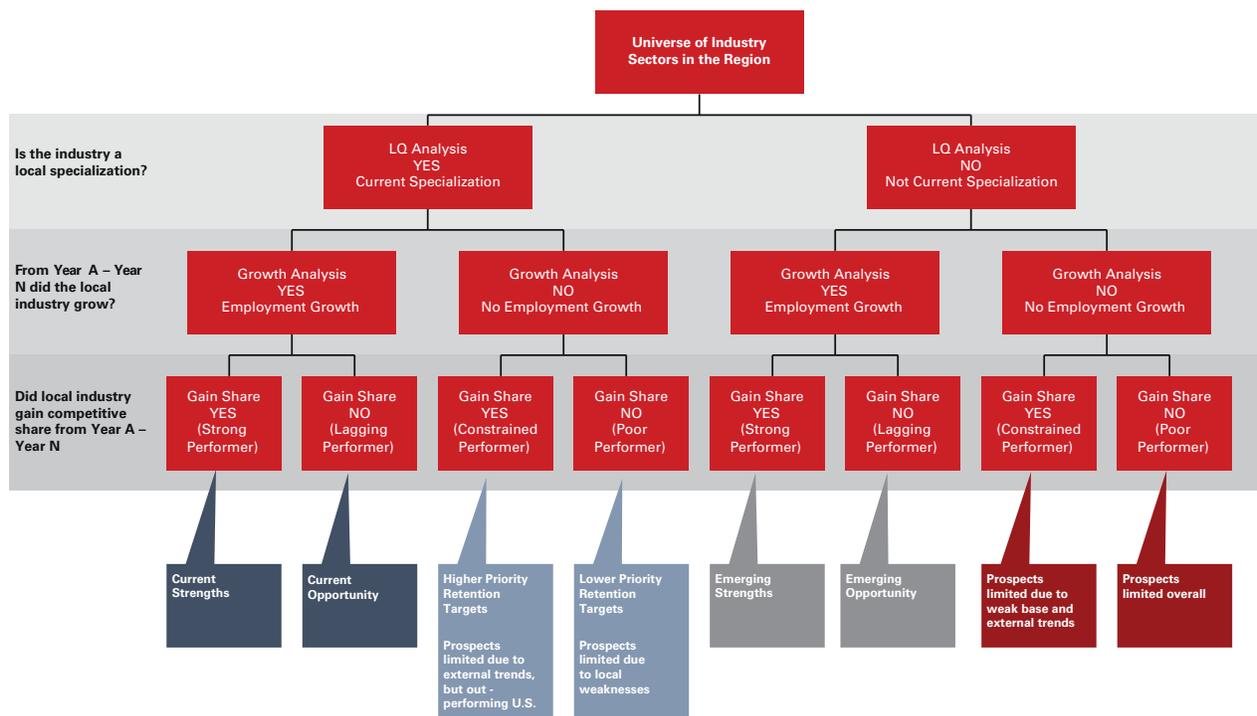
There are three questions that drive industry targeting analysis:

- Is the industry a local specialization? Specialization is measured using location quotients (LQ). If the proportion of North Carolina's total employment that is comprised of a specific industry of interest is higher than that same figure for the U.S., that industry is considered to be more concentrated locally than nationally and receives an LQ greater than one. A specialized industry is typically defined as an industry with an LQ greater than 1.2, which indicates that employment in that industry is proportionately 20% larger locally than at the national level. An LQ value below one indicates an industry is less concentrated locally than the national average.

- Has employment in the industry grown during the time period of interest? Analyses presented here focus on the period of 2014 to 2017 (the most recent complete series of data available). Employment growth over this period is a key indicator of the health of an industry segment.
- Did the local industry gain in its competitive share of the national industry during the time period of interest? If the industry grew faster locally than nationally between 2014 and 2017, the local region is gaining a competitive advantage over other parts of the country. If national employment growth outpaced local growth, the local region’s share of national employment decreased relative to other regions.

Applying this progression to food animal industry segments (conceptually illustrated in Figure 2) provides insight into how North Carolina can leverage its resources to benefit from shifting employment trends given observed changes in local employment. While industry growth or specialization alone can reveal important details about the composition of the local employment base, the combination of these metrics provides national context to local developments.

FIGURE 2: INDUSTRY TARGETING ANALYSIS DECISION TREE



Source: TEconomy Partners

Full industry employment detail is presented in Table 2. In total, the North Carolina Food Animal “Industry Vertical” employed 47,372 workers in 2017, not including individual farm proprietors producing farm animals. The largest sector in terms of employment is Food Animal-Based Food Processing, which accounts for 34,647 jobs (73% of the total). Of these jobs, Poultry Processing accounts for 23,539 and Animal (except Poultry) Slaughtering accounts for 7,362 jobs. Both of these subsectors are considered to be strong North Carolina industry specializations (LQ > 1.20). Food Animal Production (i.e., corporate farming/ranching) accounts for more than 8,000 North Carolina jobs. The majority (62%) of these jobs are within the Hog & Pig Farming subsector, which accounts for 4,996 workers. This subsector is more than five times more concentrated in

North Carolina than the U.S. average. The smallest subsector, Food Animal-Related Key Distribution Channels, accounts for nearly 4,500 jobs in North Carolina. North Carolina also had 40,499 total farm proprietors (non-corporate) in 2017 across both agricultural crop and animal production. Key details of specific NAICS industry subsectors are described in more detail in the following section.

TABLE 2: EMPLOYMENT CHARACTERISTICS OF NORTH CAROLINA'S FOOD ANIMAL VALUE-CHAIN, 2017

NAICS	2017 NAICS	2017 Estab- lishments	2017 Employment	2017 Emp LQ	NC Emp Chg 2014- 2017	NC AAGR 2014- 2017	U.S. AAGR 2014- 2017	NC Emp Chg 2010-2017	NC AAGR 2010- 2017	U.S. AAGR 2010- 2017
-----	Total Private Sector	264,945	3,633,057	1.00	7.6%	2.5%	2.0%	17.1%	2.4%	2.2%
Food Animal Production										
11211	Beef Cattle Ranching and Farming, including Feedlots	46	176	0.11	19.7%	6.6%	2.5%	23.9%	3.4%	3.2%
11212	Dairy Cattle and Milk Production	71	585	0.19	-2.8%	-0.9%	2.0%	7.7%	1.1%	2.4%
11221	Hog and Pig Farming	429	4,996	5.10	0.8%	0.3%	7.6%	1.8%	0.3%	6.1%
11231	Chicken Egg Production	29	521	0.84	4.6%	1.5%	1.4%	15.3%	2.2%	-2.3%
11232	Broilers and Other Meat Type Chicken Production	28	482	2.40	13.9%	4.6%	0.1%	-14.2%	-2.0%	-0.2%
11233	Turkey Production	23	832	5.62	-6.5%	-2.2%	-1.6%	-32.5%	-4.6%	-0.4%
11234	Poultry Hatcheries	39	429	1.60	-11.0%	-3.7%	2.5%	-46.6%	-6.7%	-1.4%
11239	Other Poultry Production	7	34	0.69	-2.9%	-1.0%	0.5%	-8.1%	-1.2%	-1.0%
11241	Sheep Farming	1	4	0.15	19.3%	6.4%	3.8%	366.2%	52.3%	6.1%
11242	Goat Farming	3	15	0.91	281.5%	93.8%	2.9%	377.7%	54.0%	1.7%
11251	Aquaculture	21	179	0.91	-16.2%	-5.4%	11.1%	3.7%	12.6%	1.8%
Food Animal-Based Food Processing										
31151	Dairy Product (except Frozen) Manufacturing	18	455	0.12	1.1%	0.4%	2.0%	-0.7%	-0.1%	0.7%
31152	Ice Cream and Frozen Dessert Manufacturing	11	307	0.49	25.8%	8.6%	-1.6%	-23.8%	-3.4%	-0.4%

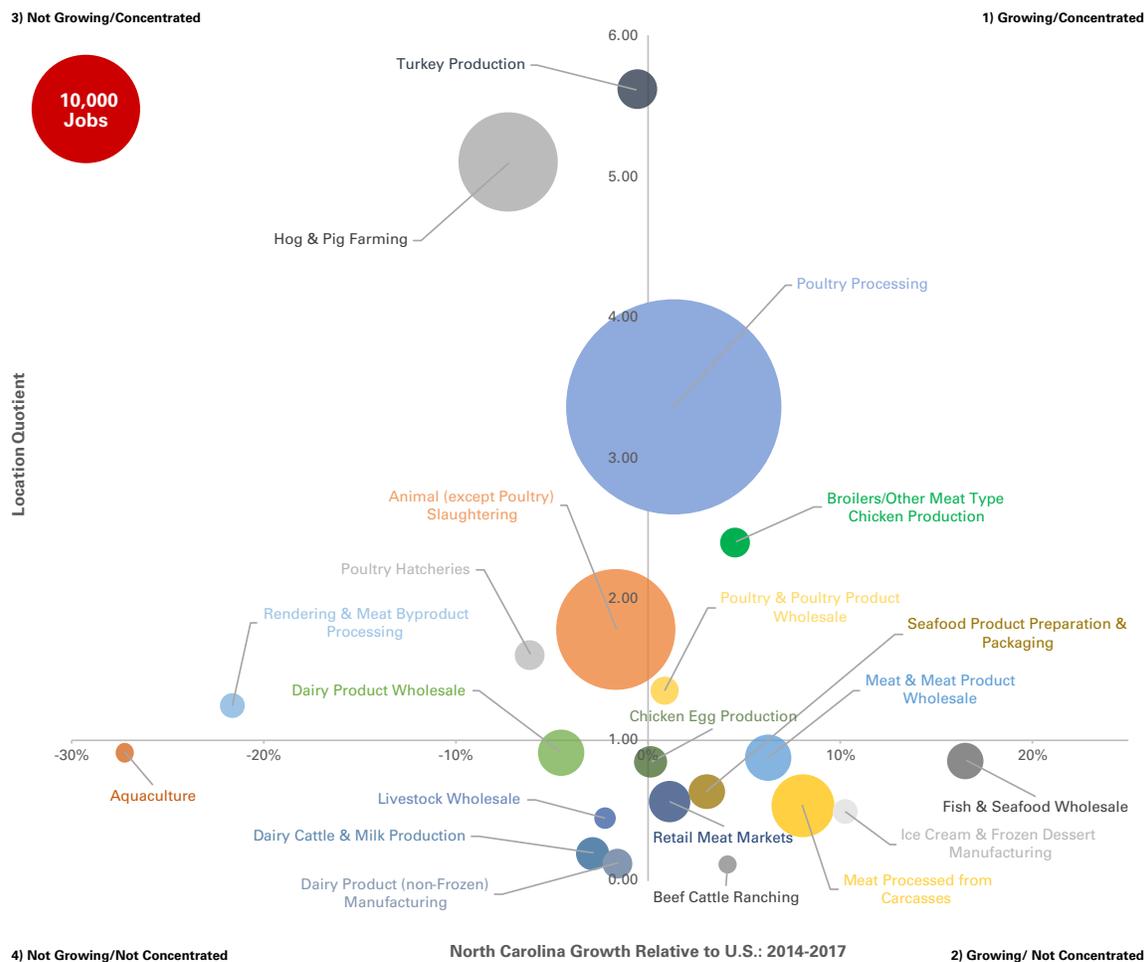
NAICS	2017 NAICS	2017 Estab- lishments	2017 Employment	2017 Emp LQ	NC Emp Chg 2014- 2017	NC AAGR 2014- 2017	U.S. AAGR 2014- 2017	NC Emp Chg 2010-2017	NC AAGR 2010- 2017	U.S. AAGR 2010- 2017
31161	Animal Slaughtering and Processing	121	33,220	2.19	6.6%	2.2%	-0.3%	6.8%	1.0%	0.0%
311611	<i>Animal (except Poultry) Slaughtering</i>	37	7,362	1.78	-2.0%	-0.7%	1.0%	-1.8%	-0.3%	-0.4%
311612	<i>Meat Processed from Carcasses</i>	36	1,998	0.53	34.0%	11.3%	3.3%	-4.8%	-0.7%	2.3%
311613	<i>Rendering and Meat Byproduct Processing</i>	7	321	1.24	-58.5%	-19.5%	2.2%	-48.0%	-6.9%	0.5%
311615	<i>Poultry Processing</i>	42	23,539	3.36	10.0%	3.3%	2.0%	12.7%	1.8%	0.7%
31171	Seafood Product Preparation and Packaging	27	665	0.63	5.2%	1.7%	-1.3%	16.9%	2.4%	-1.2%
Food Animal-Related Key Distribution Channels										
42443	Dairy Product (except Dried or Canned) Wholesale	84	1,094	0.91	-0.5%	-0.2%	4.4%	1.4%	0.2%	2.8%
42444	Poultry and Poultry Product Wholesale	19	417	1.35	0.5%	0.2%	-0.6%	94.0%	13.4%	-1.2%
42446	Fish and Seafood Wholesale	65	694	0.85	58.1%	19.4%	2.9%	37.2%	5.3%	2.0%
42447	Meat and Meat Product Wholesale	68	1,140	0.87	24.5%	8.2%	2.0%	33.8%	4.8%	2.2%
42452	Livestock Wholesale	28	230	0.44	-0.9%	-0.3%	2.0%	-12.2%	-1.7%	2.0%
44521	Retail Meat Markets	106	897	0.56	10.9%	3.6%	2.5%	24.4%	3.5%	3.2%

Source: TEconomy Partners analysis of Census of Employment and Wages (CEW) data enhanced by IMPLAN.
Note: Six-digit NAICS detail is provided for NAICS 31161.

The first two steps of Industry Targeting Analysis (Figure 2) first ask whether the industry is a local specialization and then whether the local industry is growing. The bubble chart in Figure 3 provides answers to these first two questions. The industry subsectors are plotted in Figure 3, with location quotient on the vertical axis and the subsector's employment average annual growth rate from 2014 to 2017 on the horizontal axis.

Subsectors located in Quadrant 1 (upper-right) have both a higher specialization than the national average (LQ greater than 1) and positive employment growth. Subsectors in Quadrant 2 are not highly concentrated (LQ less than 1) but are growing. Subsectors in Quadrant 3 are not growing but highly concentrated, and subsectors in Quadrant 4 are neither highly concentrated nor growing.

FIGURE 3: NORTH CAROLINA'S FOOD ANIMAL INDUSTRY SUBSECTORS – SPECIALIZATION AND EMPLOYMENT CHANGE



Source: TEconomy Partners analysis of IMPLAN data.
 Note: The chart only includes industry subsectors with 100 or more employees.

Sizable subsectors in Quadrant 1 (i.e., those which are growing and concentrated) include Poultry Processing and Hog & Pig Farming, which are two of the three largest food animal-related subsectors in North Carolina. It should be noted that this performance has been achieved within the hog and pig farming industry despite a moratorium on new swine operations being developed in the state. It is likely that, were the moratorium to be lifted, the swine industry could expand its employment and economic impact further for North Carolina.

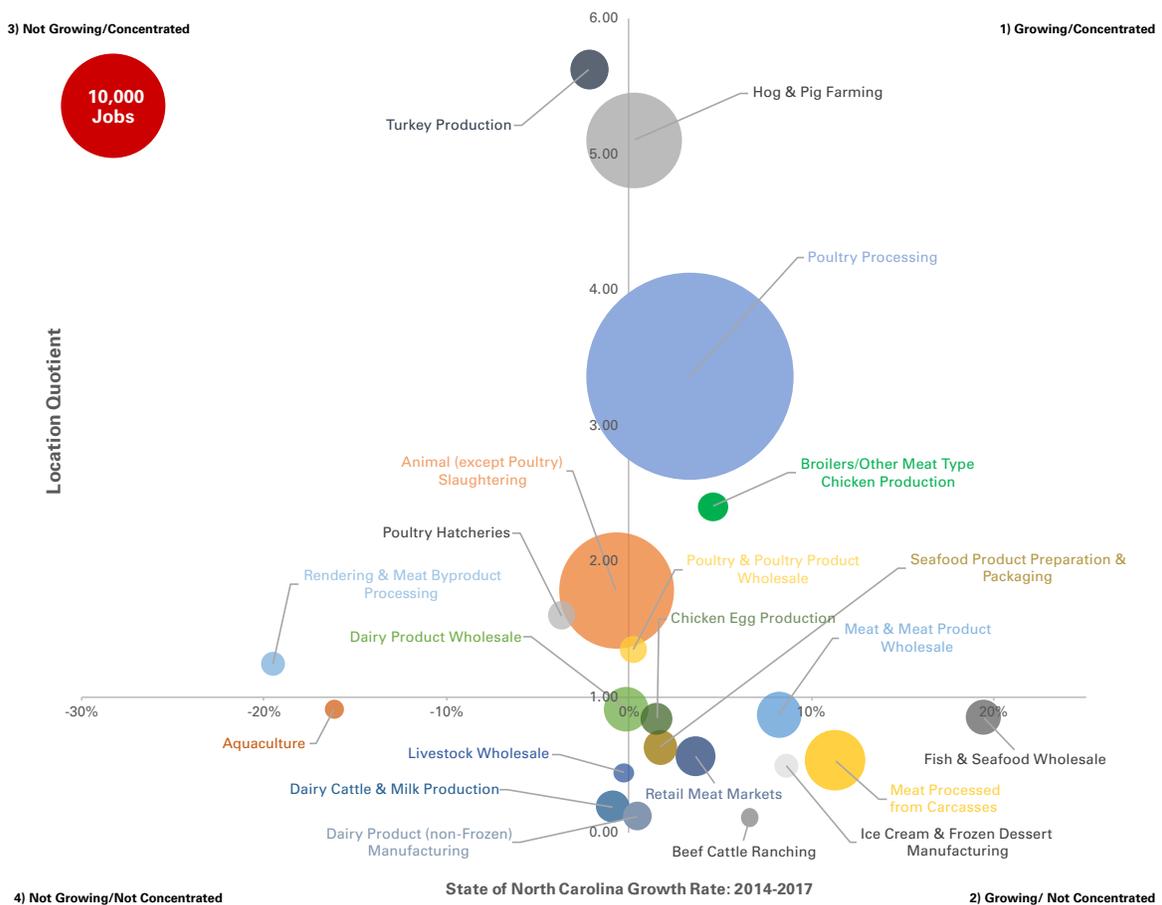
Quadrant 1 also includes the small subsectors of Poultry & Poultry Product Wholesale and Broilers and Other Meat Type Chicken Production. Employment in subsectors located in Quadrant 1 comprises 62% of total food animal-related employment in the state.

Subsectors in Quadrant 2 (i.e., those which are growing but not highly concentrated) include Meat Processed from Carcasses, Meat and Meat Product Wholesale, and Retail Meat Markets. The subsectors in Quadrant 2 comprise 15% of total food animal-related employment in North Carolina. Fish & Seafood Wholesale is the fastest growing subsector, with an average annual growth of 19% from 2014 to 2017. Overall, the well-positioned quadrants 1 and 2 comprise over three quarters (77%) of livestock and poultry sector employment.

Subsectors in Quadrant 3 (i.e., those which are concentrated but have declining employment) include Animal (except Poultry) Slaughtering, which is the 2nd largest in the state, as well as Turkey Production. Together, the subsectors in Quadrant 3 comprise 19% of the state's food animal-related employment. Rendering & Meat Byproduct Processing is the fastest declining subsector, with an average annual growth rate of -20%.

Subsectors in Quadrant 4 (i.e., those which are neither growing nor concentrated) comprise just 4% of the state's food animal-related employment. The largest subsector in this quadrant is Dairy Product (except Dried or Canned) Wholesale.

FIGURE 4: NORTH CAROLINA'S FOOD ANIMAL INDUSTRY SUBSECTORS – SPECIALIZATION AND EMPLOYMENT CHANGE RELATIVE TO U.S.



Source: TEconomy Partners analysis of IMPLAN data.
 Note: The chart only includes industry subsectors with 100 or more employees.

The final step of Industry Targeting Analysis asks whether the local industry gained competitive share over the time period of interest. In other words, if a subsector grew faster in North Carolina than at the national level, North Carolina’s increased competitive share in that subsector serves as an indicator of strong performance and future opportunity.

The industry employment bubble chart in Figure 4 is similar to that discussed above, except that the horizontal axis now represents North Carolina’s employment growth relative to that of the U.S. (calculated by subtracting national growth from local growth). Of the three largest North Carolina subsectors by employment, only Poultry Processing is growing relative to the U.S. Again, however, TEconomy would note that the large swine sector is being constrained by a moratorium on further swine operations in the state.

It is important to consider when subsectors move from Quadrant 1 to Quadrant 3 between charts – this indicates a loss of market share (with U.S. growth being greater than local growth). Hog & Pig Farming has grown in the U.S. by 7.6% compared to local growth of 0.8%; while the subsector has grown in North Carolina, the state is losing important market share to other parts of the U.S.

The Industry Targeting Analysis Decision Tree (Figure 2) is then applied to each subsector using the analyses presented above. The results of this process are in Table 3. The first two columns in Table 3 contain subsectors that have grown from 2014 to 2017. Two of the largest subsectors with greater than 1,000 employment – Hog & Pig Farming and Poultry Processing – are “Current Strengths.” These subsectors are highly specialized in the state, have experienced increases in employment, and gained a competitive share during that same period. These “star” subsectors are substantial in size and should continue to drive the overall success of the food animal industry in the state.

TABLE 3: TARGETING ANALYSIS STATEWIDE RESULTS – NORTH CAROLINA FOOD ANIMAL SUBSECTORS

<p>Current Strengths</p> <ul style="list-style-type: none"> • Hog and Pig Farming • Broilers and Other Meat Type Chicken Production • Poultry Processing 	<p>Emerging Strengths</p> <ul style="list-style-type: none"> • Beef Cattle Ranching and Farming • Goat Farming • Dairy Product (except Frozen) Manufacturing • Ice Cream and Frozen Dessert Manufacturing • Meat Processed from Carcasses • Fish and Seafood Merchant Wholesale • Meat and Meat Product Merchant Wholesale • Retail Meat Markets 	<p>High Priority Retention</p> <ul style="list-style-type: none"> • Turkey Production • Poultry Hatcheries 	<p>Prospect Limited-Constrained</p> <ul style="list-style-type: none"> • Other Poultry Production • Livestock Merchant Wholesale
<p>Current Opportunity</p> <ul style="list-style-type: none"> • Poultry and Poultry Product Merchant Wholesale 	<p>Emerging Opportunity</p> <ul style="list-style-type: none"> • Chicken Egg Production • Sheep Farming • Seafood Product Preparation and Packaging 	<p>Lower Priority Retention</p> <ul style="list-style-type: none"> • Animal (except Poultry) Slaughtering • Rendering and Meat Byproduct Processing 	<p>Prospect Limited-Poor Overall</p> <ul style="list-style-type: none"> • Dairy Cattle and Milk Production • Dairy Product Merchant Wholesale • Aquaculture

Source: TEconomy Partners analysis of IMPLAN data.

Note: white text indicates food animal subsectors with statewide employment greater than 1,000

Another pair of the largest subsectors – Meat Processed from Carcasses and Meat and Meat Product Merchant Wholesale – are “Emerging Strengths”. While not specialized locally, these subsectors have both increased in employment and outpaced U.S. employment growth. Other “Emerging Strengths” include Retail Meat Markets and Fish and Seafood Merchant Wholesale. With strong employment growth outpacing that of the U.S., these subsectors are on a trajectory to become highly specialized in the future.

The last two columns in Table 3 contain subsectors that have experienced employment declines. Animal (except Poultry) Slaughtering is a “Lower Priority Retention” target. While this subsector is specialized in North Carolina, a lack of employment growth and a loss of competitive share show limited future potential for this subsector. Turkey Production is a “High Priority Retention” target with constrained potential. Though employment in this subsector has declined, it remains highly specialized and the state’s competitive share of national employment has increased. Finally, Dairy Product Merchant Wholesale has limited prospects with poor overall characteristics. While this subsector is sizable, it is not specialized within the state and has experienced employment declines greater than that of the U.S.

Not surprisingly, “corporate” employment levels and specializations in key production areas of poultry and hogs reflect key overall commodity production and are the current strengths of the state. Poultry-related production and processing combine to account for 55% of the total food animal industry vertical employment. Undoubtedly, many sole proprietor farmers are also producing in these commodity groups.

C. Food Animal Production in North Carolina

North Carolina’s food animal-related production value totaled \$7.51 billion in 2017. Data from the USDA National Agricultural Statistical Services (NASS) Annual Survey (Table 4) show the volume of food animal production by sector and dollar value in 2017, along with North Carolina’s rank, the state’s share of national production value, average production value from 2014 to 2017, and the percentage change in production value by sector over that time period.

TABLE 4: FOOD ANIMAL-RELATED PRODUCTION VALUE, 2017

Sector	North Carolina Production Value, 2017 (\$M)	North Carolina Ranking	North Carolina Share of U.S. Production Value	North Carolina Average Production Value, 2014-2017 (\$M)	Production Value Change, 2014-2017
Chickens – Broilers	\$3,570.4	3	11.8%	\$3,491.0	-7.3%
Hogs	\$2,270.1	2	11.8%	\$2,342.2	-19.6%
Turkeys	\$739.0	2	15.3%	\$837.6	0.8%
Eggs	\$460.1	7	6.1%	\$498.5	-8.2%
Cattle (incl. Calves)	\$277.5	34	0.6%	\$341.7	-32.8%
Milk	\$179.0	28	0.5%	\$193.5	-27.5%
Trout – Food Fish	\$9.1	2	7.7%	\$8.5	15.5%
Catfish – Food Fish	\$3.1	5	0.8%	\$3.8	-21.6%

Source: USDA National Agricultural Statistical Service (NASS) Annual Survey data via Quick Stats

North Carolina remains a significant competitor in food animal production. Two sectors – broiler chickens (\$3.57 billion) and hogs (\$2.27 billion) – comprise the majority of production value (78%). The state retains a strong relative position in production value of turkeys (ranked 2nd nationally) with a 15.3% share of the U.S. total), hogs (2nd nationally with a share of 11.8%), and chickens (3rd nationally with a share of 11.8%). North Carolina also ranks among the national leaders in trout (2nd), catfish (5th), and eggs (7th).

Despite strong performance in 2017, the data reflect a decline in the production value of most animal food production sectors, including chickens and hogs (-7.3% and -19.6%, respectively) since 2014. It should be noted that this does not necessarily reflect comparative production disadvantage in North Carolina but may simply result from volatility and fluctuation in commodity prices within agricultural markets. Only turkey and trout production value grew during this period.

D. Productivity Analysis

The nature of industrial activity in and around food animal production 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 will see with respect to North Carolina’s animal agriculture sector, these contributions to value added and economic output can vary 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 food animal-related production is competing well on a value-added per worker basis, out-performing the national industry sector in each of the four major animal production subsectors for which data are available. The analysis leverages data from the IMPLAN Input/Output models specific to the U.S. and North Carolina.

TABLE 5: NORTH CAROLINA FOOD ANIMAL-RELATED SUBSECTORS – VALUE-ADDED PER WORKER, NC VS. U.S., 2017

Subsectors/Components	North Carolina	U.S.	North Carolina as Share of U.S.
Total, All Industries	\$92,217	\$99,520	93%
Beef cattle ranching and farming, including feedlots	\$44,954	\$34,379	131%
Dairy cattle and milk production	\$133,484	\$114,449	117%
Poultry and egg production	\$145,136	\$89,907	161%
Animal production, except cattle and poultry and eggs	\$72,626	\$50,743	143%
Fluid milk manufacturing	\$86,692	\$122,964	71%
Creamery butter manufacturing	\$95,116	\$251,689	38%
Cheese manufacturing	\$25,694	\$102,957	25%
Ice cream and frozen dessert manufacturing	\$91,447	\$117,754	78%

Subsectors/Components	North Carolina	U.S.	North Carolina as Share of U.S.
Animal, except poultry, slaughtering	\$98,637	\$102,933	96%
Meat processed from carcasses	\$73,712	\$83,153	89%
Rendering and meat byproduct processing	\$75,209	\$82,984	91%
Poultry processing	\$49,077	\$52,518	93%
Seafood product preparation and packaging	\$49,480	\$90,920	54%

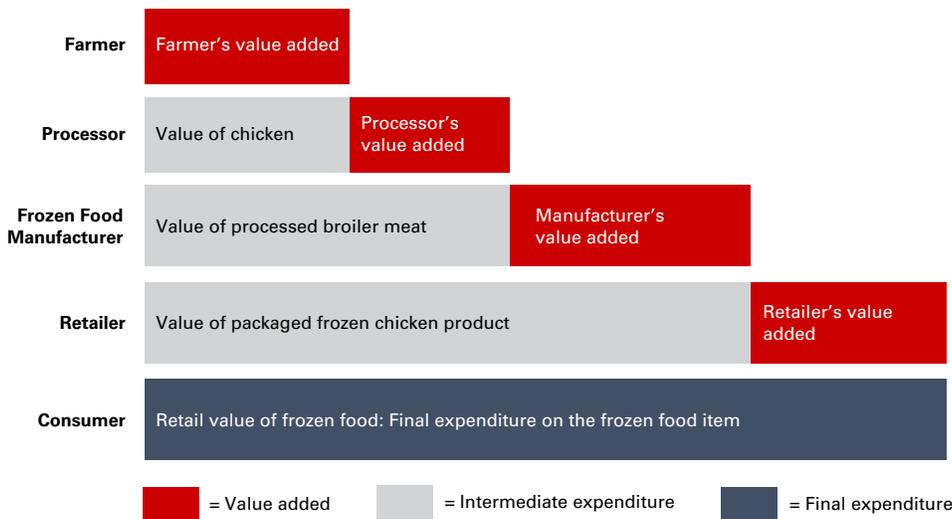
Source: TEconomy Partners analysis of IMPLAN Input/Output model data for North Carolina and the U.S.

The data in Table 5 show that North Carolina’s workers produce more value added output per worker than the national averages in all four of the food animal-related production components (highlighted in blue), while the state lags behind national productivity in the manufacturing components. For example, in “Poultry and egg production,” a component in which North Carolina is a national leader, the state generates \$145,136 value-added per worker, or 61% higher than that of the U.S. as a whole (\$89,907). Value-added per worker in beef cattle, dairy cattle, and other animal production (primarily hogs in North Carolina) also substantially exceed U.S. levels, while the state lags behind the nation across all of the manufacturing components. Typically, a state’s value-added per worker falling below national averages (e.g., creamery butter and cheese manufacturing components) indicates that production is more oriented towards small or artisanal firms. Smaller companies will typically have less capacity to invest in the latest production technologies and are at a comparative disadvantage in terms of economies of scale. The lower level of comparative productivity in the value-added manufacturing sectors should be reviewed by the Food Manufacturing Initiative, and it may well be supportive of a need to invest in meat processing and value-added production facilities at NC State (a capability area that is currently lacking and has been identified as a gap by animal science and food science faculty).

E. Value-Chain Analysis

Worldwide agricultural commodity markets are highly competitive and price driven. As a result, even though national agricultural productivity continues to increase, the real value of that production at “the farm gate” may decline. The future of agricultural and rural sustainability in North Carolina will very much depend on the ability to construct “value-added” chains of production that vertically integrate the food-related business model/value supply chain. The basic value-added concept is shown in Figure 5 and conceptually illustrates the difference in potential income between simply growing or rearing and selling any agricultural commodity (the farmer row) and the total income that may be realized in a state that provides a vertically integrated value-added chain. For example, by rearing a broiler chicken, performing the raw agricultural processing step (abattoir operations), further processing the chicken meat into a value-added frozen meal (manufacturing), and then retailing it, additional economic value is realized. An integrated value chain captures a far higher percent of the final dollar figure spent on the product for the state.

FIGURE 5: THE VALUE-ADDED CONCEPT – BROILER CHICKEN VALUE-ADDED EXAMPLE



Source: TEconomy Partners

The value-chain analysis for North Carolina is shown in Table 6, which uses the 2017 IMPLAN input/output model estimates to examine the production characteristics and distribution to “end use markets” for leading food animal commodities and manufactured products. Points further upstream in the value chain have more potential for value-added processing. Data in Table 6 demonstrate that production components (highlighted in blue) have higher potential for value-added than processing and manufacturing components. For example, the percentage of output comprised of value-added for “other” animal production (comprised largely of hogs in North Carolina) is 63.4%, while only 14.7% of the output is value-added within the hog processing component (captured in “animal, except poultry, slaughtering”).

Poultry and egg production and “other” animal production (primarily hogs) present significant opportunities for North Carolina to generate more value-added at points further along the value chain. These components have relatively high shares of output serving as domestic exports: North Carolina producers generate \$4.8 billion in poultry and egg production output with 32.9% going to domestic exports, while the “other” animal production component comprised largely of hogs generates \$2.5 billion in output, with 46.6% likewise going to domestic

exports. Significant potential exists in North Carolina for additional value-added to the large volume of poultry and hog production output if an increased percentage of processing were to occur within the state.

Poultry and hog production are sizable in total output and offer untapped potential for value-added industry economic development through additional processing. Poultry production and processing account for 54% of the state's food animal output. Hog production (captured in "other" animal production) and hog processing (captured in "animal, except poultry, slaughtering") likely account for about 30-35% of food animal output. Though smaller in output, dairy cattle and milk production presents similar opportunities in expanding value-added manufacturing operations, albeit possibly more limited by the relatively small level of production. Additionally, limited beef cattle production occurring in the state is focused almost entirely on local final or intermediate demand, with little opportunity to generate additional value-added within the state. That said, it should be noted that beef cattle operations are an important component of small farm operations in North Carolina, having production economics that can work for small farms and part time farming families. Therefore, the importance of cattle operations should not be discounted for North Carolina agriculture.

TABLE 6: NORTH CAROLINA KEY FOOD ANIMAL SUBSECTORS/ COMPONENTS – VALUE CHAIN ANALYSIS

Subsectors/Components	Production Characteristics		Output (\$M)	Demand Characteristics				
	Purchased Inputs	Value-Added		Locally-Met Institutional & Household Demand	Locally-Met Intermediate Demand	Inventory	Domestic Exports	Foreign Exports
Beef cattle ranching and farming, including feedlots	70.7%	29.3%	\$297.7	0.1%	92.9%	0.0%	6.5%	0.5%
Dairy cattle and milk production	65.7%	34.3%	\$179.0	0.4%	71.3%	0.1%	28.2%	0.0%
Poultry and egg production	77.4%	22.6%	\$4,839.1	3.0%	63.0%	0.0%	32.9%	1.1%
Animal production, except cattle and poultry and eggs	36.6%	63.4%	\$2,497.0	3.5%	45.1%	2.4%	46.6%	2.5%
Fluid milk manufacturing	87.5%	12.5%	\$256.2	58.1%	13.9%	0.0%	26.8%	1.1%
Creamery butter manufacturing	93.8%	6.2%	\$71.0	62.1%	15.6%	0.0%	18.7%	3.7%
Cheese manufacturing	96.9%	3.1%	\$67.8	8.9%	7.8%	0.0%	80.1%	3.2%
Ice cream and frozen dessert manufacturing	77.3%	22.7%	\$144.4	17.4%	20.6%	0.4%	59.8%	1.8%
Animal, except poultry, slaughtering	85.3%	14.7%	\$5,059.6	12.0%	9.4%	0.0%	65.5%	13.2%
Meat processed from carcasses	85.5%	14.5%	\$1,038.1	29.8%	8.5%	0.0%	59.7%	2.0%
Rendering and meat byproduct processing	84.3%	15.7%	\$155.3	6.2%	16.2%	0.0%	61.0%	16.6%
Poultry processing	82.9%	17.1%	\$6,881.2	11.7%	13.9%	0.1%	69.2%	5.2%
Seafood product preparation and packaging	86.1%	13.9%	\$271.6	17.6%	18.1%	0.0%	61.0%	3.2%

Source: TEconomy Partners analysis of IMPLAN Input/Output model data for North Carolina and the U.S.

F. Conclusions

North Carolina is the top ranked state in turkey production value, but that is dwarfed by production value of chickens (broilers; ranked 3rd) and hogs (ranked 2nd). Combined these two latter components account for 78% of the state's food animal commodity production. The extreme importance of the poultry and swine sectors to the food animal economy in the state certainly suggest that a Food Animal Initiative will need a substantial component of its work directed towards meeting needs and challenges in the production of these species.

While primary food animal production productivity is above (or significantly above) U.S. average productivity levels in North Carolina, it is evident that the "animal-based" food manufacturing subsectors' productivity falls below U.S. averages. This is an area where R&D and associated innovation may serve to advance productivity in North Carolina's value-added industry. It naturally leads to a conclusion that it will be important to integrate food animal processing R&D and associated training into either the Food Animal Initiative or steering work within the Food Manufacturing Initiative to address this need/opportunity.

Within a university initiative, work to address industry needs and advance opportunities for growth typically come via R&D pathways and associated innovations and practice advancements (as illustrated in Figure 1). In addition, NC State plays a crucial role in educating and training skilled undergraduate, graduate and professional degree students whose skills are needed within the workforce across the food animal value-chain.

A Food Animal Initiative may work to advance industry subsector performance and address challenges for industry sectors through:

- Development of new and improved products and technologies for livestock production and downstream processing
- Development of innovations in production processes and procedures across the full value-chain
- Development of technologies and processes to address challenges that limit production or threaten animal health or food safety
- Educating skilled human capital to meet specialized workforce needs.

III. Input from North Carolina's Animal Agriculture Industry

With livestock and poultry representing such a significant component of North Carolina agriculture it was considered imperative to gain input from industry leaders during the evaluation of the FAI feasibility. TEconomy interviewed multiple companies and stakeholders, gathering insight from a diverse profile of animal agriculture producers and inputs supplier organizations including:

- Advanced Animal Diagnostics
- Archer Farms
- BioResource International
- Braswell Family Farms
- Case Farms Processing
- Circle S. Ranch
- DSM Nutritional Products
- North Carolina Cattlemen's Association
- North Carolina Department of Agriculture
- Phytobiotics, LLC
- Pilgrim's Pride
- Premex Corporation
- Prestage Farms
- Smithfield Foods – Operations
- Smithfield Foods – R&D
- White Rock Farms

During the interviews, which were conducted by telephone, interviewees were asked a series of questions, including:

- There are many issues and areas of study relevant to animal agriculture, please rate each of the following on a 1 through 5 scale in terms of their importance for a Food Animal Initiative at NC State to focus on. A series of 12 potential focus areas were provided.
- When you think of NC State currently in animal agriculture and associated research, where do you see evident strengths?
- What type of education and training programs should the FAI be engaged in to meet the needs of animal agriculture and help advance the industry in the state?
- The FAI will involve both the College of Veterinary Medicine (CVM) and the College of Agriculture and Life Sciences (CALS), what do you see as being potential areas for collaboration between the two colleges through the FAI?
- What other thoughts or input do you have regarding the initiative?

A. Rating Potential Focus Areas for the Food Animal Initiative

The listing of focus areas for the purpose of scoring their respective importance for the FAI proved to be a highly productive question, sparking considerable discussion on each of the areas and their relative importance to North Carolina animal agriculture and animal agriculture in general. Areas listed were a mix of scientific/disciplinary foci and economic/public policy areas. Table 7 provides the resulting rank of each area discussed, ranked by mean score achieved through the 1-5 rating system.

TABLE 7: RANKING OF POTENTIAL FOCUS AREAS FOR THE FOOD ANIMAL INITIATIVE

Rank	Mean Score (1-5 scale)	Potential Focus Area for the Food Animal Initiative
1	4.7	Public opinions, public policy and freedom to operate (Communicating the reality of modern animal agriculture)
2	4.5	Food safety
3	4.4	Markets and consumer preferences
4 (tie)	4.3	Infectious diseases
4 (tie)	4.3	Precision animal agriculture technologies and solutions
5	4.2	Livestock microbiome
6	4.0	Waste management and utilization/recycling
7	3.9	Livestock nutrition
8	3.8	Animal welfare
9	3.6	Livestock genetics
10	3.5	Parasites
11	3.3	Animal reproduction

In general, all of the areas were noted to be of importance to animal agriculture. Indeed, many of those interviewed noted that advancing animal agriculture is going to require a systems approach incorporating accumulation of moderate advances through each area. There is not one single area that stands out as a potential “silver bullet” for advancing the fortunes of the industry. That said, there were two themes that emerged through the scoring (and associated discussion process) that certainly rose to the top:

1. That the FAI needs to leverage the strengths and credibility of NC State to help communicate the realities of modern animal agriculture production, proactively combat mis/disinformation that seeks to discredit or harm the industry, and work to significantly improve communications with the general public and legislators. Industry feels that NC State has remained neutral on this, yet as a Land-grant university, working to advance agricultural science, NC State needs to have the courage and conviction to stand up for modern scientific agriculture and help combat groups and forces that are trying to limit the ability of farmers to operate livestock and poultry operations. This is considered to be a critically important

statewide industry for North Carolina, and industry does not feel it is appropriate for the main agricultural research university in the state to stay on the sidelines.

2. Infectious diseases and livestock health are what keep producers “up at night”. It is a broad area of concern, covering worries relating to emerging/re-emerging infectious diseases (including exotic infectious diseases), the challenge of reducing antibiotic use, pathogen contamination and food safety, etc. **Industry views this challenge as needing an “all of the above” approach now – envisioning a systems approach** that uses: vaccines and immunotherapeutics; study of the livestock microbiome to understand impact on health and ability to stave off disease; study of livestock genomics to identify resistance/health traits and markers; nutritional approaches to boosting the livestock immune system (including during pregnancy or in-the-egg); the use of precision/digital technologies to monitor animals and produce early ID of emerging symptoms, and use of precision technologies to combat risk of food safety challenges. This broad area of focus is seen as an excellent area for engagement of both CALS and CVM, plus engineering and other university capabilities.

Interviewees were generally less interested in the FAI pursuing a push on livestock nutrition (except as it may relate to disease resistance) – feeling that nutrition is an area that is already well understood, very advanced, and that industry itself is advancing. This was noted, in spite of and along with, the understanding that NC State has a good track record of work in nutrition. It was noted by several that since livestock and poultry feed is all largely plant based, the Plant Sciences Initiative (PSI) may be the better place to handle primary R&D in this area, with connectivity to and participation of FAI scientists. In discussions with producers, waste management was also thought to be well understood by industry in terms of best practices and technologies and not in need of much focus within the FAI.¹³

Table 8 provides a summary of the main comments received on each potential focus area.

TABLE 8: SUMMARY OF INPUT RECEIVED ON POTENTIAL R&D THEME AREAS

Business and Public-Facing Areas	Summary of Main Comments Received
<p>Public Opinions, Public Policy and Freedom to Operate (Communicating the reality of modern animal agriculture)</p> <p>Rank 1 Score 4.7</p>	<ul style="list-style-type: none"> • NC State needs to get off the sidelines and get engaged in supporting animal agriculture and its role in feeding the world’s population. • UNC and Duke seem to have very vocal faculty in opposition to animal agriculture, but where is the voice of NC State in supporting it? • Why has the NC State ag college been so irrelevant in the freedom to operate debate for our animal agriculture industry? • GMO’s have been proven safe to consume in the vast majority of studies. The University needs to get behind support of this technology and associated products. • If we are to meet the anticipated growth in demand for meat protein, there should be little doubt that we must engage in gene editing and associated tech advancements. • CVM has a valuable air of independence given its work in both companion animals and livestock. As such, the voice of CVM in support of animal agriculture carries weight. We need to hear that voice. • As gene editing technology improves, it will produce opportunities for enhancing livestock species (in areas such as health, meat yield, nutrient use efficiency, reduced waste product emissions, etc.). Animal agriculture needs to learn from the mistakes made with plant genetic engineering and figure out how to position gene editing in livestock positively in the public sphere.

¹³ While industry said waste management best practices and technologies are “well understood” this does not necessarily mean that all industry has adopted or implemented them.

- This needs to go hand in hand with many of the scientific advancement areas. There is no point making genetic engineering-based advancements, for example, if the groundwork for consumer acceptance is not done.
- Have seen some NC State faculty step-up and be vocal in support of the industry but need to see more of this.

Markets and Consumer Preferences

Rank 3
Score 4.4

- We need to be knowledgeable of advancements being made in “cellular agriculture” and associated artificial meat advancements. While it may be a long-way from widespread commercialization and consumer acceptance, some major meat industry companies are engaged in the space.
- Need to recognize that 95% of the public wants safe, ethically produced food that is relatively inexpensive. This is what the system already delivers, and the FAI needs to be able to communicate that, rather than being steered by concern over activists and others who are in the minority.

Scientific and Technical Areas	Summary of Main Comments Received
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Food Safety

Rank 2
Score 4.5

- We need to study this in parallel with developing new production systems (what will be the effect of changed production systems on exposure to, spread and risk of infectious diseases?).
- Maintaining safety in meat products is extraordinarily important to the industry.
- While NC State is seen as “OK” in this area when it comes to production agriculture, the university is less engaged in the processing end of the value-chain.
- There are new regulations and reporting requirements that NC State educational programs will need to keep ahead of and teach to in animal science, poultry science and CVM.

Infectious Diseases

Rank 4 (tie)
Score 4.3

- Antibiotic use and resistance are a primary concern and there is not a clear path forward. We need the FAI to research alternatives using a systems approach or “all of the above” strategies to combat the threat.
- We are seeing valuable tools, such as antibiotics being restricted, yet the diseases are not going away. This needs to be a primary area to focus upon.
- In poultry, a move towards cage free and outdoors production may increase the threat of disease and bring back old challenges that were previously solved. Is there a way to access and learn from prior/historic production knowledge and practices?
- We will need NC State to take a holistic systems approach incorporating understanding of the role and effect of vaccines and immunotherapeutics, housing and husbandry practices, biosecurity practices, etc.
- The initiative will need to be “proactive,” working on foreign diseases before they can impact U.S. and North Carolina (and because of their importance to global food security).
- Significant programs will need to be advanced in both disease prevention and disease response.
- There are still diseases of significance and threat to animal production for which there are no effective drugs. Work to address these could be a natural fit for the FAI with both CALS and CVM engaged.

Precision Animal Agriculture Technologies and Solutions

Rank 4 (tie)
Score 4.3

- This is an exciting area with much promise. Much can be learned and gained through instrumentation of animals and production environments.
- This is an area where big companies are investing in new business ventures and entrepreneurial start-ups. There is lots of room to do interesting and important work in precision animal ag tech and applications.
- NC State will need to be careful to work here on technologies that are likely to produce a positive return on investment (ROI) when implemented by producers. Otherwise we could go down many research rabbit holes that will not ultimately be useful or economic to implement.
- There are great data science corporate assets in North Carolina (such as SAS), but they don’t seem to be interested in this space? Is there a way to engage them in the FAI through precision ag questions?
- Anticipate many opportunities using machine vision in animal agriculture and in the use of robotics in slaughter and processing. It should be recognized that this will require engineering-based solutions and so there is a need to incorporate the College of Engineering into the FAI.

- Industry is experiencing significant penetration of precision animal technology into poultry operations, and larger poultry houses are becoming “instrumented” with sensors evaluating humidity, temperature, CO2, etc. Robotics is becoming used in removal of dead birds and houses are increasingly computer controlled.
- Will need to address, in parallel with technology development, issues of poor internet connectivity in parts of rural North Carolina. Without broadband, the ability to implement precision digital technologies will likely be hindered.
- In this technology space, the FAI will need to consider that most North Carolina farms are relatively small, and it will therefore be important to concentrate on affordable technology-based solutions and solutions that can be retrofitted into existing facilities and equipment.

Livestock Microbiome

Rank 5
Score 4.2

- This is certainly an area with a lot of buzz and probably freedom to operate. Less than certain, however, when/if it will produce results that can be applied to enhance production.
- Gut health in general is an important area and it may be that the development of bacterial products and probiotics may be important antibiotic use wanes.
- Gut health is an open area for research and a great space for university and industry to collaborate.

Waste Management and Utilization/ Recycling

Rank 6
Score 4.0

- A key focus would be on R&D in how to realize value from “waste”: How to maximize manure and litter as resources.
- This should extend beyond “waste” to thinking more holistically about livestock’s environmental footprint. For example, considering ways to reduce or mitigate the carbon footprint of animal agriculture.
- NC State has been seen to have made some good hires in this area in recent years.
- Manure management is generally well handled by industry. Communicating the great progress that has been made in reducing the environmental footprint of animal agriculture should be a priority.

Livestock Nutrition

Rank 7
Score 3.9

- It would be useful to investigate alternative feed products that could be grown competitively in NC against Midwest products.
- Believe this should be formally incorporated into the Plant Sciences Initiative to cement its relevance to livestock and poultry as the largest components of NC agriculture.
- Will certainly want to see evident engagement and cross-over between PSI and FAI for work in nutrition. (Note: interviewees had heard that the PSI would be positively impacting NC agriculture, and an important way to do that is seen as working to improve feed crop performance and production in the state).
- Not sure that there is all that much more that can be done to improve performance through nutrition changes. It is certainly the largest part of the cost of livestock production, but not in terms of ability to generate more performance gains moving forward.
- Because much of the innovation in this area is driven by industry, with research being proprietary, there is a risk that university work would be duplicative of work already ongoing or completed in private industry.
- Nutrition should be considered as a component of work to improve livestock health and resistance to disease pressures.

Animal Welfare

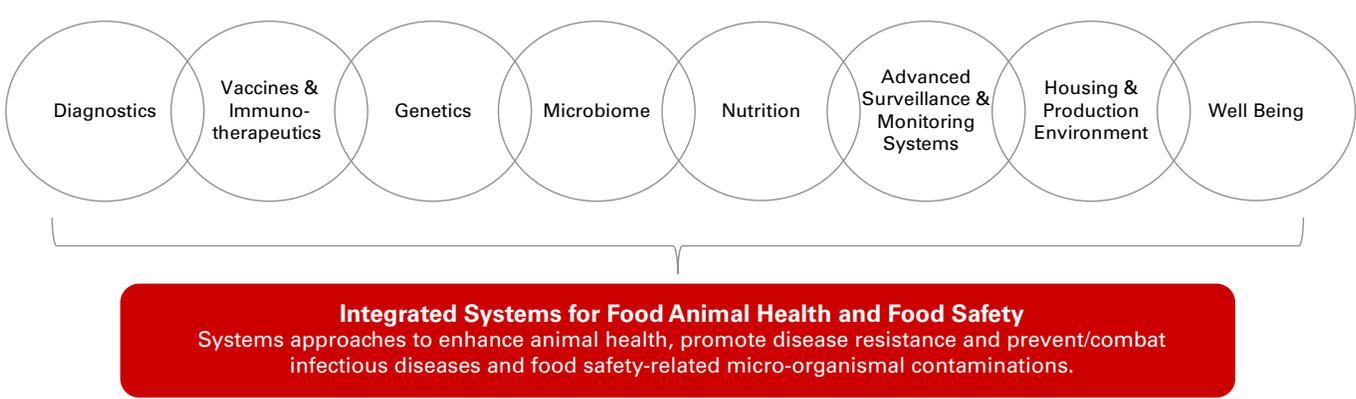
Rank 8
Score 3.8

- Believe there are three institutions that are already known for being very good in this area (U. Illinois, Iowa State and Texas Tech), so not sure there is room or need for NC State to focus here.
 - A lot of what is practiced now is already very good, the main issue is getting the word out and raising consumer understanding of currently humane production practices.
 - The main research goal here needs to be to understand the environments under which livestock and poultry will perform to the best of their genetic potential.
 - Not actually sure there is a literature on what makes a chicken, or other livestock “happy”?
 - Is a gap in knowledge of the impact of transportation systems on the health and productivity of livestock. This is important for beef operations, for example.
-

Livestock Genetics	<ul style="list-style-type: none"> • This is an area where basic research could perhaps advance the development of livestock with inherent disease resistance, including use of gene editing to achieve this goal. • While potentially important, most of the work in poultry genetics is conducted by a few large commercial breeding operations. Not sure that a university emphasis here would be productive. • This is certainly important, but it is also an area that is quite well covered by industry itself. • If this can be linked to livestock health and disease resistance, then it is a sensible area to include. • Challenge here would be in the attraction and placement of graduate students as there are quite limited employment opportunities with only a handful of major companies. • Gene editing is progressing quickly in scientific capabilities and it behooves the FAI to get ahead of the curve. NC State is viewed as good on the plant side of genetics, but far less so in terms of work in animal genetics and genomics. • Expect that more marginal gains can be made through advancements in genetics of the animal than they can be through improving nutrition products.
Rank 9 Score 3.6	
Parasites	<ul style="list-style-type: none"> • Parasites are important as they relate to being disease vectors in poultry primarily. There are certainly concerns regarding the impact of climate change on the geographic range of vectors. • Parasites are a notable issue in poultry with coccidia causing coccidiosis-related losses in production. This is an issue, however, where there is considerable research already taking place, with significant industry engagement in addition to university-based research. • A trend towards increased use of outdoors production environments that may be pursued for animal welfare/consumer preference reasons will result in an increase in exposure of poultry to parasites. This needs to be studied and anticipated.
Rank 10 Score 3.5	
Animal Reproduction	<ul style="list-style-type: none"> • Reproductive biology had been a strength of the university, but it is perceived as having dropped-off as an emphasis area (perhaps as a result of retirements). • May be approaches to be researched in terms of understanding the effect of early developmental biology on later characteristics of the animal (especially health and immune system strength).
Rank 11 Score 3.3	

Overall a quite a similar message was communicated by most, if not all, interviewees. On the FAI science side **infectious diseases and food safety** are viewed as the crucial area to emphasize. This is viewed as a broad enough area that it will allow considerable transdisciplinary engagement and naturally support CVM/CALS collaborations (indeed in discussing other areas, such as nutrition, reproduction, welfare, genetics, etc. the discussion often circled to the impact of these on livestock health and disease resistance). Examples of the types of transdisciplinary fields and subject matter to incorporate into a **Livestock and Poultry Health** focus are illustrated on Figure 6:

FIGURE 6: DISCIPLINARY AREAS OF RELEVANCE TO A LIVESTOCK AND POULTRY HEALTH FOCUS



It was noted by several interviewees that a “farm of the future” type environment, with quality livestock facilities of a high industry standard, will be needed for testing systems approaches and that industry needs to have access to these facilities and associated expertise for research.

B. Top of Mind Opinions Regarding Most Important Research Thrusts for FAI NC Industry Relevance

Prior to going through the list of potential areas highlighted on Table 7, each of the interviewees were asked an open-ended question – asking “what thrusts or research areas for the FAI do you think would be most interesting to NC industry?” The main responses to this question were as follows:

- Something that is very hard for industry to do (if not impossible), but realistic in a large university setting (if equipped with the right facilities and talent), is a major transdisciplinary initiative that integrates multiple fields of study and interest areas into a systems approach to a challenge. The example that came up repeatedly in interviews is “animal health”, where there is the huge challenge of sustaining productivity in a reduced antibiotic use environment. It was noted that the solution to the challenge is likely not to be a single technology but rather a systems approach that works to improve livestock health (and disease resistance) via integration of nutrition and nutrigenomics, gut microbes/probiotics, genetic improvement, housing/environmental improvements, etc.
- Food safety across the production and processing spectrum. It would be useful to have a systematic approach covering facilities design, sanitation, testing and monitoring, and safety program development.
- Development of new NC State facilities that will allow systematic research to be conducted in environments that can simulate and test industry production systems and practices.
- It will be important to think beyond just industry-university research contracts. Rather the partnerships between academe and industry need to run deeper, companies need to imbed personnel at the university and rent campus space. Equipment and infrastructure need to be accessible by industry and industry personnel should be allowed to operate the equipment if qualified.
- Control of pathogens, especially those associated with food safety concerns will continue to be research intensive, especially with antibiotics constraints.
- Ongoing research is needed to develop vaccines as the primary line of defense for animal health and food safety, with antibiotics residing in the second line of defense.
- The Plant Science Initiative is showing that NC State can emerge from being a bit behind the curve to accelerate itself into a leadership position. The animal ag industry hopes to see the same degree of commitment for scale and impact, and thinking big, through the FAI.
- If the FAI wants to build in a manner that is sustainable, in terms of relevance over the long-term, it will need to think about developing digital data competencies in parallel with scientific competencies. Sensing, measurement and analysis, and the integration of animal operations within an internet-of-things (IoT), is a given in the future, and the FAI needs to be built to recognize that, embrace it, and start gathering and storing data.
- There may be an opportunity to include product testing, evaluation and efficacy certification services as a component of the FAI. There are so many new technologies emerging in precision agriculture, nutritional supplements, probiotics, etc. that an independent, university-based efficacy testing and certification service could be highly valuable (and potentially provide a supporting income stream to help support the Initiative).
- The animal agriculture industry is in a defensive posture because of constant criticisms and activist attacks. The FAI has the opportunity to stand out as a bold commitment by a leading university to support the industry and become a real “go to” safe collaborative space. If NC State is able to achieve being viewed as a research ally by industry, then industry resources will likely follow.

C. Opinions Regarding Areas to Emphasize in Food Animal Initiative Education Programs

It was also noted that the FAI will have education and training as a key component of its work, incorporating activities in support of undergraduate and graduate education and potentially other certification or industry-facing programs. Interviewees were asked what they would like to see incorporated, in terms of education, within the FAI. Input received:

- The Initiative will need to cover education and training in both Animal Science and Poultry Science regarding food safety in both livestock production environments and in processing operations. The need for more of an educational focus in processing was noted by several interviewees, especially in regard to helping companies manage changing regulatory requirements and increased reporting requirements.
- It will be very important to not only consider fundamental animal science and poultry science education, but how to also integrate other important fields of education that will need to be integrated in – for example data sciences and molecular biology.
- There is a need to have more modern facilities at NC State whereby students are able to train in environments more reflective of what they will encounter in industry.
- We would like to see more content/coverage of commercial egg production in Poultry Science.
- There has been somewhat of a mismatch between CALS education programs and what the industry is looking for in terms of graduates. Some in industry note that they do better with graduates from University of Minnesota or Iowa State when it comes to the swine sector, for example. In swine it was noted that NC State does not have the depth of faculty to attract the top graduate students. In poultry, institutions noted as being very responsive to needs and demands of industry included the University of Georgia, Auburn and Arkansas.
- Concerns were expressed that although majority of CVM students have come through an Animal/Poultry Science undergraduate education they do not exit those degrees with an affinity for applying their subsequent veterinary medicine training in animal agriculture settings. The question is whether more can be done at the undergraduate level to spark interest in veterinary medicine training for livestock and poultry careers.
- The College of Engineering is seen as producing good quality graduates and having increasing relevance to the animal agriculture industry as technology and data sciences penetrate. Integrating engineers and engineering education into the FAI should be considered.
- Would be helpful to have more training of students in quality control, root cause analysis, ISO accreditation procedures and expanding governmental regulations.

D. Opinions Regarding Current Strengths of NC State in Food Animal Agriculture

This proved to be an interesting area of discussion, with a great deal of variability between some interviewees being very engaged with the university and others noting that they have very little interaction with NC State and do not feel the university to be very visible.

- Several interviewees were simply “not sure” – noting that they do not see much interaction with the university and have a generally low level of awareness of NC State capabilities and research competencies.
- Main strengths are in undergraduate education through Animal Science and Poultry Science and professional veterinary medicine education in CVM. The university is viewed as generally more competent in, and known for, training than in research (especially within CVM). While NC State is “competent” in research it is not “up there” with the very best in food animal research. Iowa State and the University of Minnesota were mentioned most for their excellence.
- Several noted that CALS has a reputation for generally good programs in animal nutrition within the Animal Science Department.
- Poultry nutrition is considered an NC State strength and industry has been hiring students trained at the university.
- NC State is OK but would not be among the top two or three institutions “we would typically go to.”
- While there are strengths in areas like nutrition, reproductive biology, etc. these tend to be concentrated around a fairly small number of faculty. Interviewees were not sure there is a real critical mass of research expertise in any highly focused areas.
- Animal nutrition and reproduction are two areas where NC State has historically been strong, but these are areas that are really covered quite well by the private sector now. Both the Animal Science and Poultry Science departments are viewed as having good capabilities and reputation in nutrition.
- CALS used to contain basic life science departments, but these moved outside of the College. The challenge is, that without the College connection, the input of the basic scientists may be lost.
- Genetics used to be quite strong, but NC State is not among the leaders now (noted to be Iowa State, University of Georgia and Wageningen). Expertise in CRISPR, however, may present an opportunity to recruit around.
- It was also noted, by multiple respondents, that the University could do a better job of keeping them informed regarding its self-identified research strengths and the appropriate contacts for industry to access these strengths.
- Poultry Science is viewed principally as a quality undergraduate education program, with a relatively limited base of research activity. Still, it is viewed as being responsive to industry and a differentiator for the university. It may not be “glamorous”, but it does fulfill an important need in the state and beyond.
- A key strength was noted to be the wide diversity of faculty and areas of expertise – although this is typical within larger LGUs and not unique to NC State.
- It may not have been applied to food animal applications yet, but there is significant expertise at NC State in gene editing technology.
- Animal Science is perceived as doing a good job in forage management and cattle grazing systems, and to already be thinking systematically in terms of use of livestock manure, reduced inputs purchases, soil health and overgrazing controls.
- CALS has done important work through the Beef Quality Assurance program, again taking systems approach that leverages multiple university personnel.

E. Gaps That Should be Filled or Addressed at NC State

It was generally noted that infrastructure and facilities at NC State are showing their age and certainly do not approach the type of advanced environments being used in industry currently. Several notable gaps in infrastructure and capabilities were noted by the interviewees:

- Upgrading of NC State farm(s), facilities and infrastructure to be able to simulate/duplicate the type of state-of-the-art production environments deployed by industry. This would allow testing of new technologies and innovations in a realistic setting, enable industry to better participate in joint research, and provide a better environment for student training.
- Upgrading of facilities will need to cover not only primary agricultural production facilities, but also include processing facilities. The Food Manufacturing Initiative work at Kannapolis is viewed to be oriented towards plant-based food processing, and it should have a matching animal processing focus located in Raleigh to be accessible to Animal Science and Poultry Science faculty and students.
- Infrastructure improvements need to be performed with an eye towards being open and welcoming for industry use and for collaborative trials activity with multiple livestock and poultry species.
- Development of FAI facilities should be pursued such that they would be a hub, or focal meeting place, for industry and academic interactions and for students to rub shoulders with industry. Space should also be set aside for pursuit of entrepreneurial new business development activities.
- A proactive communications and outreach program to industry is needed that will provide details on university capabilities, available services or partnerships with industry, and how to access these. Communications should be repeated at regular intervals as industry personnel changes.
- Faculty and graduate students need to get out more to visit industry and see actual production and processing practices.
- There is concern that the Poultry Science Department at NC State, as at other universities, is seeing multiple faculty with pending retirement. Interviewees in the poultry sector asked if there will be reinvestment in hiring faculty in this field?
- NC State could be more engaged in testing services for producers and processors. Several interviewees noted they must send samples to Iowa State or the University of Minnesota, because NC State does not offer these services.

F. Potential Areas for Collaboration between CALS and CVM

Interviewees responded positively to the fact that the FAI is an initiative of both CALS and CVM.

- Infectious disease prevention and treatment, in light of reduced use of antibiotics, would be a logical focus.
- Examining effects of various housing systems on the health of animals.
- The livestock microbiome is also a logical area where collaborations could occur.
- Consideration needs to be paid to increasing the number of CVM graduates who seek to pursue careers in large animals/animal agriculture. This may require some form of financial incentive to be provided to encourage students to pursue a track in Animal Science or Poultry Science at an undergraduate level with ongoing incentive provided for continuing in large animal veterinary medicine at NC State. Tuition discounts or scholarships may be pursued with a requirement to stay and work in the industry within NC for a defined period post-graduation.
- Perhaps pick a broad-enough question area that gives lots of room for joint collaboration and pre-competitive engagement with industry. An example given was “what are the markers of inflammation?”

- Development of diagnostics and diagnostics tools and test could be a natural fit for work between the colleges, together with integration of the College of Engineering. Antibiotics were seen as a crutch, and with that being curtailed, technologies will need to be applied to diagnose problems as early as possible (identifying stress, physiological changes, behavioral changes, etc.)

G. Other Issues and Observations

- University research overhead rates are high, and it can be considerably less expensive to access research and testing capabilities in the private sector. As such, the FAI needs to be designed to facilitate access in an affordable way. We must be careful not to build something that then is underutilized because of high costs.
- It is good that this independent analysis is being performed for the FAI. Up until now the initiative has felt a bit like a knee-jerk afterthought following the PSI.
- It is important that NC State shows it is doing the FAI to have an impact not just to generate a stream of research revenue or student support.
- Veterinary medicine colleges have a difficult balance to achieve in terms of students' love of animals and also a need to support the use of animals for food. In general, they have been skewing to companion animal medicine as opposed to livestock production and this leads to shortages in qualified animal ag veterinarians.
- Auburn is certainly competition in terms of poultry science – with a good emphasis on applied poultry science and associated engineering. Auburn also operates a very effective poultry extension service.
- University of Georgia noted for having a very good Masters in Avian Medicine program.
- The FAI needs to be designed to that it is flexible, able to move at the speed industry needs, and able to respond quickly to emerging challenges. Having a pre-executed master agreement with favorable IP access terms is viewed as advantageous.
- What NC State is considering here with the FAI would be quite differentiated. While other universities were cited for being good in certain areas of work with industry, no one was able to name a competing location with something like the FAI. The Kansas City Animal Health Corridor was mentioned as a cluster, but it was with a caveat that it is mostly a marketing initiative not a scientific initiative.
- The North Carolina Department of Agriculture should be seen as a potential partner of the FAI. There is already an excellent working relationship between NC State and the Department, including joint appointments, and between the State diagnostics lab and CVM.

IV. North Carolina State University – Core Competencies in Animal Agriculture, and Food Animal Research Frontiers

To understand opportunities to advance the North Carolina economy through food animal science, poultry science, and veterinary medicine for food animals, it is necessary to identify the existing areas of R&D strength upon which further research and innovation excellence can be built. By rooting food animal sector development in rigorously identified established and emerging R&D core competencies, North Carolina can leverage existing clusters of investment in research talent and infrastructure to advance food animal agriculture, value-added industries and associated technology and input industries.

R&D core competencies are those fields with an established or emerging critical mass of ongoing activity along with identifiable measures of excellence. No one single source of information is sufficient to identify research core competencies. Rather, a variety of integrated and complementary analyses are typically deployed by TEconomy to identify an institution's current or emerging position and R&D core competencies that may contribute to innovations and discoveries that further food animal industry growth and associated economic advancement in the state.

To evaluate NC State's core competencies in food animal agriculture and associated R&D areas, TEconomy undertook several tasks:

1. A review of the degree of institutional specialization in research disciplines of relevance, or potential relevance, to food animal agriculture.
2. Assessment of NC State's position across a publishing universe identified through key terms associated with food animals and food animal agriculture. Two separate analyses were performed on the resulting dataset of 41,143 publications (published between 2015 and 2018):
 - a. Evaluation of these publications by their Web of Science disciplinary or field classification to identify competencies based on NC State having a high comparative specialization index.
 - b. Use of a machine learning-based research frontiers cluster analysis to categorize publications based on their textual content, with an analysis then performed of where NC State shows strengths in terms of a high specialization index in specific topics.
3. Evaluation of university self-identified research focus areas through reference to designated research centers and institutes
4. Assessment of patenting across NC institutions, including NC State, in food animal related patent classes.
5. Performance of a series of on-campus interviews with faculty and university research leadership to gain their perspective on areas of established or emerging core competency.

A. Publications Analysis

Web of Science (WoS) data provide a basis for examining the comparative specialization of NC State in research disciplines by using publications as a proxy for research. The analysis performed uses a publications quotient¹⁴ to measure how concentrated (specialized) NC State is in each referenced discipline versus the universe of all institutions.

Research focused on food animal species spans multiple different scientific discipline areas including, for example: agricultural science and engineering; animal science: poultry science: veterinary medicine; environmental science; food science; biochemistry and molecular biology; microbiology, genetics, and more. Obviously, many of these disciplines include work that is directly or indirectly relevant to food animals as well as work that is not – for example, microbiology may contain work focused on food animal diseases or on pathogens and food safety, but may also contain research focused on human diseases, industrial applications of microorganisms, etc. Similarly, veterinary medicine will contain a considerable volume of research directed towards companion animals or exotic animals, in addition to food animal work. Because of this, assessment of publications by discipline is informative but imperfect (more depth and perspective are provided through key word based cluster analysis reported herein – see page 51). Still, the analysis of publications by discipline does help contribute to identification of core competencies that are, or may be, applied to food animal science and applications. 21,243 publications (for 2015-2018) were ultimately included in this analysis.

Tables 9 through 13 are divided into five categories of disciplines:

- Those that are core in terms of a focus on food animals and their processing of their meat or other output (e.g. milk and eggs) into value-added food products.
- Life science and physical science disciplines that may contain research of direct or indirect relevance to food animals and their products.
- Adjacent agricultural and environmental disciplines, that again that may contain research of direct or indirect relevance to food animals, their products, waste stream utilization or environmental impact.
- Adjacent engineering and data sciences. Many of these have relevance to agricultural engineering of production and processing equipment and infrastructure, technologies for precision agriculture applications and other potential relevance.
- Adjacent social science, communications and business and economics disciplines.

For each discipline placed within these classification groups, a publications quotient is calculated to show whether NC State is more or less specialized in this discipline than would be expected given the general level of publishing activity across the universe of research performing organizations that generate publications. In each of the five categories, the disciplines are ranked by the number of publications with an NC State author, and a publications quotient is shown in red if ≥ 1.2 (generally considered a “specialization”), blue if >1 and <1.2 (above the universe average but below the 1.2 specialization threshold), and black if below 1.0.

As anticipated, each of the four core disciplines (veterinary science, animal science, food science and agricultural engineering) demonstrated a very specialized publications quotient. This is to be expected given that agricultural sciences are primarily pursued through a select subset of research universities – primarily Land-grant universities, and the fact that veterinary medicine is largely confined to a smaller subset of institutions with a college of veterinary medicine.

14 A publication quotient (PQ) measures the concentration of publication in a particular discipline for an individual institution relative to the entire publications volume in that discipline. The PQ consists of the ratio of the share of total institutional publishing that is in the particular discipline and the share of total publishing volume in that discipline. A PQ greater than 1.0 for a particular discipline indicates that the institution is more concentrated in that discipline than the overall disciplinary universe of publication, whereas a PQ less than 1.0 signifies a relative underrepresentation. Generally a PQ above 1.20 denotes a specialization well above the average.

TABLE 9: NC STATE SPECIALIZATION IN RESEARCH AS MEASURED BY PUBLICATIONS IN FOOD ANIMAL RELATED CORE AND POTENTIALLY RELEVANT ADJACENT DISCIPLINES – CORE DISCIPLINES

Core	Records	Pub. Quotient
Veterinary Sciences	1,014	7.12
Food Science Technology	422	2.83
Agriculture Dairy Animal Science	421	5.57
Agricultural Engineering	107	4.09
Sum	1,965	

Adjacent life and physical sciences (Table 10) contains 6,128 publications with NC State authors (more than three times the volume in the core disciplines). Eight of the 18 disciplines with >100 publications demonstrate a specialized publication quotient – with NC State specializations evident in: “Biotechnology/ Applied Microbiology”, “Genetics Heredity”, “Microbiology”, “Evolutionary Biology”, “Entomology”, “Toxicology”, “Mathematical Computational Biology” and “Analytical Chemistry”. It is evident that each of these NC State specialized disciplines are in fields that may be applied to research in **food animal health**. At a level of publishing below 100 publications, three additional specialized areas are evident (again with relevance to animal health) – “Parasitology”, “Mycology” and “Microscopy”.

TABLE 10: NC STATE SPECIALIZATION IN RESEARCH AS MEASURED BY PUBLICATIONS IN FOOD ANIMAL RELATED CORE AND POTENTIALLY RELEVANT ADJACENT DISCIPLINES – LIFE AND PHYSICAL SCIENCE DISCIPLINES

Relevant or Potentially Relevant Life and Physical Sciences	Records	Pub. Quotient
Biochemistry Molecular Biology	741	0.88
Biotechnology Applied Microbiology	479	1.68
Genetics Heredity	453	1.26
Cell Biology	371	0.55
Biology	324	1.06
Microbiology	323	1.28
Evolutionary Biology	277	1.96
Entomology	267	3.72
Toxicology	254	1.58
Pharmacology Pharmacy	252	0.48

Relevant or Potentially Relevant Life and Physical Sciences	Records	Pub. Quotient
Mathematical Computational Biology	229	1.90
Zoology	228	1.10
Chemistry Analytical	192	1.24
Neurosciences	171	0.21
Immunology	139	0.28
Chemistry Organic	127	1.18
Endocrinology Metabolism	123	0.41
Nutrition Dietetics	111	0.81
Infectious Diseases	94	0.39
Physiology	88	0.54
Chemistry Medicinal	87	0.74
Dermatology	83	0.51
Parasitology	79	1.20
Developmental Biology	75	0.96
Virology	69	0.57
Tropical Medicine	60	0.76
Respiratory System	49	0.12
Gastroenterology Hepatology	42	0.13
Pathology	39	0.15
Orthopedics	38	0.19
Medical Informatics	36	0.53
Reproductive Biology	36	0.35
Mycology	35	1.96
Surgery	33	0.05
Hematology	29	0.08
Cardiac Cardiovascular Systems	23	0.05

Relevant or Potentially Relevant Life and Physical Sciences	Records	Pub. Quotient
Anatomy Morphology	20	0.88
Microscopy	16	1.28
Allergy	14	0.22
Anesthesiology	7	0.10
Neuroimaging	5	0.09
Otorhinolaryngology	5	0.06
Urology Nephrology	5	0.03
Sum	6,128	

Every one of the 10 disciplines listed on Table 11 as “Adjacent Agricultural and Environmental Sciences” demonstrates a specialized publications quotient for NC State. Plant science, agronomy, and soil science obviously have direct relevance to the production of crops used as livestock and poultry feed. Multiple strengths in environmental science-related fields can also have significant applicability to animal agriculture issues and challenges.

TABLE 11: NC STATE SPECIALIZATION IN RESEARCH AS MEASURED BY PUBLICATIONS IN FOOD ANIMAL RELATED CORE AND POTENTIALLY RELEVANT ADJACENT DISCIPLINES – ADJACENT AGRICULTURAL AND ENVIRONMENTAL SCIENCES

Adjacent - Agricultural and Environmental	Records	Pub. Quotient
Environmental Sciences	1,050	2.14
Plant Sciences	817	3.61
Ecology	672	2.39
Agronomy	486	6.18
Biodiversity Conservation	194	2.29
Marine Freshwater Biology	171	1.52
Soil Science	121	3.13
Environmental Studies	103	1.43
Agriculture Multidisciplinary	87	2.62
Limnology	42	1.40

In addition to life sciences, disciplines in engineering and data science increasingly intersect with and impact food animal agriculture. Progress in digital agriculture and associated precision agriculture technologies, for example, benefit from competencies in these disciplines. NC State is well known for its excellence in engineering disciplines and the University has invested significantly in developing modern engineering infrastructure on the Centennial Campus. While the majority of the publishing taking place in engineering and data sciences at NC State likely falls outside of agricultural applications currently, the core competencies of the University hold significant promise for relevance and potential application to emerging opportunities in food animal agriculture. Sensors, optics (machine vision), wireless communications, robotics, advanced data analytics, etc. are among many technological areas of relevance to modern animal agriculture that will see their advancement dependent upon transdisciplinary engagement of engineers and data scientists with CALS and CVM faculty and research teams.

The largest area of publishing in these fields is “Electronic and Electrical Engineering,” with 1,912 publications by NC State authors (a PQ of 1.58). This is an area of engineering that is increasingly relevant to precision animal agriculture. Robust NC State capabilities in computer science and software engineering also hold promise (given their increasing importance to advancements in modern animal agriculture operations and research).

TABLE 12: NC STATE SPECIALIZATION IN RESEARCH AS MEASURED BY PUBLICATIONS IN FOOD ANIMAL RELATED CORE AND POTENTIALLY RELEVANT ADJACENT DISCIPLINES – ADJACENT ENGINEERING AND DATA SCIENCE DISCIPLINES

Adjacent - Engineering and Data Sciences	Records	Pub. Quotient
Engineering Electrical Electronic	1,912	1.58
Energy Fuels	774	2.47
Nanoscience Nanotechnology	711	1.97
Computer Science Theory Methods	455	1.20
Engineering Civil	432	2.15
Engineering Chemical	357	1.99
Computer Science Interdisciplinary Applications	347	1.51
Computer Science Information Systems	342	1.05
Computer Science Software Engineering	341	2.17
Engineering Mechanical	339	1.24
Engineering Biomedical	311	1.52
Optics	310	0.76
Engineering Environmental	286	2.28
Water Resources	274	1.92
Computer Science Artificial Intelligence	242	0.87
Instruments Instrumentation	228	1.63
Engineering Multidisciplinary	219	2.05
Engineering Industrial	218	2.93
Operations Research Management Science	217	1.98
Automation Control Systems	212	1.29
Mechanics	198	1.29
Materials Science Biomaterials	161	2.22
Chemistry Applied	152	2.31
Radiology Nuclear Medicine Medical Imaging	142	0.29

Adjacent - Engineering and Data Sciences	Records	Pub. Quotient
Engineering Manufacturing	139	2.28
Remote Sensing	130	1.35
Cell Tissue Engineering	71	1.10
Imaging Science Photographic Technology	70	0.84
Spectroscopy	64	1.24
Computer Science Cybernetics	53	1.43
Robotics	50	0.70
Medical Laboratory Technology	5	0.16

It should be noted that engineering, life sciences and physical sciences are not the only macro disciplinary areas that need to be considered for relevance to a Food Animal Initiative. As will be seen in the discussion of input received from industry, there is considerable concern over economic, social and political issues as they relate to freedom to operate intensive animal agriculture operations and the effects of public opinion on relevant public policies and emerging market preferences. A holistic view suggests that a broad variety of social science, communications, political science and public policy, business and economics disciplines and fields of study will be directly relevant to application in a Food Animal Initiative. Table 13 shows the publications data for NC State across many potentially relevant disciplines, but it is clear that the volume of publications, and the extent to which NC State specializations appear, is far lower here than in the scientific and engineering fields.

These data suggest that for a Food Animal Initiative to be world class in addressing the “freedom to operate and public facing policy” issues – issues of great concern to industry – the Initiative may find depth of capabilities within NC State lacking, and new recruitment or strategic collaborations with other institutions may be necessary.

TABLE 13: NC STATE SPECIALIZATION IN RESEARCH AS MEASURED BY PUBLICATIONS IN FOOD ANIMAL RELATED CORE AND POTENTIALLY RELEVANT ADJACENT DISCIPLINES – ADJACENT SOCIAL SCIENCE, COMMUNICATIONS, POLICY, BUSINESS AND ECONOMICS DISCIPLINES.

Adjacent - Social Science, Communications, Policy, Business And Economics	Records	Pub. Quotient
Public Environmental Occupational Health	289	0.61
Economics	98	0.61
Behavioral Sciences	65	0.52
Psychology Applied	55	1.32
Psychology	53	0.28

Adjacent - Social Science, Communications, Policy, Business And Economics	Records	Pub. Quotient
Agricultural Economics Policy	40	2.60
Communication	20	0.74
Psychology Multidisciplinary	20	0.31
Social Sciences Interdisciplinary	18	0.41
Sociology	18	0.56
Social Issues	16	0.64
Ethics	15	0.54
Cultural Studies	6	0.32
Political Science	6	0.09
Psychology Educational	3	0.40

B. Publications Analysis – Using a More Refined Dataset of Publications Identified Through Key Word Searches.

An alternative approach to using the predetermined categories for disciplines in Web of Science is to instead use computing horsepower to mine the full Web of Science dataset using key terms to identify publications pertaining to food animals. Using this approach, a universe of 41,143 publications was identified, of which 481 (1.12%) comprised publications with NC State authors. Many fields had less than 10 publications in them, and Table 14 shows just those fields identified for which NC State had 10 or more papers published. Again, specialized disciplines (as measured by publications quotient) are highlighted in red.

It should be noted that the labels for the “disciplines” are the primary category given to the publication by WoS. However, their presence in this dataset indicates that key words pertaining to food animal agriculture were present in the publication.

TABLE 14: NC STATE SPECIALIZATIONS IDENTIFIED BY KEY WORDS PERTAINING TO FOOD ANIMALS AND FOOD ANIMAL AGRICULTURE IN THE WEB OF SCIENCE DATASET. (FIELDS WITH ≥ 10 PUBLICATIONS) 2015-2018

Fields	Count of WoS Category	NCSU Pubs Quotient
Agriculture, Dairy & Animal Science	232	1.50
Veterinary Sciences	123	1.34
Food Science & Technology	97	1.09
Biochemistry & Molecular Biology	45	0.52
Genetics & Heredity	23	0.51
Agriculture, Multidisciplinary	17	1.00
Biotechnology & Applied Microbiology	17	0.73
Chemistry, Applied	13	1.00
Nutrition & Dietetics	13	0.38
Cell Biology	12	0.46
Fisheries	11	0.33

The analysis again illustrates that NC State is a “specialized” institution in performing Animal Science and Veterinary Sciences research. The data suggest that NC State is on the threshold of specialization in Food Science (PQ = 1.09). In none of the other areas with publication counts over 10 does the institution rise to the level of a specialization.

It should be noted that much more insight into food animal research activity within the research universe, and within NC State as a component of that universe, is provide in Chapter IV which reports the results of machine learning-based research frontiers analysis. The approach taken in Chapter IV uses real text cluster analysis to segment the food animal literature and identifies where NC State is performing at a specialized level within that literature.

C. Research Frontiers in Animal Agriculture – Results of Publications Analysis and Assessment of NC State’s Position

To add further depth to the investigation of NC State’s comparative research strengths, TEconomy undertook a machine-learning based latent topic analysis of the 41,143 publication records (for 2015 through 2018). In order to identify research publications specific to food animals for use in the analysis a combination of research fields and keyword queries was used, including

- All research publications from agriculture, dairy, and animal science;
- Research publications from a set of related fields in agriculture, biosciences, and veterinary sciences that included keywords specific to food animals; and
- Research publications in any other fields which contained a limited set of specific food animal-related keywords

Publications data included activity from North America, including the US, Canada, Mexico, and the Caribbean. The top 15 research institutions by publication volume are listed in Table 15. Publication activity was led by the USDA and, as expected, includes many Land grant universities and systems specializing in agricultural sciences. NC State ranked 12th in publications volume over this time period.

TABLE 15. RESEARCH PUBLICATIONS ACTIVITY IN FOOD ANIMAL SCIENCE BY RESEARCH INSTITUTION OR SYSTEM, 2015 TO 2018

Research Institution or System	Food Animal Publications Count	Institution Publications Volume Rank
US Department of Agriculture	3,528	1
University of Guelph	1,475	2
University of California Davis	1,424	3
Iowa State University	1,385	4
Texas A&M University College Station	1,181	5
University of Illinois at Urbana-Champaign	1,141	6
Agriculture and Agri-Food Canada	1,137	7
Cornell University	1,069	8
University of Florida	1,041	9
Kansas State University	1,035	10
University of Wisconsin Madison	1,004	11
NC State University	906	12
University of Georgia	898	13

Research Institution or System	Food Animal Publications Count	Institution Publications Volume Rank
Ohio State University	891	14
University of Minnesota Twin Cities	891	15

Source: National Science Foundation

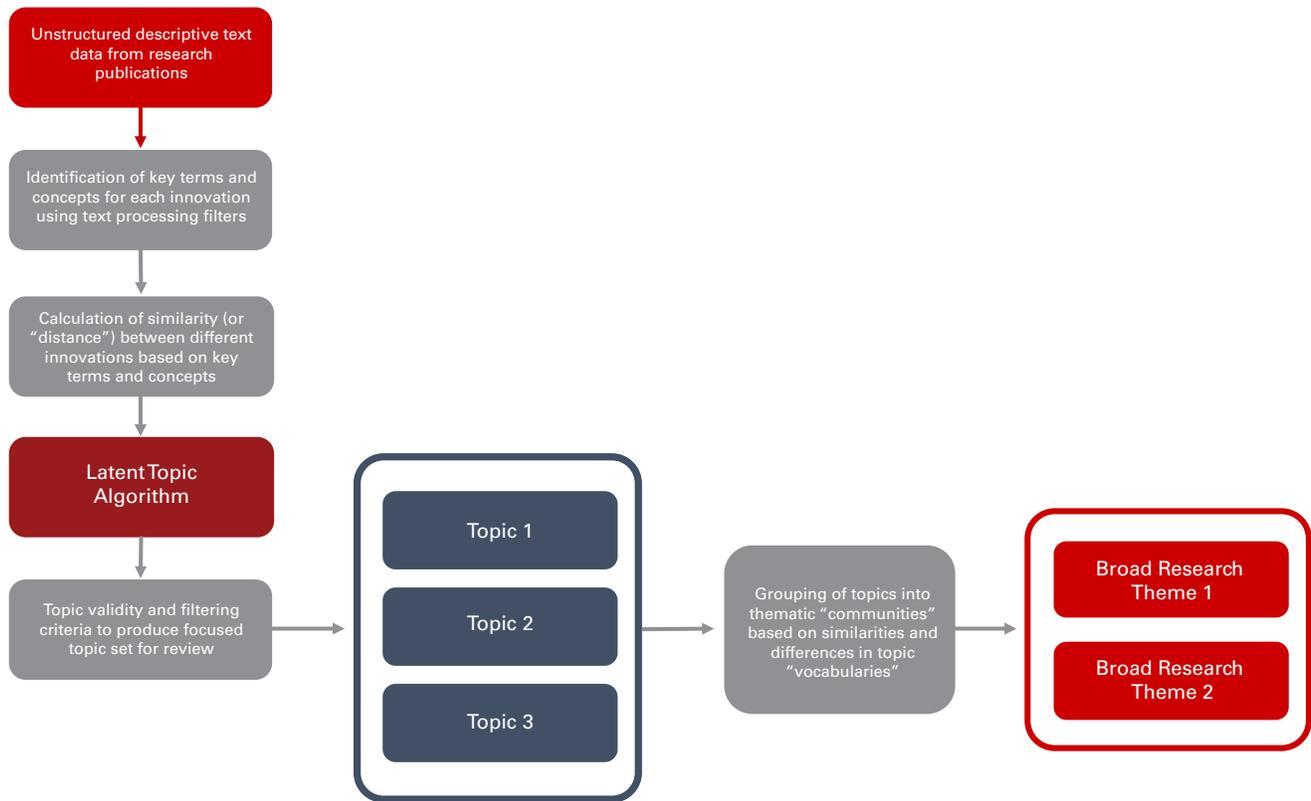
It should be noted that while NC State ranks 12th in publications volume related to food animal topics, there is not a large magnitude of difference between the number 1 ranked U.S. university on the list (UC Davis) with 1,424 publications and NC State (with 906).

In order to best assess North Carolina’s role as a prominent location for food animal research, it is critical to understand not only the recent innovation landscape but also the trends in research activity that give insights into the discoveries and technologies just over the horizon. Although it is not possible to predict the next breakthrough in food animal research with certainty, certain indicators of research and innovation activity in this area can function as “research frontiers” or new directions in research and market applications. Identifying transformative innovations before they reach the height of their impact is a fundamentally difficult process, as they are often both highly unexpected and highly disruptive in nature. However, by identifying a robust set of research frontiers, the distinct innovation themes present in emerging research can be distilled from large data sets that point to areas of particularly significant potential that are likely to be sources of new innovation.

To identify comprehensive research themes that show promise for emerging innovation, TEconomy utilized a technique known as latent topic model analysis. The analysis uses machine learning algorithms to identify topics (or themes) that are “latent” within the underlying vocabulary of a set of text data using a combination of natural language processing (NLP) and unsupervised clustering methods. Descriptive text content from relevant journal article and USDA grant abstracts, SBIR project descriptions, and news aggregator articles were used to form the data set of unstructured text that serves as the input to this analysis. A text processing algorithm was used to clean the text data and then identify frequently appearing terms and multiword phrases through techniques such as word stemming and stop-word removal, which are commonly used in NLP methods that help process “noisy” text content into more structured data for analysis.

Figure 7 outlines the process used to then analyze the text data to determine the underlying themes present across research activity at NC State as observed through publications and grant awards activity. First, the descriptive data are analyzed for key terms and concepts. Then those key terms are used to calculate similarity or “distance” between different innovations. The latent topic algorithm then creates a set of focused topics for further review and analysis. These topics are subsequently grouped into “thematic communities” based on similarities and differences in topic “vocabularies.” Finally, these communities are distilled into broad research themes.

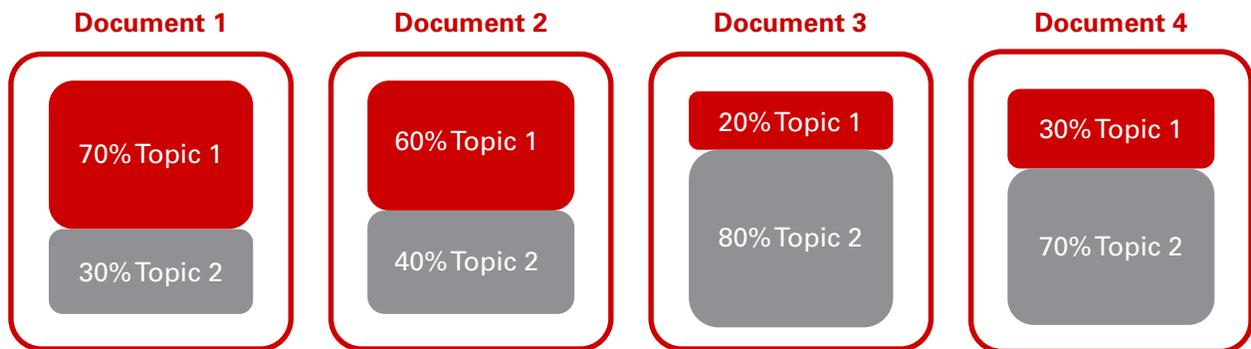
FIGURE 7: LATENT TOPIC MODEL ANALYSIS



Source: TEconomy Partners

As opposed to more basic clustering algorithms which evaluate text content at the overall record level and then assign a unique theme to a data record, latent topic modeling estimates the mixture of topics present in an individual record to better approximate the structure of real life text content which often contains multiple themes within a single record. Figure 8 below gives a graphical example of how this methodology is used to parse out the underlying latent themes present in an overall set of text data.

FIGURE 8: EXAMPLE OF TWO TOPIC LATENT TOPIC MODEL EVALUATION OF TEXT DATA



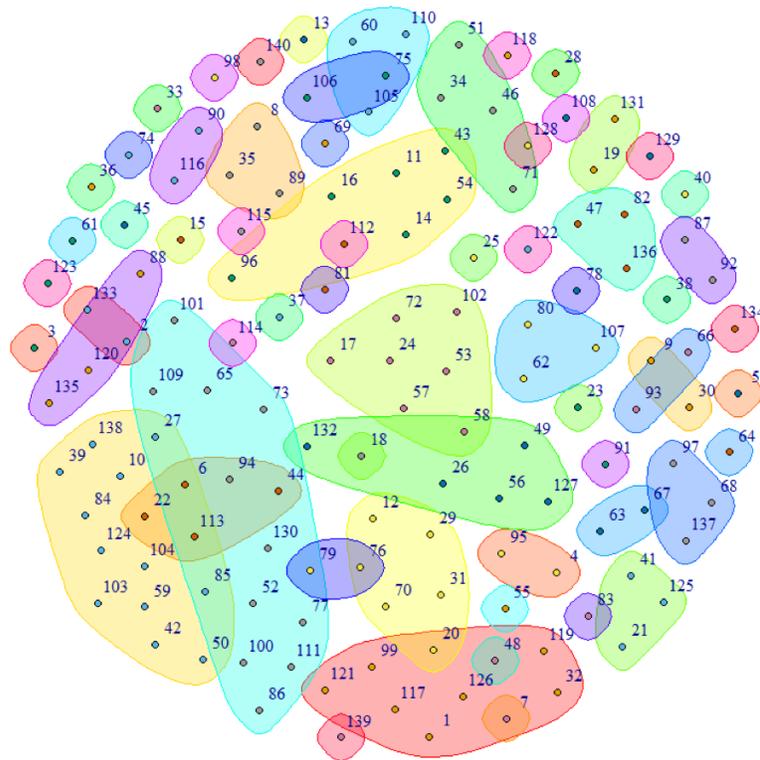
Source: TEconomy Partners

Even after identification of an initial set of topic clusters by the clustering algorithm, it is still necessary to evaluate the cluster groupings to determine cohesiveness and critical mass around a single relevant subject based on analysis of key terms appearing in cluster records. These validation steps filter out clusters that are not focused or are not relevant to emerging food animal research and innovation themes.

The latent topic model analysis identified 160 topics from the set of 41,087 food animal-related research publications from North American institutions – these can then be grouped into broad research themes. The analysis uncovered 66 thematic “communities” of food animal research activity in U.S. publications, comprising:

- 8 “anchoring” communities displaying a critical mass of records in highly interrelated research themes that serve as basis for major research activity in food animal space,
- 12 “focused” communities displaying significant cohesion around common research themes but smaller volume of related records,
- 25 “niche” communities with focused themes but lower linkages to broader topic vocabularies, and
- 21 “artifact” communities which did not display evident coherent themes focused on specific identifiable food animal agriculture topics. These are omitted from further analysis.

FIGURE 9: RESULTS OF LATENT MODEL ANALYSIS – 66 THEMATIC “COMMUNITIES” OF ANIMAL RESEARCH ACTIVITY



Source: TEconomy Partners analysis of WoS records.

1. “Anchoring” Communities

The eight “anchoring” themes in food animal research are shown in Table 16 each with an example of research topic themes present within the community as well as illustrative examples of research activity. These anchoring themes include:

- **Animal feedstocks and impacts on growth performance;**
- **Dairy cattle diagnostics, milk production, and reproduction;**
- **Proteomic properties of food animal products;**
- **Detection and treatment of bacterial contamination and disease;**
- **Genetic profiling applications;**
- **Environmental and climate impacts of farming operations**
- **Beef cattle production applications; and**
- **Food animal microbiomes.**

TABLE 16: ANCHORING THEMES IN FOOD ANIMAL RESEARCH (2015-2018)

Broad Thematic Community	Examples of Research Topic Themes Present in Community	Illustrative Examples of Research Activity in Community
Animal Feedstocks and Impacts on Growth Performance	Animal metabolism and nutrient intake, animal digestion and gastroenterological processing of food, evaluation of novel feedstock compounds, tracking of growth performance	Recent advances in sunflower seed meal as an alternate source of protein in broilers; Effect of dietary excess of branched-chain amino acids on performance and serum concentrations of amino acids in growing pigs
Dairy Cattle Diagnostics, Milk Production, and Reproduction	Reproduction strategies and technologies (such as artificial insemination), dairy cattle disease spread and vectors (with emphasis on mastitis), factors impacting milk yields and quality, milk spoilage and impacts of environmental uptake of various substances, biomarkers and other monitoring for transition cows, whole herd monitoring	Accuracy of a cow-side test for the diagnosis of hyperketonemia and hypoglycemia in lactating dairy cows; Comparison of 4-versus 5-day Co-Synch plus controlled internal drug release (CIDR) plus timed artificial insemination protocols in dairy heifers; Relationship between intramammary infection prevalence and somatic cell score in commercial dairy herds
Proteomic Properties of Food Animal Products	Egg white and milk proteins, microbiology in cheese production, effects of processing on protein contents, proteomic analysis of allergenicity and health impacts of food products, bioactive protein compounds and inhibitors in food products, impact of hen laying environment on egg quality	Purification and identification of adipogenic-differentiating peptides from egg white hydrolysate; Design of a starter culture to produce a reduced-fat soft cheese with added bio-value; Effects of UV induced photo-oxidation on the physicochemical properties of milk protein concentrate
Detection and Treatment of Bacterial Contamination and Disease	Microbiology of major bacterial infection vectors (salmonella, listeria, e. coli, campylobacter, staph, etc.), decontamination and prevention strategies in animal production operations, inhibitor and antimicrobial compounds, treatment pharmacokinetics and antibiotic resistance	Inactivation of Salmonella enterica in chicken feces on the surface of eggshells by simultaneous treatments with gaseous chlorine dioxide and mild wet heat; Synovial fluid pharmacokinetics of tulathromycin, gamithromycin and florfenicol after a single subcutaneous dose in cattle; Antibiotic resistance profiles among mesophilic aerobic bacteria in Nigerian chicken litter and associated antibiotic resistance genes

Broad Thematic Community	Examples of Research Topic Themes Present in Community	Illustrative Examples of Research Activity in Community
Genetic Profiling Applications	Genetic biomarker detection and screening, sequencing methods for food animal genomes (including whole genome sequencing and genomic libraries), epigenetic mapping of food animal species	Candidate gene association analyses for ketosis resistance in Holsteins; Construction of a dairy microbial genome catalog opens new perspectives for the metagenomic analysis of dairy fermented products; Genome-wide association studies (GWAS) identify a QTL close to PRKAG3 affecting meat pH and color in crossbred commercial pigs
Environmental and Climate Impacts of Farming Operations	Pollutant and environment contamination uptake vectors (particularly metals), sustainable farming and climate/carbon emission impacts of food production, precision livestock farming and integration of green technologies, adoption of agricultural automation and innovation in developing countries	Nutritional Strategies for Minimizing Phosphorus Pollution from the Livestock Industry; Impact of the intensification of beef production in Brazil on greenhouse gas emissions and land use; Hydro-environmental assessment and grazing capacity valuation by thermo-pluviometrics indicators; Agricultural technology assessment for smallholder farms: An analysis using a farm simulation model (FARMSIM)
Beef Cattle Production Applications	Impact of growth-promoting implants and supplements on meat quality, feedstock compounds and metabolics, biometric measurement of growth/development, genomic indicators and cross-breeding, prediction of carcass characteristics/quality	Comparison of growth-promoting implant regimens from calthood to finishing in beef steers: stocker phase; Inferring genotypes of functional variants in crossbred beef cattle; Effects of Ruminally-protected Lysine on Performance and Carcass Characteristics of Finishing Cattle
Food Animal Microbiomes	Rumen fermentation and associated emissions, profiling of food animal microbiomes/microbiotica, intake and digestion of starches, dry matter, and other foods, gut and skin microbiome implications for animal health and disease, impacts of silage and environmental factors on microbiome	Potential of tannin-rich plants for modulating ruminal microbes and ruminal fermentation in sheep; Relationships between dry matter content, ensiling, ammonia-nitrogen, and ruminal in vitro starch digestibility in high-moisture corn samples; Influence of gut microbiota on appetite in post-partum cows

Source: TEconomy Analysis

2. Focused Themes

A list of the next tier “focused themes” in food animal research are presented in Table 17. As noted on page 55, these are research communities displaying significant cohesion around common research themes but containing a smaller number of records versus the large-scale anchoring clusters shown on Table 16.

TABLE 17: FOCUSED THEMES IN FOOD ANIMAL RESEARCH (2015 – 2018)

Focused Thematic Community	Illustrative Examples of Research Activity in Community
Disease reduction and infection control in broiler production – in particular coccidiosis and necrotic enteritis	Comparative evaluation of probiotic and salinomycin effects on performance and coccidiosis control in broiler chickens
Animal welfare, pain, and feeding behavior	Minimal floor space allowance for gestating sows kept in pens with electronic sow feeders on fully slatted floors
Rapid diagnostics for detection of animal disease or food contamination	Integration of colorimetric and SERS detection for rapid screening and validation of melamine in milk; Rapid detection and grouping of porcine bocaviruses by an EvaGreen® based multiplex real-time PCR assay using melting curve analysis
Reproduction biomarker/biometric signals and sample preservation	Minor FSH surge, minor follicular wave, and resurgence of preovulatory follicle several days before ovulation in heifers; Novel and traditional traits of frozen-thawed porcine sperm related to in vitro fertilization success
Aquaculture applications for fish and shellfish stocks – feedstocks, reproduction, water quality management (recirculation, denitrification, etc.)	Evaluation of Stocking Density during Second-Year Growth of Largemouth Bass, <i>Micropterus salmoides</i> , Raised Indoors in a Recirculating Aquaculture System; Nitrate removal effectiveness of fluidized sulfur-based autotrophic denitrification biofilters for recirculating aquaculture systems
Food animal virus pathogenicity and vaccine efficacy – avian influenza, BVD, FMD	Antigenic Characterization of H3 Subtypes of Avian Influenza A Viruses from North America; Vaccination of cattle against bovine viral diarrhea virus; An Integrative Analysis of Foot-and-Mouth Disease Virus Carriers in Vietnam Achieved Through Targeted Surveillance and Molecular Epidemiology
Transcriptomic and microscopy analysis applications in food animal science	Combined use of variable pressure scanning electron microscopy and confocal laser scanning microscopy best reveal microstructure of comminuted meat gels; A genome-wide transcriptomic analysis of articular cartilage during normal maturation in pigs
Fetal gestation/development and programming – mostly cattle-related, but some sheep and porcine	Differences in embryo survival between <i>Bos indicus</i> and <i>Bos taurus</i> females receiving energy restricted diets during early gestation
Epigenetic studies of specific food animal populations	Genetic diversity and patterns of population structure in Creole goats from the Americas; Construction of a high-density, high-resolution genetic map and its integration with BAC-based physical map in channel catfish
Calf health and bovine immunogenetics/metagenomics – focus on identification and treatment bovine respiratory disease	The effect of dystocia on physiological and behavioral characteristics related to vitality and passive transfer of immunoglobulins in newborn Holstein calves; Evaluating the metagenome of nasal samples from cattle with bovine respiratory disease complex (BRDC)
Immune response and inflammation pathways in food animals	Impact of Micronutrients on the Immune Response of Animals; In vitro differential modulation of immune response by probiotics in porcine peripheral blood mononuclear cells

Focused Thematic Community	Illustrative Examples of Research Activity in Community
Assessment and prediction of post-harvest meat quality	Predicting pork loin chop yield using carcass and loin characteristics; challenges and technologies for postmortem prediction of beef tenderness

Source: TEconomy analysis

3. Niche Themes

Although niche themes display lower similarity to text content in other communities (i.e. quantitative connectivity), their areas of focus are still potentially aligned with more significant thematic areas. Niche themes are evident in:

TABLE 18: NICHE THEMES IN FOOD ANIMAL RESEARCH

- | | |
|--|---|
| <ul style="list-style-type: none"> • African swine fever epidemiology • Biomarkers for predicting livestock oocyte development/ maturation • Bovine mammary epithelial cell pathways • Bovine tuberculosis biomarkers and eradication programs • Channel catfish production – disease prevention, hybrid breeds • Epidermal Growth Factor Receptor (EGFR) pathways in food animal disease and development • Food animal cardiovascular systems • Genetic variation in oysters raised for food product • High resolution mass spectrometry applications for food animal tissue – determining meat quality, pollutant uptake, etc. • Heat stress physiological response and mitigation strategies in livestock • Impacts of dietary fatty acids on livestock • Identification and derivation of food animal stem cells | <ul style="list-style-type: none"> • Integrated crop-livestock systems • Infectious bronchitis virus and vaccines • Oxidative stress impacts and prevention in livestock • Paratuberculosis infections and associated host dynamics of mycobacterium vectors • Porcine reproductive and respiratory syndrome virus • Plant poisoning of ruminant animals • Porcine epidemic diarrhea virus pathogenesis, biosecurity measures • Reproductive traits and disease in sheep – focus on bighorn sheep • Selenium supplements and toxicity • Shrimp aquaculture – diet, environment, disease prevention • Trout farming impacts on natural migration and habitats • Treatment of tritrichomonas foetus in bulls • Tilapia production – diet, breeding |
|--|---|

4. NC State’s Position in the Clusters Resulting from the Latent Topic Analysis

To examine where NC State displays specialized activity amongst the broader research landscape, we can utilize a measure of the “concentration index” for topics within NC State’s food animal focused publications.

Topic areas where NC State publications had at least 1.2 times the average concentration of that topic across all U.S. publications represent themes where the university is likely to display differentiated strength. Note that this is not a measure of publishing volume but only specialization. There were 13 topic areas where NC State’s research activity was significantly more specialized than national trends. An additional 5 topics were moderately above the national norm.

TABLE 19: NCSU SPECIALIZED RESEARCH THEMES (CONCENTRATION INDEX ≥ 1.2) 2015-2018

Topic Area	NC State Topic Concentration Index
Disease reduction and infection control in broiler production – in particular coccidiosis	2.28
Sow gestation and lactation performance	2.21
Swine feedstocks and impact on growth performance	2.17
Swine nutrient and feedstock additives	2.05
Animal feed applications of whey protein	2.02
Infectious bronchitis virus and vaccines	1.96
Antibiotic pharmacokinetics/pharmacodynamics in food animals	1.79
Impacts of hen laying environment on egg quality	1.79
African swine fever epidemiology	1.51
Animal feedstocks and impacts on growth performance	1.33
Assessment and prediction of post-harvest meat quality	1.22
Immune response and inflammation pathways in food animals	1.22
Beef cattle production	1.20

Source: TEconomy analysis

TABLE 20: NCSU SPECIALIZED RESEARCH THEMES (CONCENTRATION INDEX $>1.0 <1.2$) 2015-2018

Topic Area	NC State Topic Concentration Index
Proteomic properties of food animal products	1.11
Detection and treatment of bacterial contamination and disease	1.07
Fetal gestation/development and programming in ruminants	1.05
Dairy cattle diagnostics, milk production and reproduction	1.03
Calf health and bovine immunogenetics – especially focused on respiratory disease	1.01

Source: TEconomy analysis

Figure 10 summarizes the findings to illustrate where NC State demonstrates specializations in the food animal literature (for 2015-2018) based on the findings of the latent topic analysis, and where it does not. The graphic is divided into the high level “anchoring communities” at the top, and the more “focused themes” at the bottom. Those communities/themes highlighted in yellow represent areas with NC State demonstrated specialization.

FIGURE 10: SUMMARY OF NC STATE SPECIALIZATIONS WITHIN ANCHORING AND FOCUSED THEME COMMUNITIES IN FOOD ANIMAL AGRICULTURE, AS IDENTIFIED THROUGH LATENT TOPIC ANALYSIS OF PUBLICATIONS (2015-2018)

ANCHORING COMMUNITIES	NC State Specialization? ≥ 1.1
Animal feedstocks and impacts on growth performance	YES = 1.33 (especially in swine feedstocks 2.17 and feedstock additives 2.05)
Dairy cattle diagnostics, milk production and reproduction	
Proteomic properties of food animal products	YES = 1.11 (especially in feed applications of whey protein 2.02, and impact of laying environment on egg quality 1.79)
Detection and treatment of bacterial contamination and disease	NO = 1.07 (however 1.79 in antibiotic pharmacokinetics/pharmacodynamics in food animals)
Genetic profiling applications	
Environmental and climate impacts of farming operations	
Beef cattle production	YES = 1.20
Food animal microbiomes	
FOCUSED THEMES	NC State Specialization? ≥ 1.1
Disease reduction and infection control in broiler production	YES = 2.28 (especially in coccidiosis)
Animal welfare, pain and feeding behavior	
Rapid diagnostics for detection of animal disease/food contamination	NO = 0.80 (however 1.96 for infectious bronchitis virus and vaccines, 1.51 for African Swine Fever epidemiology)
Reproduction biomarker/biometric signals & sample preservation	
Aquaculture	
Food animal virus pathogenicity & vaccine efficacy	
Transcriptomic & microscopy analysis in food animal science	
Fetal gestation/development & programming in ruminants	
Epigenetic studies of food animal populations	
Calf health/bovine immunogenetics/metagenomics – respiratory dis.	
Immune response and inflammation pathways in food animals	YES = 1.22
Assessment and prediction of post-harvest meat quality	YES = 1.22

It is evident from the analysis that the study of bacterial and viral pathogens and associated food animal diseases or food animal product contamination is a particular strength for NC State – encompassing multiple specialized areas of inquiry. Livestock and poultry nutrition, and its effect on livestock and their products, is also an area of strength. The other notable areas relate to food animal immunology (which, again, may link to the infectious disease competency), and beef cattle production. Expertise in swine and poultry is evident as being crosscutting across the strength areas.

D. Patenting Activity in Animal Agriculture and North Carolina’s Position Therein

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 food animal-related products and services.

Patent records outlining technologies related to food animals are sometimes difficult to distinctly identify because of the multidisciplinary nature of these technologies. For example, an automated monitoring system for livestock might be categorized across technology classes related to sensors/cameras, image analysis, data analytics, networking/wireless communication, animal husbandry, veterinary instruments, industrial automation, diagnostic medical devices, food product properties/quality and potentially others depending on the information gathering methods used, the characteristics of interest to be monitored, and the type of animal population being monitored.

Because much of food animal IP is based on combination technologies, it is important to include both core animal husbandry and veterinary patent classes as well as a variety of other technology areas that contain key terms related to animal and food science. To identify patents related to food animal technologies across areas such as animal welfare and care, disease control, genetics, food quality/safety, and infrastructure, a tiered search approach was utilized using the following criteria.

We first included any patents with identified technology classes in specific food animal-related areas:

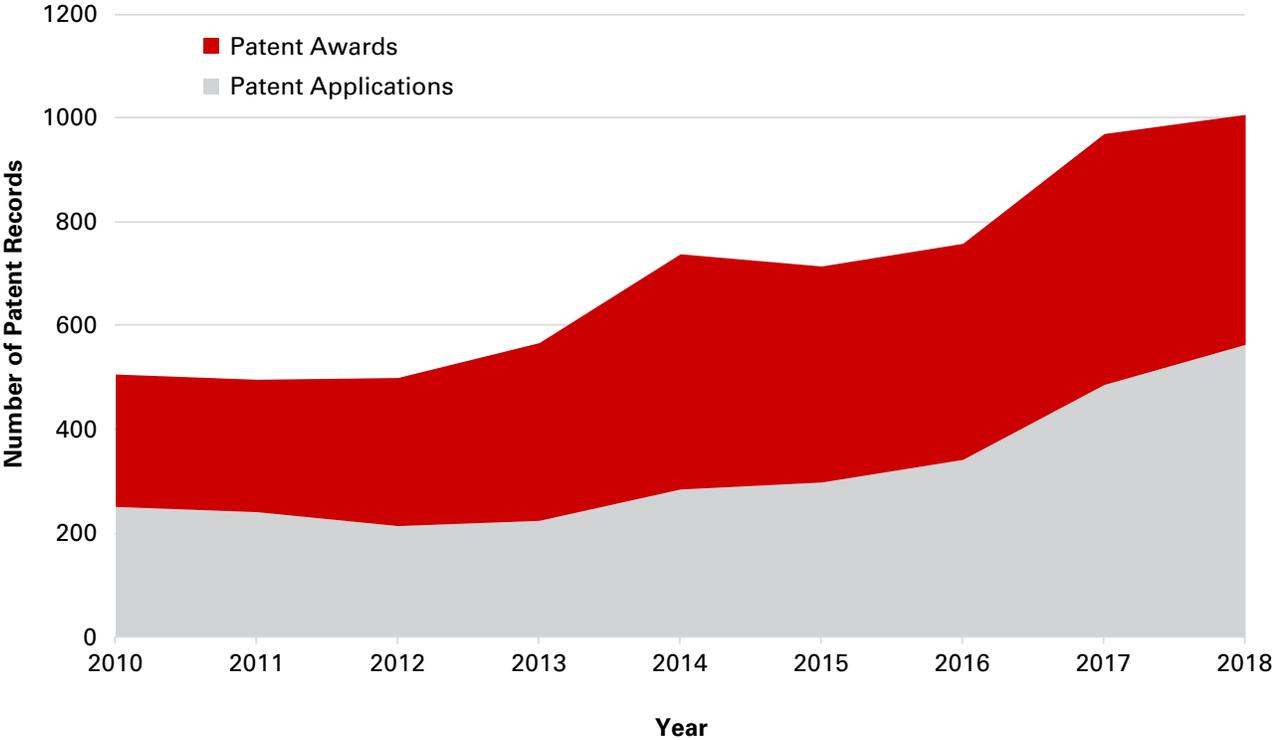
- Manufacture of dairy products,
- Veterinary science (large animal), and
- Animal slaughtering and upstream food animal processing.

We then included any other patents with identified technology classes in potentially food animal-related areas that also contained food animal keyword references:

- Animal husbandry and breeding (and associated devices/infrastructure),
- Animal feedstuffs and fodder,
- Pharmaceuticals and biologic therapeutics (for treating food animals and associated diseases),
- Genetic engineering and biochemistry,
- Biological analysis, sampling, and testing, and
- Upstream food product quality/safety.

While potential food animal IP generation may also occur in other peripheral technology areas, this approach identifies IP focused on core food animal-related innovation and captures the majority of patenting activity in the US in this space. Note that this approach does not include the downstream food product processing and packaging technologies present in major food manufacturing operations and instead focuses on food production.

FIGURE 11: U.S. FOOD ANIMAL PATENT AWARDS AND APPLICATIONS, 2010 TO 2018



Source: Clarivate Analytics, Derwent Innovation Patent Analysis Database

To determine key areas of innovation strength, we extracted and analyzed patents and patent applications from January 2010 through December 2018. During this period, the analysis identified 6,473 total U.S. patent records in food animal production, comprised of 3,435 awarded patents and another 3,038 pending applications. The overall volume of patenting activity in this space has increased over time, but food animal production-related activity remains a niche space within overall U.S. patenting – for reference, awards in the core food animal space represent only 1% of total 2018 awards.

TABLE 21: MAJOR ASSIGNEES IN US FOOD ANIMAL TECHNOLOGIES PATENTING, 2010-2018

Primary Patent Assignee	Company/Institution Focus	Patent Applications	Patent Awards	Total Patent Records
DeLaval	Dairy and farming machinery	68	147	215
Technologies Holdings Corp	IP licensing	35	136	171
Lely	Farm management, milk and meat production	56	58	114
GEA Farm Technologies	Farm equipment and herd management	36	67	93
DSM	Animal nutrition and health	29	20	49
Wisconsin Alumni Research Foundation	Research university	15	29	44
Intervet Inc. (Merck Animal Health)	Veterinary medicines and services	15	25	40
Purina Animal Nutrition	Animal feed products	17	20	37
US Department of Agriculture	Government agency	12	23	35
Zoetis Services LLC	Animal health therapeutic and diagnostic products	11	23	34
Boehringer Ingelheim Vetmedica Inc.	Animal vaccines and pharmaceuticals	9	23	32
Monsanto Technology LLC	Agriculture and plant science	8	23	31
Cargill Incorporated	Food, agriculture, and industrial products	14	17	31

Source: Clarivate Analytics, Derwent Innovation Patent Analysis Database

Patent activities are unique in that the geography of the patent can be defined by either the location of the actual inventor(s) or by the location of the organization (e.g., company or university) that is assigned or “owns” the patent. The first set of analyses examine patents in North Carolina based on the organization tied to the state to which the patents were assigned. The data in Table 22 show that industry patenting in the food animal space is most highly concentrated in large scale dairy market applications with patents awarded in those areas to DeLaval (3.3% of total records) and Lely (1.8%). Other prominent assignees include Technologies Holding Corp. (2.6% of total records) and GEA Farm Technologies (1.4%).

Major technology areas are displayed in more detail in Table 22. Common themes include animal health and veterinary medicine (with more than 15% of total records), animal husbandry (more than 11% of total records), milking and dairy applications (more than 9% of total records), and animal feed (more than 5% of total records).

As NC State advances the Food Animal Initiative the innovation areas that show higher levels of patenting should be noted , because these may represent technology licensing opportunities or provide a pathway forward through new start-up businesses for North Carolina rooted in the innovations.

TABLE 22: MAJOR TECHNOLOGY AREAS IN US FOOD ANIMAL TECHNOLOGIES PATENTING, 2010-2018

Patent Technology Class	Patent Applications	Patent Awards	Total Patent Records
Milking machines or devices	137	287	424
Animal husbandry in general, especially cattle-raising	124	160	284
Medicinal preparations containing organic active ingredients	151	93	244
Medicinal preparations containing antigens or antibodies	86	144	230
Devices for grooming or caring of animals, e.g. curry-combs; Fetlock rings; Tail-holders; Devices for preventing crib-biting; Washing devices; Protection against weather conditions or insects	89	80	169
Accessories for milking machines or devices	47	120	167
Accessories for use during or after slaughtering	38	123	161
Feeding devices for stock or game	54	87	141
Feedstuffs specially adapted for particular animals	83	44	127
Measuring or testing processes involving enzymes or micro-organisms; Compositions therefor; Processes of preparing such compositions	65	56	121
Accessory food factors for animal feedstuffs	77	43	120
Other apparatus for animal husbandry	52	67	119
Medicinal preparations containing materials with undetermined constitution	68	44	112
Devices or methods for introducing solid, liquid, or gaseous remedies or other materials into or onto the bodies of animals	63	48	111
Rearing or breeding animals; New breeds of animals	62	40	102
Peptides having more than 20 amino acids; Gastrins; Somatostatins; Melanotropins; Derivatives thereof	27	65	92
Instruments or methods for reproduction or fertilization	48	44	92
Medicinal preparations of undetermined constitution containing material from algae, lichens, fungi or plants, or derivatives thereof, e.g. traditional herbal medicines	45	46	91

Patent Technology Class	Patent Applications	Patent Awards	Total Patent Records
Biological sample analysis	42	48	90
Mutation or genetic engineering; DNA or RNA concerning genetic engineering, vectors, e.g. plasmids, or their isolation, preparation or purification; Use of hosts therefor	55	32	87

Source: Clarivate Analytics, Derwent Innovation Patent Analysis Database

Finally, Table 23 shows the major patent technology classes for patents assigned to North Carolina inventors. 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. Despite a significant local industry presence, IP generation by NC residents in food animal-related technologies is limited to only 121 total patent records (58 applications, 63 awards) from 2010 to 2018, representing 1.9% of total records

TABLE 23: NC-INVENTED PATENTS IN FOOD ANIMAL TECHNOLOGIES

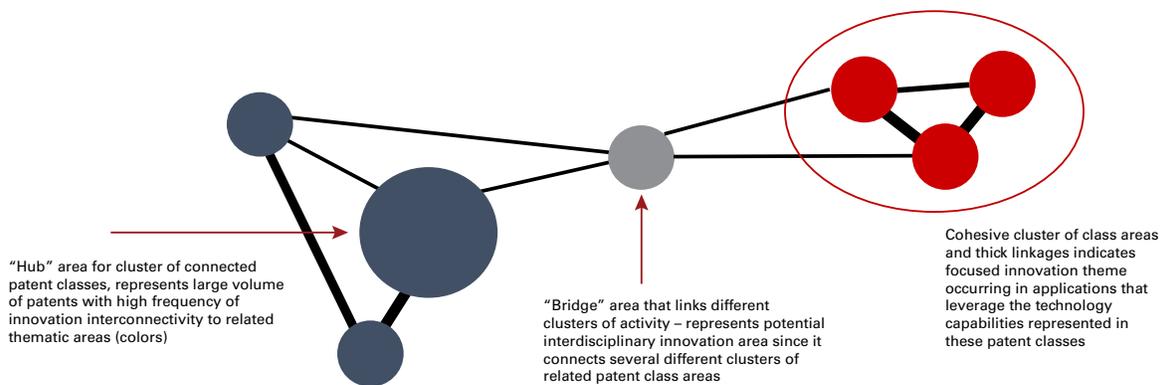
Patent Technology Classes for NC-Invented Food Animal Patents	Patent Applications	Patent Awards	Total Patent Records
Receptacles for live fish, e.g. aquaria; Terraria	4	3	7
Devices for grooming or caring of animals, e.g. curry-combs; Fetlock rings; Tail-holders; Devices for preventing crib-biting; Washing devices; Protection against weather conditions or insects	4	3	7
Medicinal preparations containing materials with undetermined constitution	5	2	7
Animal husbandry in general, especially cattle-raising	4	3	7
Devices for taming animals, e.g. nose-rings or hobbles; Devices for overturning animals in general; Training or exercising equipment; Covering boxes	1	5	6
Accessories for use during or after slaughtering		5	5
Medicinal preparations containing peptides	1	4	5
Biological sample analysis	2	3	5
Medicinal preparations containing antigens or antibodies	2	3	5
Medicinal preparations containing organic active ingredients	2	2	4
Testing, sorting, or cleaning eggs	1	3	4

Patent Technology Classes for NC-Invented Food Animal Patents	Patent Applications	Patent Awards	Total Patent Records
Enzymes, e.g. ligases; Proenzymes; Compositions thereof; Processes for preparing, activating, inhibiting, separating, or purifying enzymes	3	1	4
Treating manure; Manuring	4		4

Source: Clarivate Analytics, Derwent Innovation Patent Analysis Database

The variety of combination technologies present in broader U.S. food animal technologies patenting can also be examined through connections in co-occurring technology area classifications present in patents. Network analysis of patent records provides a way to show how the “landscape” of innovative capabilities are organized in a technology area of interest and how patenting activity gives insight into cross-disciplinary linkages across broader themes. Given the limited level of patenting activity currently occurring in the state, this approach can provide insights into food animal technology areas represented in recent patenting activity that might be of interest for NCSU to develop research or commercialization activities around that are aligned to market.

FIGURE 12: EXAMPLE OF A NETWORK FORMED BY PATENT TECHNOLOGY CLASS AREAS

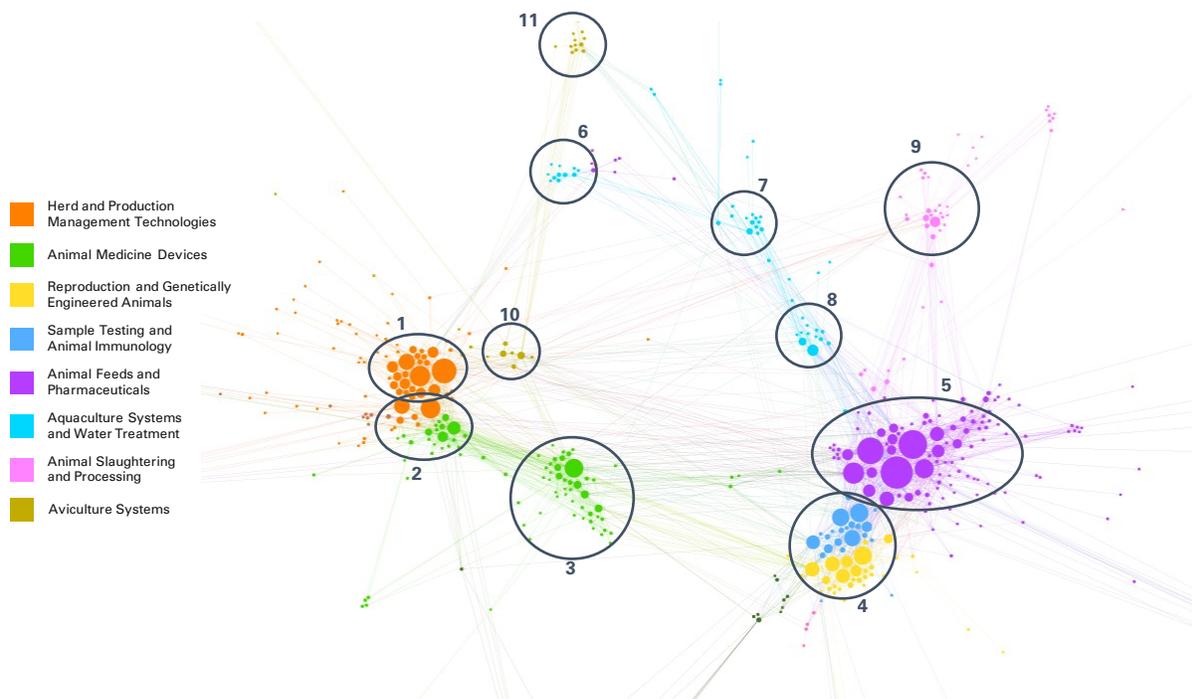


Source: TEconomy Partners

Using the overall patterns of connection between cooccurring technology area classifications, it is possible to build out a network “map” of the structure of research activity occurring across animal-food related areas. An example of network map linkages is displayed in Figure 12. The bubbles themselves, or “nodes,” represent detailed patent class areas. The size of the nodes indicates the number of patents in a given class area that were invented in North Carolina. Using the entire structure of the network defined by its sets of connections, the network is also colored using a community detection algorithm that identifies clusters of closely connected nodes connected by common co-occurring technology areas. The lines that connect bubbles represent forward citation connections between patent class areas, with line thickness indicating the strength of the connection.

The results of the network analyses are shown in Figure 13.

FIGURE 13: TECHNOLOGY CLASS NETWORK FOR US FOOD ANIMAL PATENTS, 2010-2018



Source: TEconomy analysis

The **orange nodes** represent patents that fall within the broader theme of **Herd and Production Management Technologies**. There are two distinct clusters within this theme:

1. The first cluster (label 1 in Figure 13) has an emphasis on **dairy production technologies and integration of robotics, industrial automation, and image analysis/predictive analytics technologies**.
2. The second cluster within Herd and Production Management Technologies sits adjacent to one of the clusters comprised of **green nodes (Animal Medicine Devices)**. This joint cluster (label 2) contains patents **where the themes of Herd Production Management Techniques and Animal Medicine Devices intersect – this cluster represents a significant presence of integrated animal identification and diagnostic health monitoring technologies with an emphasis on real-time metric tracking**. The other, distinct green cluster (label 3) contains patents around **surgical tools and drug delivery devices**.

The **dark blue nodes (Sample Testing and Animal Immunology)** and **yellow nodes (Reproduction and Genetically Engineered Animals)** form highly integrated technology clusters based on genetics and microbiology capabilities (label 4). Genetic engineering and sample collection technologies are key for the reproduction and breeding cluster, while the importance of companion diagnostics for vaccines and other immunological therapeutics is apparent with an emphasis on rapid, in the field diagnosis of disease in applications.

The **purple nodes (Animal Feeds and Pharmaceuticals)** form a cohesive cluster around the intersection of animal feedstock products/additives and biopharmaceuticals/therapeutics targeted at animal health or disease prevention. This cluster includes many examples of patenting that incorporate targeted therapeutics

or other animal health modifying additives within feed sources. An underlying capability in biochemistry and bioengineered compounds appears to be a driver of innovation.

Several remaining clusters of activity exist around more niche technology areas with less patenting volume and fewer multidisciplinary connections. The **light blue nodes (Aquaculture Systems and Water Treatment, labels 6 through 8)** contain a focus on water treatment and mixing/circulation of water types. The **pink nodes (Animal Slaughtering and Processing, label 9)** represent a cluster of animal slaughtering and upstream food processing technologies, which is primarily focused on the automation of carcass processing and measurement as well as sterilization and disinfection of machinery. The **tan nodes (Aviculture Systems, labels 10 and 11)** particularly focus on lighting conditions for laying hens and egg production monitoring.

NC State's Position in Patenting/Technology Licensing Activity in Animal Agriculture

As the strengths and core competencies of NC State in food animal agriculture are triangulated through the TEconomy analysis, the findings of the patent analysis become relevant in identifying potential intellectual property protection and commercialization pathways that might be anticipated. Given a focus of the Food Animal Initiative on enhancing the economic impact of food animal agriculture and associated industries in North Carolina through R&D, the extent to which research core competencies are directed to commercialization opportunities becomes an important consideration.

TABLE 24: LICENSED FOOD ANIMAL TECHNOLOGIES (INCLUDING TECHNOLOGIES WITH POTENTIAL APPLICABILITY TO FOOD ANIMALS)

Food Animal Associated Technology	Lead Innovator
Compositions for multiple guide RNAs for use with CRISPR-Cas9 technologies	Chase Lawrence Beisel
Peptide-based antimicrobials	Chase Lawrence Beisel
Attenuated FNR Deficient Enterobacteria	Hosni M. Hassan
Culture of Avian Embryonic Stem Cells	James N. Petite
Microalgal biomass production with swine waste	Karen O'Connell
Novel Proteins for Immunization Against Cryptosporidiosis	Lance E. Perryman
Transgenic Animals	Paul E. Mozdziak Ph.D.
Antibacterial and Antiviral Targets	Paul F. Agris Ph.D
High Through-put screen for anti-infectives against gram positive pathogens (HTGP)	Paul F. Agris Ph.D
Novel Type II CRISPR-Cas system	Rodolphe Barrangou
Methods and Composition for Sequences Guiding CAS9 Targeting	Rodolphe Barrangou
Novel Cas9 proteins and guiding features for DNA targeting and genome editing	Rodolphe Barrangou
Novel Type I CRISPR-Cas systems for eukaryote genome editing	Rodolphe Barrangou
Lactobacillus probiotic strains for animal health	Rodolphe Barrangou
Vacuum device for the removal of flies from livestock	Steven S. Denning
Development of an Anti-inflammatory Probiotic Strain of Lactobacillus acidophilus for Treatment of Gastro-Intestinal Disorders	Todd R. Klaenhammer
Targeted Delivery of Biotherapeutics to the Gastrointestinal Tract via Bile Sensitive Lactic Acid Bacteria	Todd R. Klaenhammer
Efficient Delivery of CRISPR-Cas9 for Genome Editing via Self-Assembled DNA Nanoclews	Zhen Gu

Source: NC State CALS

Food Science Technologies Applicable to Food Animal Products	Lead Innovator
Dynamic Radiant Frying Process to Produce Fried Foods	Brian E. Farkas
The use of wild yeast species isolated from insects for the production of malt beverages	John Douglas Sheppard
Strains of Lachancea thermotolerans with application to fermentation beverage production	John Douglas Sheppard
Method, System and Devices for Conservative Evaluation, Validation and Monitoring of Continuous Thermal Processing of Foods and Biomaterials	Josip Simunovic
Methods and Apparatuses for Thermal Treatment of Foods and other Biomaterials and Products Obtained Thereby	Josip Simunovic
Method for Measurement and Recording of Minimum Delivered Time-Temperature Exposure of a Biocidal Thermal Treatment and time -Temperature recording Devices	Josip Simunovic
NEW EMBODIMENTS: Microwave Transparent Composite Assemblies for Continuous Flow Microwave Thermal Treatment of Foods, Beverages, Chemicals and Biomaterials	Josip Simunovic
Methods and Apparatuses for Thermal Treatment of Foods and Other Biomaterials and Products Obtained Thereby	Josip Simunovic
Modular Devices and Systems for Advanced Continuous Flow Thermal Processing Using Commercial Microwave Ovens	Josip Simunovic
Hybrid Systems for Continuous Flow Thermal Processing for Treatment of Pumpable Foods and Biomaterials (Heating, Pasteurization, Sterilization) Using Modular 2450 MHz Microwave Equipment	Josip Simunovic
Microwave (2450 MHz) based pre-heaters and continuously recirculated heaters for batch vessel (continuously stirred) reactors for chemicals, biochemical, foods and other biomaterials	Josip Simunovic
Simulated Particles and Methodology for Residence Time Measurement for Process Calculation and Verification for Continuous Aseptic Processing of Foods Containing Particles	Josip Simunovic
DNA Aptamers with Binding Affinity to Human Norovirus Strains	Lee-Ann Jaykus
Novel process for reducing allergenicity of semi-soluble allergenic proteins	Mary Ann Lila
The use of wild yeast species isolated from insects for the production of bread, including sourdough bread	Robert Roberdeau Dunn
Probiotic-based delivery of CRISPR elements for antimicrobial applications	Rodolphe Barrangou
Use of probiotic bacteria to render dietary phytochemicals bioavailable to the host	Rodolphe Barrangou
Engineering of a novel L. acidophilus strain for PKU	Rodolphe Barrangou
Catabolism of and adaptation to plant compounds by probiotic lactobacilli	Rodolphe Barrangou
Expression of Alanine-Glutamine Rich Peptides from Streptococcus thermophilus for Oral Delivery and Mucosal Repair of Clostridium difficile toxin-induced intestinal injury	Todd R. Klaenhammer
Mitigation of Colon Cancer by Gram Positive Lactic Acid Bacteria Deficient in Lipoteichoic Acid	Todd R. Klaenhammer
Lactobacillus acidophilus NCK2187	Todd R. Klaenhammer

Source: NC State CALS

E. Key Learning from NC State Faculty and Leadership Interviews

While quantitative analytics are a crucial tool in identification of core competencies and comparative research strengths, it is also important to reach out to faculty to gain their perspectives on current areas of research emphasis and potential future directions. Interviews also help to identify strengths in research capabilities and infrastructure as well as highlight gaps or weaknesses that may need to be addressed to further advance research in established or emerging core competency areas. With the assistance of CALS and CVM leadership, a series of on-campus interviews were held with faculty from both colleges and multiple academic departments – gaining insight into ongoing research strengths and the application of research innovations to animal agriculture and associated value-added activities through the work of NC State Extension.

The interviews were highly informative in terms of identifying:

- R&D and associated Extension expertise specific to types of food animals.
- Academic disciplines where faculty consider NC State to be a leader, or among key leading institutions, in the performance of research.
- Areas of strength in terms of higher education relevant to food animal veterinary medicine, animal agriculture and value-added processing of food animal products.
- Faculty opinions and suggestions for Food Animal Initiative themes or focus area that should be considered based on NC State established or emerging strengths and assets.
- Gaps or needs associated with advancing NC State in food animal research and associated economic activity.

Each of these focal areas of interview content are summarized below:

1. NC State strengths, and established or emerging core competencies, in food animal agriculture and associated disciplines.

In general, interviewees emphasized applied areas of food animal related research as strengths more so than a basic science focus. This was not exclusive, and there are certainly strengths apparent in a series of more basic scientific inquiry areas, but overall food animal agricultural sciences and veterinary medicine at NC State have a pragmatic, applied focus directed toward problem solving and advancing industry productivity and quality characteristics. In regard to fundamental science strengths, key areas noted include:

- Immunology and infectious diseases
- Livestock reproductive physiology
- Livestock nutrition and metabolism
- Fatty acids
- Pharmacology and pharmacokinetics.

Given the applied nature of food animal sciences, research strengths at NC State tend to be differentiated across species lines. Areas of species-specific core competency were noted by faculty to include:

TABLE 25: LIVESTOCK AND POULTRY SPECIES – AREAS OF RESEARCH STRENGTH AS NOTED BY FACULTY

Species	Research Strengths Identified
Poultry – Broilers	<ul style="list-style-type: none"> • Nutrition impacts on bird health and physiological characteristics • Developmental biology and impact on bird health and physiological characteristics • Digestibility of feed nutrients • Gut health • Waste (litter) processing and utilization • Infectious diseases and parasitology • Poultry muscle biology
Turkeys	<ul style="list-style-type: none"> • Nutrition impacts on bird health and physiological characteristics • Gut health • Infectious diseases and parasitology
Swine	<ul style="list-style-type: none"> • Applied genetics and production management • Swine nutrition • Reproductive physiology • Physiology and meat science – fatty acids • Swine diseases, primarily viral
Cattle	<ul style="list-style-type: none"> • Pasture based production systems and herd management • Nutrition • Reproductive physiology • Biofilms and mastitis

2. Academic disciplines where faculty consider NC State to be a leader, or among key leading institutions, in the performance of research.

Areas noted for specific disciplinary strengths within CALS and/or CVM include:

- **Poultry Science** – as one of only five institutions in the U.S. with a specific department focused on poultry science and associated animal agriculture production and processing.
- **Reproductive Biology** – seen as a broad area of expertise at NC state that crosscuts multiple species including poultry, ruminants and swine. Novel research highlighted in the impact of nutrition on embryo development and impact on later livestock metabolism, health and production characteristics.
- **Microbiology and Infectious Diseases** – crosscutting in both CVM and CALS, there is broad expertise in immunology, virology, bacteriology and parasitology together with applied expertise in diagnostics (development and application), therapeutics, and population health (including prevention and treatment).
- **Waste management and utilization** – with specific infrastructure developed to support research and innovation in the collection, treatment and use of livestock waste streams as inputs to crop/pasture production and energy.

- **Nutrition** – again, this is noted as a broad area of expertise that spans species. Research is facilitated not only by multiple faculty, but also through the support of a world-class feed mill for feed processing, feed product development and testing. Nutrition research includes both fundamental research on physiology and impact on livestock development through to applied studies for improving production and positively influencing livestock health.

3. Areas of strength in terms of higher education relevant to food animal veterinary medicine, animal agriculture and value-added processing of food animal products.

It was noted that the College of Veterinary Medicine is highly ranked among peer institutions, a particularly noteworthy achievement given that the College is comparatively young. While DVM students certainly gravitate more to companion animal medicine, there is a concerted effort within CVM to encourage pursuit of large animal veterinary medicine. The Food Animal Scholars program was cited as a great collaboration between CVM and CALS, working to encourage undergraduate students with an interest in pursuing a DVM degree to get engaged in food animal agriculture opportunities and education.

Having a dedicated Poultry Science Department is a significant differentiator and students graduating with majors from the department are in high demand.

4. Faculty opinions and suggestions for Food Animal Initiative themes or focus area that should be considered based on NC State established or emerging strengths and assets.

TEconomy asked NC State interviewed faculty to identify potential research platforms, or core themes, for the Food Animal Initiative that would leverage identified NC state established or emerging research excellence and have a line-of-sight towards addressing opportunities or challenges of significant scale. Key areas to emerge from discussions on potential themes included:

- **Systems approaches to the prevention and treatment of livestock diseases.** This was noted by most to be a clear area of strength that would quite naturally be able to integrate capabilities and core competencies across both CVM and CALS. A key driver for this opportunity is the changing profile of antibiotic use in food animal agriculture (i.e. a substantial reduction/restriction in antibiotic use) and the fact that there is no “silver bullet” coming to replace antibiotics. NC State’s broad strengths across a diversity of fields, both directly focused on infectious disease (e.g. immunology, parasitology, pharmacology) and influential to livestock health and positive immune system characteristics (e.g. genetics, gut microbiome, nutrition, reproductive biology, etc.) are seen to present a real opportunity for taking a systems-approach to enhancing livestock health and resistance to disease. Faculty noted that they do not know of any other institution driving such a holistic “all of the above” approach to addressing alternatives to antibiotics, and NC State would be especially well positioned to leverage this as an opportunity area. This “all of the above” approach has an analogue in Integrated Pest Management, which representing a well-proven multidisciplinary methodology for addressing complex multi-factor challenges.
- **Digital animal agriculture.** Capabilities within CALS and CVM, and additionally within NC State’s world class College of Engineering (in combination with NC State core competencies in advanced data analytics), are viewed as presenting an opportunity to build a strong position in the emerging field of digital agriculture. This field, which may also be called precision animal agriculture, uses digital

data capture and analysis to inform production practices. This is a fast emerging opportunity area that incorporates both hardware (sensors, wireless data transmission tools, etc.) and advanced analytics processes (machine vision, machine learning, artificial intelligence) focused on livestock feed and water consumption, movement, behavior, physiological characteristics, production environment characteristics, etc. Data collected is analyzed to inform decisions to optimize the production system, fine tune the production environment and identify emerging health issues and mitigate production challenges.

- **Livestock nutrition.** This is viewed by many faculty as a clear area of cross-disciplinary strength at NC State that spans the scientific spectrum from fundamental biological research through to applied innovations and livestock production practice recommendations development. Supported by robust resources for feed production and associated capabilities to support large-scale nutrition trials, this is an area also noted as addressing the largest cost component of production animal agriculture (feed costs). Interviewees noted that this is also the space that would serve as the most direct link between the large-scale investment in the Plant Sciences Initiative and the largest component of NC agricultural production (food animal production). It was also noted that a livestock feed and nutrition theme also connects to NC State assets and scientific capabilities at the NC Research Campus in Kannapolis. It was noted, however, that the core faculty with livestock nutrition expertise at the university may be approaching retirement.
- **An integrated “Farm of the Future” theme with associated infrastructure development.** A general theme across faculty interviews was concern that animal agriculture research facilities, especially (but not limited to) university farm facilities, are outdated and not equipped to duplicate modern production practices used in industry. This is viewed as hampering the ability of the university to perform work of relevance to industry or jointly with industry. It is also viewed as a limiting factor in terms of educating students to understand, appreciate and be ready for employment within modern animal agriculture production. Multiple faculty noted that the Plant Sciences Initiative has come with parallel major investment in physical infrastructure for advanced plant science research, and that attention on infrastructure is similarly required for the Food Animal Initiative. Notably, however, the type of infrastructure viewed as being needed differs substantially from that of the PSI (which focuses on a state of the art transdisciplinary plant science building on the Centennial Campus,) to be focused on building a “farm of the future” – a development (typically recommended for location at Lake Wheeler) that would provide the infrastructure required to duplicate/simulate modern livestock production systems and be flexible and reconfigurable for the testing of new production systems, practices, digital technologies, etc. Such development is viewed as central not only to research relevance but also to education and training relevance within both CALS and CVM. A key point made regarding this “farm of the future” concept is that it should be designed to facilitate transdisciplinary holistic-systems oriented research, enabling multi-faceted approaches to be tested to improving livestock health and disease resistance, instrumenting the farm for data collection and analytics, and for testing integrated approaches for utilization of waste streams and minimizing the environmental footprint of intensive animal agriculture. It was also noted that a farm of the future should be designed to develop and test scalable production systems, within this being important given the diversity of farming operation sizes across the state.
- **Improving the ability to perform research focused on increasing value-added to primary livestock and poultry production within North Carolina.** It was noted that while North Carolina has high levels of primary animal production (especially in, but not limited to poultry and swine), the value-added processing end of the value-chain is relatively undersized in the state in comparison. Greater utilization of livestock output in the state and in-state production of value-added food animal-based products, is seen as a logical pathway to increasing the economic impact of the agriculture sector on the state. A key gap identified by multiple faculty that limits the ability of the University in value-added work is the lack

of slaughter and meat processing facilities at NC State. Building a theme more focused on value-added products is seen as important for the University to pursue to show relevance to industry. It was noted that perhaps such a value-added products emphasis should fall under the Food Manufacturing Initiative, but animal science and poultry science faculty view the FMI as being focused on plant-based foods, rather than animal products, in its work as currently structured.

- **Early engagement in disruptive/complementary technology.** As a research university, faculty consider it important to not only focus on relevance to the production systems of today, but to also look forward to the integration of potentially disruptive technologies or complementary/tangential technologies that may have a profound effect on animal agriculture in the future. Certainly, the move into digital agriculture, as outlined above is one example of this, as could be the leveraging of NC State engineering expertise for examining applications of automation and robotics to livestock production and downstream processing. It was also noted that NC State has some signature expertise in muscle biology and biotechnology that lends itself to R&D in the emerging field of cellular agriculture (also referred to as “artificial meat”). It was noted that while some may consider cellular agriculture to be disruptive to animal agriculture it may actually prove to be a complementary technology – representing a parallel pathway to food animal production helping to meet the large scale predicted growth in demand for animal protein and being used for lower-value products (like comminuted meat products) where simulating the actual characteristics of a specific meat cut is less necessary to satisfy market demands. With companies such as Smithfield Foods performing work in this area, and some of the industry interviews noting they see themselves as being in the “protein-production” industry and that does not limit them to traditional meat products, this is an area of research that NC State should feel free to pursue without being overly concerned by its potential disruptive effect on traditional production. What could perhaps be developed would be a “food protein center” at a farm of the future, that would incorporate both processing of traditional animal products and cellular agriculture.

5. Gaps or needs associated with advancing NC State in food animal research and associated economic activity.

In discussing the Food Animal Initiative with individual faculty the conversations also covered areas of capability or infrastructure at the University that represent gaps to address or needs to fill. The Food Animal Initiative is viewed not only as a means to leverage R&D core competencies of the university to advance animal agriculture, but also as a potential means to address current deficiencies or weaknesses in certain fields of inquiry or physical infrastructure that may be limiting the full potential of CALS and CVM. The main categories and examples of gaps and barriers to address via the Initiative, as relayed to TEconomy through faculty interviews, were as follows:

TABLE 26: PRINCIPAL GAPS, CHALLENGES AND BARRIERS NOTED IN FACULTY INTERVIEWS.

Theme	Issues, Gaps or Barriers to Address
University or college policies and procedures	<ul style="list-style-type: none"> Action is needed to incentivize faculty collaborations, especially across departmental or college lines. There is a risk, especially for untenured faculty, in pursuing transdisciplinary work with others outside of one's direct department/field unless it is spelled-out as a direct institutional goal and reward systems put in place to encourage it. There is concern that the cost of using university core facilities is becoming prohibitively expensive for faculty, let alone for external parties like industry. Faculty numbers in many departments have declined, with persons retiring not being replaced. This has substantially increased the workload for remaining faculty and is a significant constraint in terms of available time to work on research and innovation. Perceptions of non-competitive salaries at NC State may lead faculty to seek employment at other academic institutions or outside of academe.
NC industry profile	<ul style="list-style-type: none"> While NC State has a world class poultry science department, all of the large poultry companies are headquartered outside of the state (and thus may be more inclined to work with universities located more proximate to their HQ/R&D centers). North Carolina only has a relatively small presence of companies in the animal health industry.
Education and training	<ul style="list-style-type: none"> NC State is not producing enough graduates to meet the job demands in food animal sectors. The growth of the poultry industry, in particular, has outstripped the ability of the university to produce sufficient graduates. There is concern that the quality of teaching is slipping within CALS is slipping as a result of increased numbers of students and reduced numbers of faculty. University farm facilities and associated physical infrastructure and equipment have not kept pace with the types of modern environments deployed in industry. Because of this, students are not adequately prepared to understand the environments they will need to operate in, and the skills needed in those environments.
Specific infrastructure	<ul style="list-style-type: none"> Caliber of university infrastructure, at Lake Wheeler and other locations, is insufficient to sustain relevance in research and training work. A lack of slaughter and meat processing facilities limits the ability to perform work of relevance to enhancing processing industries in the state. This is needed on both the livestock and poultry side. Current, relatively long-standing, moratorium on building new swine facilities is hampering NC's ability to lead in swine innovation and management practices – within industry and the university. The livestock industry is increasingly moving to deployment of automated systems, yet NC State does not have facilities that duplicate this environment for relevance of education and training.
Faculty research support	<ul style="list-style-type: none"> Faculty note that insufficient resources are available for hiring technicians, and thus their research time is spent performing tasks that could be more efficiently and cost effectively undertaken by technician level personnel. CVM faculty mentioned a need for more support with research design, especially in terms of statistics expertise.

F. Key Learning from Prior Meetings and Input Sessions at NC State for the FAI

In early planning for the Food Animal Initiative, NC State conducted multiple input sessions, retreats and group meetings to solicit stakeholder (faculty, student, industry, etc.) input regarding opportunities and needs for an initiative, strengths to build upon, gaps to address, etc.

1. Key Topics for the Future of Food Animal Agriculture

One of the key events was a November 2015 retreat attended by more than 80 faculty representing 3 colleges and 8 departments. Deliberations from the event resulted in identification of multiple “key topic areas” considered to be likely drivers of food animal agriculture into the future. These key topic areas include:

- Animal agriculture efficiency – with an emphasis on the interactions of production management (Genetics, Nutrition, Physiology, etc.) with disease prevention and treatment.
- Food animal microbiomes
- Food safety
- Science advocacy to the public (communications and messaging)
- Transdisciplinary student training (workforce development)
- Environmental stewardship
- Antibiotic resistance/alternatives
- Animal welfare
- Dig data (mining and modeling)
- Biosensors and robotics (advanced animal and environmental monitoring)
- Immunology and vaccinology
- Epigenetics
- Genetic editing/engineering
- New/alternative feedstocks for food animals
- Food processing innovation
- Global/international technology transfer and trade economics.

An evaluation matrix was used by the FAI coordinating committee and administration leadership to subsequently rank these topic areas, using a 1-5 scale of weak to strong in terms of “disruptive innovation potential”; “NCSU competitive potential”; “external funding potential”; “interdisciplinarity” and “stakeholder alignment”. The resulting evaluation matrix and rank of each topic area is shown on Table 27:

TABLE 27: KEY TOPIC AREAS LIKELY TO BE KEY DRIVERS OF FOOD ANIMAL AGRICULTURE INTO THE FUTURE. (COORDINATING COMMITTEE AND ADMINISTRATION SCORING OF TOPIC THEMES IDENTIFIED AT FACULTY RETREAT)

Rank	Collaborative Theme	Disruptive Innovation Potential	NCSU Competitive Potential	External \$ Potential	Inter-disciplinary	Stakeholder Alignment	Avg. Score
1	Biosensors & robotics (animal & environmental monitoring)	4.5	3.5	3.8	4.5	3.4	3.9
2	Environmental stewardship	3.3	3.3	4.3	3.5	4.6	3.8
3	Efficiency: production mgmt. X health	4.6	3.6	3.5	4.2	3.0	3.8
4	Big data (mining & modeling)	3.8	3.5	3.7	3.8	3.6	3.7
5	Genetic editing/engineering	3.6	3.6	3.5	4.0	3.7	3.7
6	Science advocacy (communications/ messaging)	2.6	3.8	3.2	4.2	4.4	3.6
7	Food safety	3.5	3.2	3.0	4.2	4.0	3.6
8	Antibiotic resistance/ alternatives	4.0	3.5	3.8	3.8	2.6	3.5
9	Microbiome – discovery & manipulation	2.8	3.5	3.7	3.0	4.1	3.4
10	Food processing innovation	3.5	2.8	2.7	3.0	4.9	3.4
11	Immunology/vaccinology	2.4	3.8	2.5	3.8	3.5	3.2
12	Transdisciplinary student training (workforce development)	3.0	2.8	3.2	2.8	3.6	3.1
13	New/alternate feedstocks for food animals	3.0	2.0	3.6	3.6	2.7	3.0
14	Animal welfare	2.6	3.3	2.8	2.3	3.8	2.9
15	Global/international tech transfer & export economics	2.6	2.8	2.0	2.8	4.4	2.9
16	Epigenetics	3.0	2.0	2.0	3.0	2.5	2.5

2. Faculty Interests and Capabilities by Topic

Each of the topics were subsequently incorporated into survey that was completed by 108 faculty respondents. The survey focused on faculty interests and expertise in relation to each topic. In effect the survey findings show where faculty have interests and self-rated capabilities in each topic, where they believe new faculty hires are needed, and where they view the university already having relevant infrastructure. Table 28 tabulates the results of the analysis, showing the mean score on a 1-5 scale and then using coloring to provide a heat map to make the findings relatively easy to observe.

From this analysis it is evident that the faculty rate the following scientific areas as areas of current capacity and also areas where the university should also reinforce through recruits:

- Animal agriculture efficiency – with an emphasis on the interactions of production management (Genetics, Nutrition, Physiology, etc.) with disease prevention and treatment.
- Food safety
- Food animal microbiomes (discovery and manipulation)
- Environmental stewardship.

In addition, the faculty (quite understandably) rate “transdisciplinary student training (workforce development” highly as a topic, and also “science advocacy to the public (communications and messaging).”

The results suggest that faculty are more likely than not to recommend new faculty hires to reinforce areas of existing strength, more than they are to fill perceived disciplinary gaps or address weaknesses.

TABLE 28: KEY TOPIC AREAS LIKELY TO BE KEY DRIVERS OF FOOD ANIMAL AGRICULTURE INTO THE FUTURE.

Faculty Interest and Expertise Survey Results.

(Mean score on 1-5 scale, where 1=none, 2=little, 3=moderate, 4=strong, 5=very strong).

Rank	Collaborative Theme	I have interest	Relevant experience	Currently working	Would join team	Should recruit	Have Infra.
1	Biosensors & robotics (animal & environmental monitoring)	3.05	1.73	1.46	2.47	3.06	2.38
2	Environmental stewardship	3.28	2.53	2.27	2.86	3.15	3.21
3	Efficiency: production mgmt. X health	3.54	2.84	2.59	3.16	3.47	3.51
4	Big data (mining & modeling)	3.06	1.93	1.84	2.45	3.15	3.08
5	Genetic editing/engineering	2.74	1.66	1.53	2.15	3.20	2.96
6	Science advocacy (communications/ messaging)	3.37	2.56	2.12	3.01	3.09	3.17
7	Food safety	3.43	2.78	2.40	3.05	3.26	3.71
8	Antibiotic resistance/ alternatives	3.17	2.39	2.01	2.61	3.13	3.33
9	Microbiome – discovery & manipulation	3.47	2.26	2.17	2.99	3.63	3.33
10	Food processing innovation	2.60	2.13	1.89	2.34	3.04	3.06
11	Immunology/vaccinology	2.95	2.20	2.06	2.64	3.23	3.14
12	Transdisciplinary student training (workforce development)	3.33	2.92	2.63	3.04	2.74	3.22
13	New/alternate feedstocks for food animals	2.72	2.11	1.73	2.36	2.68	3.08
14	Animal welfare	3.17	2.42	1.81	2.71	3.15	3.21
15	Global/international tech transfer & export economics	2.49	1.93	1.76	2.14	2.51	2.57
16	Epigenetics	2.83	1.83	1.64	2.33	3.01	2.97

Heat map scale

1-3	Top 3
4-6	4-6
7-10	7-10
11-13	11-13
14-16	14-16

In terms of volume of faculty with interest and capability in each of the topics, the survey results also provide insight. Table 29 lists each of the topics and places a count of faculty who gave a score of 4 (strong) or 5 (very strong) for their capabilities or interests.

TABLE 29: KEY TOPIC AREAS LIKELY TO BE KEY DRIVERS OF FOOD ANIMAL AGRICULTURE INTO THE FUTURE.

Faculty Interest and Expertise Survey Results. Count of Faculty Scoring at 4=strong or 5=very strong.

Rank	Collaborative Theme	I have interest	Relevant experience	Currently working	Would join team
1	Biosensors & robotics (animal & environmental monitoring)	40	6	7	22
2	Environmental stewardship	41	23	20	31
3	Efficiency: production management X health	51	28	26	39
4	Big data (mining & modeling)	35	11	10	22
5	Genetic editing/engineering	27	7	8	15
6	Science advocacy (communications/ messaging)	37	23	13	37
7	Food safety	45	29	24	33
8	Antibiotic resistance/alternatives	39	21	13	27
9	Microbiome – discovery & manipulation	44	17	20	40
10	Food processing innovation	25	19	14	19
11	Immunology/vaccinology	31	18	13	29
12	Transdisciplinary student training (workforce development)	39	29	25	25
13	New/alternate feedstocks for food animals	26	11	10	19
14	Animal welfare	41	13	6	28
15	Global/international tech transfer & export economics	21	11	11	15
16	Epigenetics	28	10	10	21

Heat map scale

	>40 faculty
	31-40
	21-30
	11-20
	<11

As would be anticipated, the broader and more transdisciplinary the topic area the more faculty there are with interests and capabilities to apply. That said, in every one of the topics there are at least 20 faculty respondents who express interest in that topic. In terms of relevant experience or current work in the topic, however, there is a significant drop-off in numbers.

Several of the topics contain between 20-29 faculty who claim relevant experience in the topic, but only 5 of the topics contain 20 or more faculty who state they are currently working in the specific topic area – these being in “efficiency: production management X health”, “food safety”, “environmental stewardship” and “microbiomics”. In addition, 25 faculty state they are currently working in “transdisciplinary student training”.

Interest in joining a team focused on each topic varies considerably. The topics attracting the lowest number of faculty (n=15) are “genetic engineering/editing” and “global/international technology transfer and export economics”. The highest levels of faculty engagement on teams would likely be in:

- Microbiome – discovery & manipulation (n=40)
- Efficiency: production management X health (n=39)
- Science advocacy (communications/messaging) (n=37)
- Food safety (n=33)
- Environmental stewardship (n=31)
- Immunology/vaccinology (n=29)
- Animal welfare (n=28)
- Antibiotic resistance/alternatives (n=27).

It should be noted that the survey only went to CALS and CVM faculty, yet for many of the topics there would likely be faculty in other NC State colleges with expertise and interest in the subject matter. For example, faculty in the College of Engineering and College of Sciences would have relevance to work in “biosensors and robotics” or “big data”, while others in the College of Humanities and Social Sciences and the College of Education would have relevant expertise to apply to “science advocacy (communications/messaging” for example. Several of the areas would be likely to draw faculty from within the College of Sciences and the College of Natural Resources. For several of the topic areas it would be crucial to engage these additional colleges.

3. Recommendations for Enhancing CALS and CVM Infrastructure

Several work sessions or group meetings brought faculty together to discuss needs in terms of infrastructure improvement – especially infrastructure that would be of benefit to joint work between the colleges. Table 30 provides a summary of those noted in TEconomy’s review of summary notes from these meetings.

TABLE 30: JOINT INFRASTRUCTURE CONCEPTS FOR CVM AND CALS

Focus	Description
Poultry hatchery and incubation center	Development of a unique and high visibility university facility targeting the most technologically demanding component of the poultry industry. Provides opportunities for research and training in reproduction and immunology/vaccination together with the ability to develop and test automation and precision technologies.
Protein processing and food safety innovation center	Development of a center for animal protein product processing and for research and innovation in processing technologies, food safety (including ability for BSL2 studies), and for improving waste product utilization, energy consumption and other production factors. The center would be used for research and also for education of NC State students and training of industry and regulatory personnel.

Focus	Description
Metabolism education and small ruminant unit	Development of new facilities to provide an optimized environment for both research (basic and applied) and training.
Instrumented facilities	Installation of sensors and broadband connectivity into existing research farms and animal facilities to benefit research and teaching activities. The integration of the Internet-of-Things into animal facilities.
BSL facilities for work on animal health and biosecurity	Infectious diseases that impact production or present downstream food safety issues are a top concern for industry. NC State currently lacks the BSL2 (and potentially BSL3) facilities required for safely pursuing the work that is needed. Potential to be unique capability on the East Coast.
Farm of the Future	Rather than taking a piecemeal approach that tries to repair and reinvest in existing infrastructure (much of which is of poor standard, past its useful life, and spread out) there could be investment in a new Farm of the Future with new facilities set-up to duplicate best practices in industry and developed to integrate the latest scientific methods and technologies and instrumentation to facilitate research. Lake Wheeler is generally considered the logical location and would be beneficial in its proximity to the metro area for demonstration events with the public.

4. Recommendations for Themes for the Food Animal Initiative

Based on the faculty survey results, group meetings, retreats and other deliberations, in 2018 the Food Animal Initiative’s Coordinating Committee and senior leadership from CALS and CVM began to group core competencies, interests and identified opportunities into multidisciplinary/transdisciplinary “themes” for further discussion. Four themes emerged:

- **Food, Nutrition and Health.** Comprising innovations to improve growth efficiency of food animals: health, novel feedstocks, genetic engineering, and management of the gut metagenome.
- **SMART Animal Technologies.** Integrating adaptive and precision technologies to optimize animal production and environmental stewardship: on-farm wireless data networks, biosensors, smart sensors and control systems, drones, robotics, and big data analytics.
- **Value-Added Processing and Food Safety of Animal Foods.** Focused on animal food processing technologies to enhance economic development and food safety: food processing innovation, pre- and post-harvest food safety, food borne pathogens and product quality.
- **Food Animal Health and Management for a Global Market.** Comprising sustainable application of food animal systems technologies: antimicrobial use (including surveillance and alternatives), animal well-being, new and emerging infectious diseases and trade economics.

V. Potential Development Platforms for the Food Animal Initiative

While NC State demonstrates a variety of disciplinary and thematic core competencies, not all research core competencies are created equal in terms of their overall scale, their associated commercialization or in-state economic development potential, or their line-of-sight to large markets. Several factors need to be taken into account when developing a major initiative such as the FAI and moving from core competencies to consideration of actual development platforms (core programmatic themes with the potential to generate innovations, relationships, or clusters of R&D activity that may generate significant innovation and growth within the North Carolina economy).

Ideally, a PLATFORM for science- and technology-based economic development should meet several key threshold criteria:

- Be built on a cluster of competencies with a significant current or emerging base of R&D and established clusters of scientists, faculty, or centers to build upon.
- Be directed towards an area of R&D with significant funding potential and relevance to identified needs in science, society or industry.
- Contain a clustering of existing businesses and institutions with interests in similar R&D areas, products, or technologies with which the platform can interact.
- Represent a platform around which 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.

Identification of development platforms for the Food Animal Initiative represents an important step in coalescing assets and investment around focused themes that leverage strengths and reflect important needs or challenges in food animal agriculture. Clearly the Food Animal Initiative cannot be all things to all people, rather it needs to direct investment and resources towards areas where it can have the most robust impacts, achieve significant R&D based innovation, generate institutional leadership and recognition, and provide pathways to education that fulfills market needs.

A. Summary Analysis

As a first step in identifying potential platforms, the prior intelligence gathered through TEconomy's quantitative and qualitative evaluation of core competencies, and NC State's internal deliberations, needs to be summarized. Table 31 does this, finding 11 topics represented across the various forms of analysis and input received. The table summarizes the evaluated information in terms of:

- Quantitatively identified core competencies at NC State as measured by publications volume and publications quotient and NC State specializations identified in the latent topic analysis.

- Whether components of the topic area were cited as NC State strengths or core competencies in the TEconomy interviews with faculty and leadership at NC State.
- The degree to which faculty are currently working in the area and/or express interest in joining a relevant research team (as identified through the NC State performed faculty survey)
- Adjacent disciplinary strengths of potential relevance to the topic identified through the research publications analysis.
- Prioritization of the topic area noted in interviews with industry in North Carolina.

TABLE 31: SUMMARY OF FOOD ANIMAL INITIATIVE POTENTIAL FOCUS AREAS AND ASSOCIATED CORE COMPETENCIES

Topic	Associated NC State Quantitative Competencies	Faculty Cited as an NC State Strength	Faculty Interest & Experience	Adjacent Strengths	Industry Cited as a FAI Priority	Notes
Infectious diseases & animal health	<p>YES.</p> <p>Multiple strengths identified via latent topic analysis & publications analysis. (Detection & treatment of bacterial contamination and disease, disease reduction and control in broilers, food animal virus pathogenicity and vaccine efficacy, immune response pathways, microbiology).</p> <p>Main species focus in poultry and swine.</p>	<p>YES.</p> <ul style="list-style-type: none"> Immunology & inf. Diseases. Pharmacology & pharmacokinetics. Work in poultry (broilers and turkeys), swine and cattle. 	<p>YES.</p> <p>Largest cluster of faculty “currently working” in relevant area of “Efficiency: production management X health” (26).</p> <p>Among stronger area for faculty interest in joining a team (production management X health 39, immunology & vaccinology 29, antibiotic resistance and alternatives 27).</p>	<p>YES</p> <ul style="list-style-type: none"> Genetics heredity. Microbiology Biotechnology & applied microbiology. 	<p>YES.</p> <p>Number 4 (tie) ranked priority area.</p>	<p>An area “keeping industry up at night” and certainly needing innovation in the face of reductions in antibiotic use. Natural fit for joint work between CVM and CALS. Addresses global and NC needs and offers pathway for economic development via commercialization.</p>
Microbiome	<p>UNCLEAR.</p> <p>May be embedded as a component within core competencies in nutrition, immunology, microbiology and genomics.</p>	<p>YES.</p> <p>“Food animal microbiomes” did emerge as a “focused theme cluster” in the latent topic analysis, but NC State did not show a specialization there.</p>	<p>YES.</p> <p>Particularly cited by poultry science faculty focusing on gut health, and as a component of expertise in livestock nutrition.</p> <p>4th highest cluster of faculty saying “currently working” in microbiome discovery and manipulation.</p> <p>Highest area of interest for “joining team” with 40 faculty.</p>	<p>YES.</p> <ul style="list-style-type: none"> Microbiology Genetics/ Genomics 	<p>YES.</p> <p>Number 5 ranked priority area.</p>	<p>Seen as an area with significant “freedom to operate” that has interesting fundamental science questions and relevance to production efficiencies and livestock health. Draws upon multiple areas of NC State competencies. Potential pathway for economic development via commercialization.</p>

Topic	Associated NC State Quantitative Competencies	Faculty Cited as an NC State Strength	Faculty Interest & Experience	Adjacent Strengths	Industry Cited as a FAI Priority	Notes
Food safety	<p>YES.</p> <p>Multiple core competencies identified related to pathogens (see above).</p> <p>Core competency in publishing in “Food Science Technology” (422 pubs and 2.83 PQ). Clear evidence of relevant NC State developed technologies in the patenting and licensing data.</p>	<p>NO.</p> <p>Was not specifically called out but implied as an area that is addressed across the production system.</p>	<p>YES.</p> <p>3rd highest cluster of faculty saying “currently working” in food safety.</p> <p>Strong interest for “joining team” with 33 faculty.</p>	<p>YES.</p> <ul style="list-style-type: none"> • Microbiology 	<p>YES.</p> <p>Number 2 ranked priority area.</p>	<p>Again, this is a strong concern for industry. Interfaces with competencies in the infectious disease and animal health space. Addresses global and NC needs and offers pathway for economic development via commercialization and NC State has already commercialized in the space.</p>
Livestock nutrition and feedstocks	<p>YES.</p> <p>Cluster in animal feedstocks and impacts on growth and performance with specializations in swine feed and also in feedstock additives. Also, strength in use of whey protein</p>	<p>YES.</p> <p>Cited strengths in livestock nutrition and metabolism. Specializations in poultry nutrition and nutrient digestibility, swine nutrition and cattle nutrition. World class expertise and facilities in feed mill operations and formulations research.</p>	<p>MODERATE.</p> <p>One of the lower areas of interest as a topic for future work. Tied for 3rd lowest area of interest for faculty wanting to join a team as “new/ alternative feedstocks for animals”. However, also an area that would be directly relevant to the strongly supported area of “Efficiency: production management and health”.</p>	<p>YES.</p> <p>Obvious connection to both Plant Science Initiative and Food Manufacturing Initiative in terms of feedstock development. Adjacent expertise potentially in microbiology and other life science disciplines.</p>	<p>MODERATE.</p> <p>Industry perceives this as an area generally well covered by the private sector, but notes importance of researching nutrition as a component of enhancing livestock health and immune system performance</p>	<p>A definite historic area of strength for NC State, although some faculty noted that it may be seeing significant reductions in faculty on the horizon due to pending retirements. Industry interested in seeing research that ties nutrition (across the animal lifespan – from embryo onwards) to livestock health and immune system strength.</p>

Topic	Associated NC State Quantitative Competencies	Faculty Cited as an NC State Strength	Faculty Interest & Experience	Adjacent Strengths	Industry Cited as a FAI Priority	Notes
Precision animal agriculture	NO. Does not show up in analytics as an area of current core competency at NC State. However, there are robust core competencies in many fields that would be potentially relevant to building a significant position.	MODERATE. Was discussion of work taking place between engineering and poultry science in machine vision applications in poultry houses.	YES. Towards the middle in terms of faculty interest in engaging (circa 20 faculty). Low levels of current engagement in the space.	YES. Broad and deep expertise in multiple engineering, computer science and data analytics areas at NC State.	YES. Number 4 (tie) ranked priority area.	Understood to be an area of opportunity and importance, but not a current strength in terms of agricultural or veterinary sciences currently. Deep expertise in engineering, computers and data science at NC State presents opportunity to connect to College of Engineering. Industry very interested. Potential pathway for economic development via commercialization.
Meat science & protein processing	YES. Strengths evident in: proteomic properties of food animal products; fatty acids in pork, and the assessment and prediction of post-harvest meat quality.	YES. Noted strengths in muscle biology, fatty acids (especially in relation to swine), and cellular agriculture.	UNCLEAR. Was not specifically asked on faculty survey, except as pertains to “food processing innovation” (where there are 14 faculty currently working and 19 express interest in joining a team.	YES. Robust expertise in engineering disciplines potentially of relevance.	NO. However, the profile of interviewed organizations skewed to production agriculture and inputs companies.	Very relevant to a need to increase value-added processing of food animal products in the state, which is comparatively undersized given level of livestock and poultry production. Lack of slaughter and processing facilities on campus was cited as a serious challenge to advancing work.
Waste management and utilization	NO. While environmental impacts and climate impacts of farming operations is a cluster in the latent topic analysis, NC State did not demonstrate a specialized PQ.	YES. Specialized infrastructure cited, and historic track record in working with industry. Also waste-to-energy research, and strong programs in use of waste products for pasture (cattle) and agronomic soil improvement.	YES. Generally strong faculty interest in “environmental stewardship” as a theme and the university is strong in environmental sciences. 5th highest number of faculty (31) wanting to join a team. 20 faculty say they are currently working in environmental stewardship (but not necessarily waste management per se).	YES. Multiple NC State specialized fields with potential relevance in environmental science, engineering and biotech disciplines.	MODERATE. Ranked 6th in industry interviews. Industry generally noted that private sector is on top of this, but noted that there is room for improvement.	Seen as an area where NC State has done well in thinking holistically about “closing the loop” and enhancing the sustainability profile of animal agriculture. May be room for technological advancement in waste-to-energy applications within the ag value chain.

Topic	Associated NC State Quantitative Competencies	Faculty Cited as an NC State Strength	Faculty Interest & Experience	Adjacent Strengths	Industry Cited as a FAI Priority	Notes
Reproduction and developmental biology	YES. Evident in specialization in “genetics heredity” classification. However, both “reproductive biology” and “developmental biology” do not have specialized PQs.	YES. Cited as a robust area of expertise, particularly in swine, poultry and beef cattle.	UNCLEAR. Was not asked as a “topic” within the faculty surveys.	MODERATE. Are multiple life science disciplines at NC State of relevance, but most do not demonstrate specialized PQ.	MODERATE. Industry expressed some interest in this as an area of research for understanding the impact of early development of the animal and later impact on health and the immune system.	Seen as an area to integrate into an “all of the above/ systems approach” to improving livestock health and immune system resistance to pathogens together with other factors such as nutrition, housing and environmental controls, vaccines, management practices, etc.
Genomics and gene editing	UNCLEAR. University specialized PQ in “genetics heredity” category with 453 publications and a 1.26 PQ.	YES. “Genetic profiling applications” is one of the 8 anchoring communities in the latent topic analysis, but NC State did not show a specialization in it.	MODERATE. Noted as a moderate strength but felt to be undersized on the food animal side. World class reputation in CRSPR gene editing technologies that could be applied. One of the lower scored areas in terms of faculty interest, experience and current work focus. Lowest number of faculty wanting to “join team”. However, ranked 4th in terms of areas where faculty say NC State “should recruit”.	MODERATE. Potentially relevant strength in “mathematical computational biology” publications (229 pubs, 1.9 PQ)	MODERATE. Industry noted that improvement of genetic lines is largely in commercial sector now. However, multiple interviewees noted importance of genetics to livestock health and immunology.	Strongly evident, in terms of gene editing technologies employing CRSPR in patenting data. Viewed as perhaps best deployed as part of an “all of the above/systems approach” to improving livestock health and immune system resistance to pathogens together with other factors such as nutrition, housing and environmental controls, vaccines, developmental biology, management practices, etc.

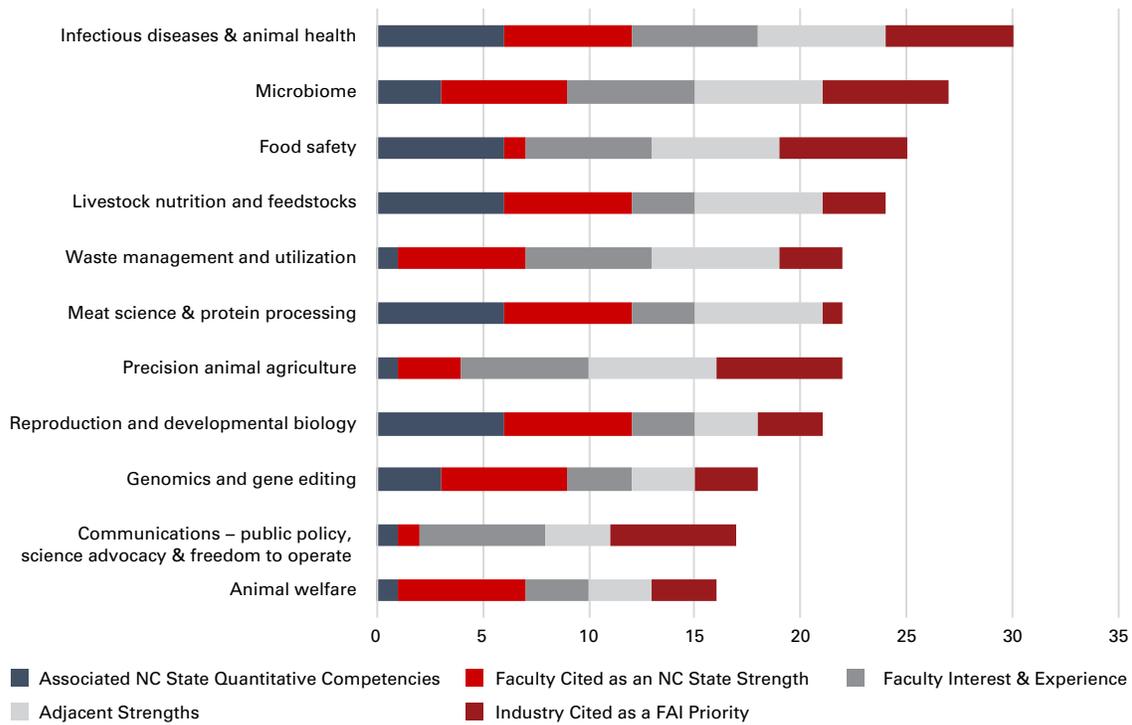
Topic	Associated NC State Quantitative Competencies	Faculty Cited as an NC State Strength	Faculty Interest & Experience	Adjacent Strengths	Industry Cited as a FAI Priority	Notes
Animal welfare	NO. "Animal welfare, pain and feeding behavior" is a cluster in the latent topic analysis, but NC State did not show a specialization in it.	YES. Mentioned as an area where there have been some new CALS hires, and an area of interest within CVM.	MODERATE. Among the top areas for faculty interest, but only 6 faculty reported currently working in it. One of the lower scored areas for faculty wanting to join a team.	MODERATE. Multiple potential areas of adjacent strengths, mostly in various engineering disciplines.	MODERATE. Industry perceives this as a strength at other institutions that cover the space well.	Seen as being a topic area that is generally well addressed within industry and other institutions, but again noted as a topic that should be integrated into a holistic understanding of impacts on animal health and performance.
Communications – public policy, science advocacy & freedom to operate	NO. Not evident in the food animal research analysis, nor in adjacent disciplines in areas such as communications, public policy, political science,	NO. Recognized as an issue, but faculty were unable to point to significant programs focused on this (beyond traditional work of Extension/4-H).	YES. Strong interest in "joining team" for work in this area (ranked 3rd among topic areas with 37). 13 faculty indicated they are doing work in this area.	MODERATE. NC State has a specialized PQ in applied psychology that could be relevant. Comparatively weak showing however in behavioral sciences, communication, social issues, ethics, political science and educational psychology.	YES. Number 1 ranked issue cited in industry interviews. Industry sees it as imperative for the FAI to work on this.	This will be a challenging space to address, but industry very much wants NC State "on this" and faculty show interest too. Key areas needed in scientific advocacy, combatting dis/mis-information, interfacing with the public regarding modern food animal practices, and addressing public policy issues and constraints. Issue of this area having relatively weak programs in communications and associated political and social sciences at the university.

To develop a basic overview of the comparative "score" for each of these potential topic areas, Figure 14 uses a scoring system as follows for each of Table 31's columns.

- 1 = NO
- 3 = UNCLEAR or MODERATE
- 6 = YES

Under this scoring scheme, each of the scored columns is weighted evenly, with a maximum cross-column cumulative score possible of 6x5=30.

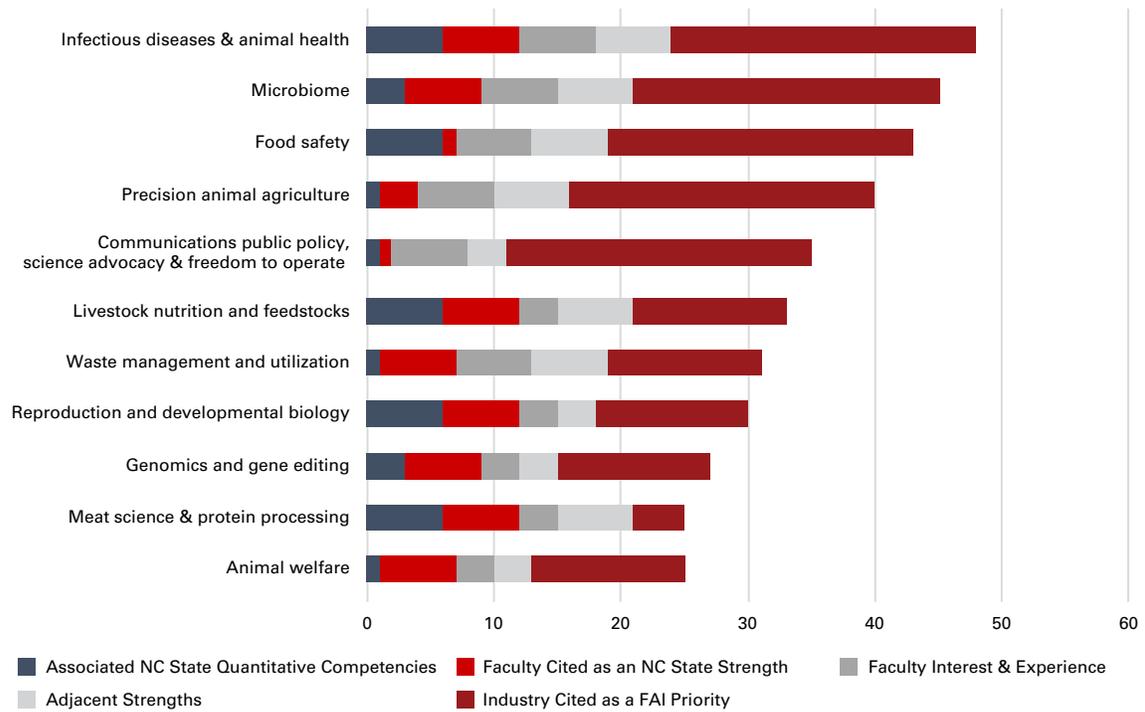
FIGURE 14: SUMMARY OF TOTAL SCORING FOR ELEVEN IDENTIFIED TOPICS FROM TECONOMY ANALYSIS



(each metric equally weighted)

Given that the Food Animal Initiative has a specified goal of not only building NC State leadership in food animal agriculture and associated sciences, but also meeting the expressed needs of industry (working to address industry challenges), an alternative view of the scoring across the 11 topics is shown in Figure 15. Under this scoring scheme the weight of the industry metric is scaled to be equal to the four university focused metrics (i.e. for the industry scoring the scores are “no” = 4, “unsure or moderate” = 12, and “yes” = 24). This weighted scoring results in a redistribution of the 11 topics in terms of overall score – most notably in terms of increasing the comparative importance of “communications, public policy, science advocacy and freedom to operate” and lowering the rating of “meat science and protein processing.” It should be noted/cautioned however that “meat science and protein processing” as a category was not referenced much in the discussions with industry since most of the interviews were not with processing/value-added product companies. Given the earlier economic analysis showing that the processing end of the value chain in North Carolina is comparatively undersized, this may actually be an area that the FAI may wish to emphasize and build in.

FIGURE 15: SUMMARY OF TOTAL SCORING FOR ELEVEN IDENTIFIED TOPICS FROM TECONOMY ANALYSIS

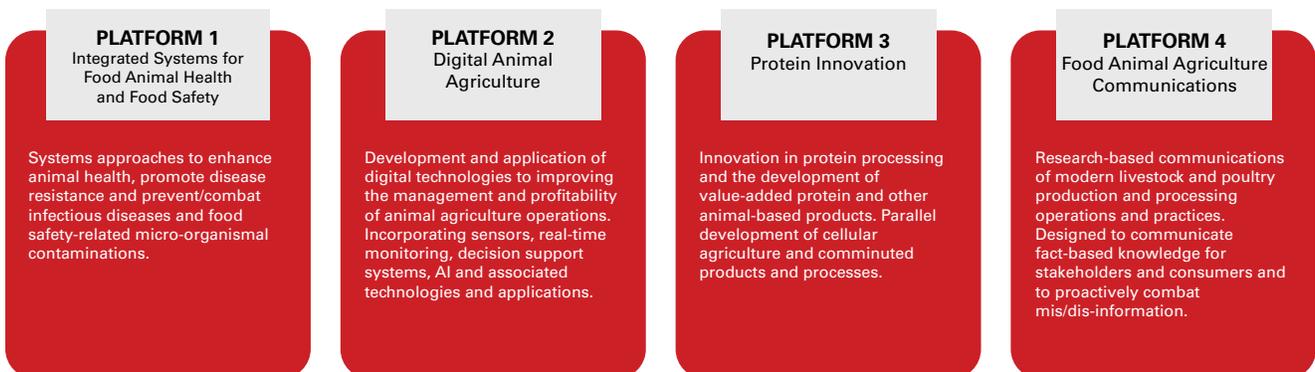


(Adjusted to equally weight the four university metrics collectively and the industry metric)

B. Moving from Core Competency Topics to Development Platforms – Identification of Potential Development Platforms for the Food Animal Initiative

Taking into account the rating of topics, together with all the input provided during the project from faculty, industry and other key stakeholders, plus review of previous deliberations at NC State performed in preparing for the Food Animal Initiative, TEconomy concludes that a logical pathway forward for the FAI becomes evident. TEconomy recommends that the FAI comprise four development platforms, as summarized on Figure 16:

FIGURE 16: FOUR RECOMMENDED PLATFORMS FOR THE FOOD ANIMAL INITIATIVE



Platform 1: Integrated Systems for Food Animal Health and Food Safety – a transdisciplinary approach to develop and quantify effective systematic solutions to improve animal health and address pathogen contamination. Will include research, education and extension activity in areas such as:

- Surveillance and monitoring systems in primary production and processing
- Diagnostics and rapid pathogen detection systems
- Immunology, vaccines and immunotherapeutics
- Nutritional impacts on animal health and livestock immune systems
- Microbiome and gut health effects on livestock health
- Housing, management and handling system impacts on livestock health
- Genetics and livestock improvement for health and pathogen resistance
- Health decision and practices that positively influence animal well being
- Operation of new BSL2 facilities, and potentially BSL 3.

Platform 2: Digital Animal Agriculture – focused on development and application of digital technology in livestock and poultry production and downstream processing operations. Platform leverages NC expertise in engineering, computer science, advanced analytics together with the domain specific expertise contained in CALS and CVM. Will include research, education and extension activity in areas such as:

- Sensors and networked systems
- Advanced analytics and AI
- Machine vision and recognition
- Agricultural engineering
- Animal health and well being
- Food processing.

As Noted in Chapter III:

*Infectious diseases and livestock health are what keep producers “up at night.” It is a broad area of concern, covering worries relating to emerging/ re-emerging infectious diseases (including exotic infectious diseases), the challenge of reducing antibiotic use, pathogen contamination and food safety, etc. **Industry views this challenge as needing an “all of the above” approach now – envisioning a systems approach** that uses: vaccines and immunotherapeutics; study of the livestock microbiome to understand impact on health and ability to stave off disease; study of livestock genomics to identify resistance/health traits and markers; nutritional approaches to boosting the livestock immune system (including during pregnancy or in-the-egg); the use of precision/digital technologies to monitor animals and produce early ID of emerging symptoms, and use of precision technologies to combat risk of food safety challenges. This broad area of focus is seen as an excellent area for engagement of both CALS and CVM, plus engineering and other university capabilities.*

As discussed below, each of the platforms, including the Digital Animal Agriculture platform will benefit from development of NC State’s Lake Wheeler site into a modern research, education and demonstration farm, purposefully designed to be fully instrumented and reconfigurable for demonstrating, testing and innovating livestock production systems. This will require livestock housing systems of a high industry standard, fully instrumented and networked to facilitate the development and use of precision animal agriculture technologies. This “Forefront Farm” should be structured to facilitate industry engagement and co-location of university-industry collaborative teams for joint participation in research programs. The Farm of the Future should also form the hub of a network for precision animal infrastructure installed at other major NC State livestock research facilities and at participating industry sites, serving to build a powerful data collection and analysis network for application to work across the platforms.

Platform 3: Protein Innovation – Potentially collocated with the envisioned Forefront Farm a platform in Protein Innovation would focus on R&D and training focused on value-added meat and other animal protein products (such as eggs and milk) processing. Incorporating slaughter and processing operations, the platform and its Protein Innovation Center would allow innovation to be pursued in the safe processing of protein products, integration of sensing and digital technologies into a holistic livestock rearing through processing value-chain, and potential integration of emerging NC State capabilities (and industry interests) in cellular agriculture. This platform could also work on other value-added food animal products, but protein is viewed as a principal demand area based on growth in global population and food demand patterns.

Platform 4: Food Animal Agriculture Communications – Voiced by industry and faculty alike, there is strong recognition that freedom to operate in animal agriculture is under threat and subject to significant misinformation and disinformation challenges. TEconomy believes that these challenges should be addressed through a two part approach:

- Design of the recommended Forefront Farm to be visitor friendly (within the constraints imposed by biosecurity), representing a showplace and demonstration site for modern approaches to livestock agriculture and food animal welfare.
- Development of a small team at NC State focused on proactive communications with the public, policy makers and other key stakeholders regarding modern animal agriculture and focused on combatting mis/disinformation where identified. The team should connect to and support the existing Council for Agricultural Science and Technology (CAST), which is an existing science-based agricultural communications organization¹⁵ and with other organizations and initiatives such as The Center for Food Integrity¹⁶. By leveraging existing organizations the Food Animal Initiative can work to meet the goals of combating mis/disinformation without having to undertake major research programs or substantial faculty recruitment in the area.

Infectious diseases and food safety are certainly viewed as a crucial area for the FAI to emphasize by industry. The review of NC State core competencies, across CALS, CVM and beyond, show that this is also a logical area where current and emerging strengths can be built upon collaboratively. Digital Animal Agriculture provides similar opportunities for collaborative research and education activity between CALS, CVM and other University colleges (most notably Engineering). The Food Animal Initiative provides an opportunity to do something that is very hard for industry to do (if not impossible), but realistic in a large university setting, that of developing major transdisciplinary programs that integrate multiple fields of study and interest areas into a systems approach to major challenges.

¹⁵ CAST is a nonprofit 501 (c)(3) organization composed of scientific societies and many individual, student, company, nonprofit, and associate society members. CAST's Board is composed of representatives of the scientific societies, commercial companies, and nonprofit or trade organizations, and a Board of Directors. CAST was established in 1972 as a result of a 1970 meeting sponsored by the National Academy of Sciences, National Research Council. The primary work of CAST is the publication of task force reports, commentary papers, special publications, and issue papers written by scientists from many disciplines. The CAST Board is responsible for the policies and procedures followed in developing, processing, and disseminating the documents produced. These publications and their distribution are fundamental activities that accomplish our mission to assemble, interpret, and communicate credible, balanced, science-based information to policymakers, the media, the private sector, and the public. The wide distribution of CAST publications to nonscientists enhances the education and understanding of the general public. CAST addresses issues of animal sciences, food sciences and agricultural technology, plant and soil sciences, and plant protection sciences with inputs from economists, social scientists, toxicologists or plant pathologists and entomologists, weed scientists, nematologists, and legal experts. CAST's mission statement is: "CAST, through its network of experts, assembles, interprets, and communicates credible, balanced, science-based information to policymakers, the media, the private sector, and the public." Its vision statement is: "A world where decision making related to agriculture and natural resources is based on credible information developed through reason, science, and consensus building." See: <http://www.cast-science.org/about/>

¹⁶ <http://www.foodintegrity.org/about/who-we-are-2/faq/what-programs-does-cfi-offer/>

C. Infrastructure Needs

The Plant Sciences Initiative is investing in a state of the art plant sciences research and education building on the Centennial Campus in Raleigh. The development of the new building is, in part, a response to recognition that agricultural science facilities at the University had become very much outdated and presented a serious constraint to the pursuit of advanced R&D in plant sciences. The same also holds true for facilities on the food animal R&D and training side of the equation. In some areas critical infrastructure that is needed to advance R&D in food animal agriculture is missing altogether (for example animal housing and research facilities with required biosecurity levels, meat processing facilities), while other facilities and infrastructure are not to modern standards or are experiencing heavy maintenance requirements as they have been used beyond their anticipated life. Overall, the infrastructure and livestock/poultry facilities at NC State are no longer able to demonstrate best industry practices for education and research purposes or support the types of advanced research needed to address major challenges in food animal agriculture.

If NC State wants to lead in advanced food animal agriculture research and training and be able to maximize its positive impacts in North Carolina it really needs to invest in facilities and infrastructure.

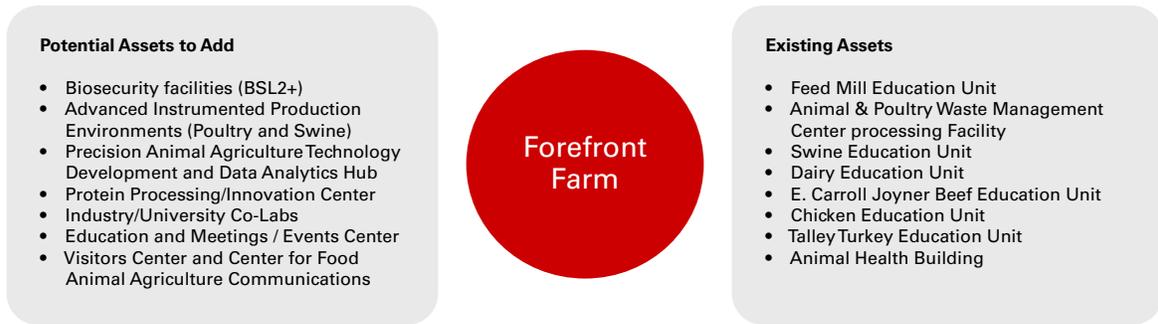
Facilities and infrastructure are ideally required that will be able to demonstrate/duplicate current industry best-practices and standards and be reconfigurable and fully instrumented to allow for experiments, testing programs and education and Extension programs. The 1,500 acre Lake Wheeler Road Field Laboratory (Figure 17), located in Raleigh, provides an extremely well-located site for development of the envisioned infrastructure.

FIGURE 17: VIEW OF LAKE WHEELER ROAD FIELD LABORATORY



The Lake Wheeler site contains existing facilities and assets that may be integral to systems approaches to animal agriculture and contains the space required for the development of new and renovated assets into a “Forefront Farm”.

FIGURE 18: ADDITIONAL AND EXISTING ASSETS FOR FOREFRONT FARM AT LAKE WHEELER¹⁷

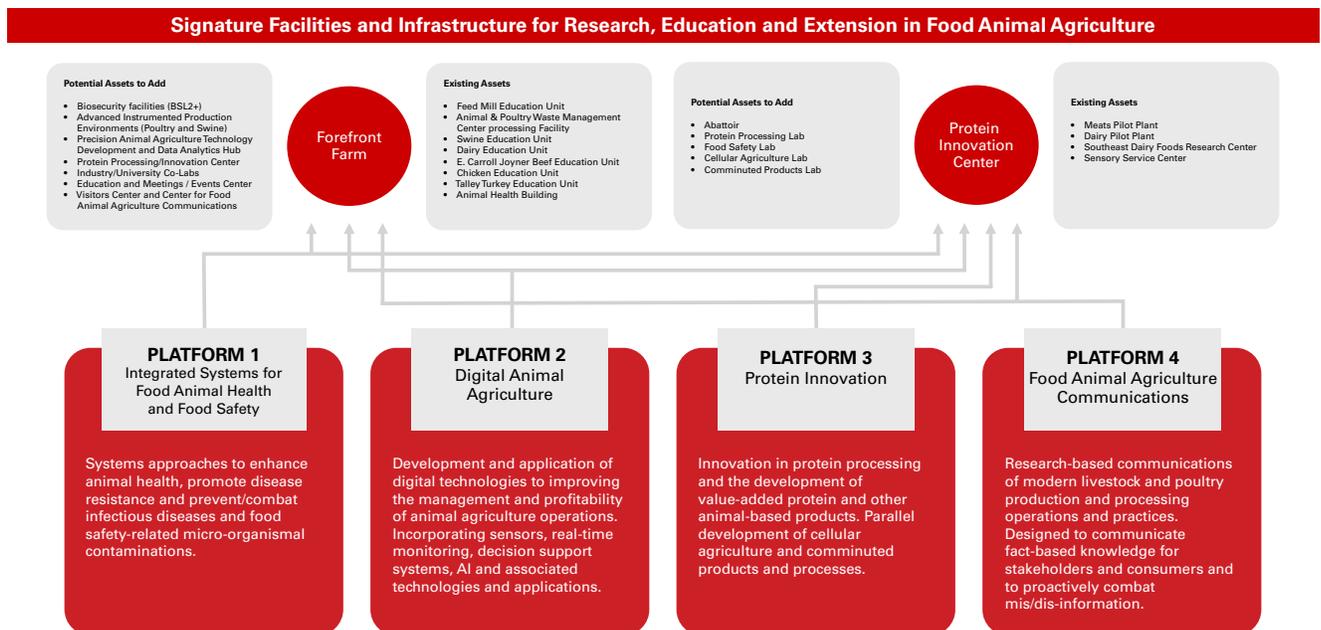


As envisioned, Forefront Farm would form the central location for joint CALS, CVM (and other NC State colleges) interactions and collaborative education, research and extension activity in food animal agriculture, with direct relevance to three of the four platforms:

- Integrated Systems for Food Animal Health and Food Safety
- Digital Animal Agriculture
- Food Animal Agriculture Communications.

It is further recommended that development of a physical Protein Innovation Center take place and be collocated with the Forefront Farm. Figure 19 shows the recommended signature facilities and infrastructure investments and their relationship to the four platforms.

FIGURE 19: FOOD ANIMAL INITIATIVE RECOMMENDED PLATFORMS AND SIGNATURE FACILITIES DEVELOPMENT¹⁸



¹⁷ Note: The Teaching Animal Unit (TAU) and infectious diseases research facilities of the College of Veterinary Medicine also represent important components to integrate as non co-located assets for Forefront Farm.

¹⁸ Ibid

Rather than limiting activities in the Food Animal Initiative to just one or two main disciplines of fields, the four platforms proposed for the FAI provide the ability to integrate a substantial number of core competency areas identified across the University into focused initiatives directed at challenge-oriented needs and opportunities of relevance to both global challenges and issues of direct relevance to the North Carolina agricultural economy. Platforms 1, 2 and 4 also provide signature opportunities for CALS and CVM collaboration in areas that are of demonstrated concern and interest to industry and are structured to accomplish work in ways that industry would find highly difficult to do alone. This leverages the transdisciplinary strengths of a world class research university and the Forefront Farm concept focuses investment in assets and infrastructure to support innovative research, technology development, innovation piloting and demonstration. This also builds a unique environment for education and training across undergraduate, graduate and professional fields.

The recommended four-platform model also has the advantage of building connectivity to other major NC State initiatives:

- The Integrated Systems for Food Animal Health and Food Safety clearly brings CVM and CALS together around a highly relevant shared focus, and also provides opportunities to link to the Plant Sciences Initiative in relation to feed impacts on animal health and may leverage the microbiomics capacity developing within the PSI.
- Both the Integrated Systems for Food Animal Health and Food Safety and Protein Innovation platforms connect the FAI and the Food Manufacturing Initiative, and give the Food Manufacturing Initiative a base of operations within Raleigh and the proposed Lake Wheeler Forefront Farm
- Forefront Farm provides opportunities for interfacing with the PSI in precision and digital technologies, and its Digital Animal Agriculture platform allows the powerful investment that NC State has made in engineering capabilities and data sciences to be leveraged.

VI. Strategies and Actions for Advancing the Food Animal Initiative

Both the Plant Sciences Initiative and the Food Manufacturing Initiative at NC State eminently prove the ability of the University to take bold steps to advance NC State to the forefront of research, innovation and education in sciences applied to the grand challenge of feeding the world's expanding population. Having raised substantial funding support, NC State is now beginning the construction of a state-of-the-art plant science building on the Centennial Campus in Raleigh and developing the faculty teams of existing faculty experts and new recruits that will pursue focused R&D and training across several focused plant science advancement platforms.

In North Carolina, as in many of the world's agricultural production environments, plant focused agriculture is one component of a two-part food production system that also comprises food animal production – the production of livestock (for meat and dairy products) and poultry (for meat and eggs), our main source of dietary protein and other nutrition staples. Indeed, in **North Carolina the livestock and poultry sectors account for the majority of agricultural production value, represent critical markets for plant feeds, and supply into an important statewide value-added processing sector.** Food animal agriculture is intensely important to economy of the state, supports farm operations from small holdings to very large-scale operations, and supplies into large and expanding markets.

With a long-standing history in the state, North Carolina's animal agriculture industry is foundational to state, regional and local economies and impacts both rural and urban communities through its value-chain operations. It is also, however, an industry that faces significant change. Changing public policies, regulations, consumer preferences, technologies and other factors are influencing industry prospects. Changes in major practices, such as the reduced use of antibiotics in animal agriculture production, create significant challenges in terms of sustaining animal health and productivity, and the global movement of people and products exposes our agriculture to the threat of pathogens and other biosecurity issues. Mass communications and social media are enabling the democratization of information but also enabling large scale dis/mis-information campaigns to spread, threatening the freedom of farmers to operate in animal agriculture. Modern animal agriculture is, at the same time, experiencing unprecedented opportunities to advance on the back of digital, biological and technological advancements that promise enhanced nutrition, refined genetics, high precision animal management and monitoring, and new approaches to enhancing the immune system of our livestock and poultry to stave off disease.

Against this complex background of economic importance, and operating environment threats and opportunities, there is no single academic institution that has emerged as the global leader in food animal agriculture. There are certainly institutions active in this space (and several are discussed in detail in the benchmarking work outlined in Appendix A), but no place, so far, has put together the pieces of the research and training puzzle that are needed to provide a transdisciplinary, systems-based approach to meeting the most pressing challenges and needs. **This then presents the opportunity for NC State – an opportunity to become the preeminent institution in applying a systems approach to meeting the challenges of global protein**

and animal product production through research, education and extension programs that will assure North Carolina is positioned to sustain and expand upon its large scale animal agriculture value-chain.

A. Vision and Goals

Planning sessions and associated work products from NC State for the Food Animal Initiative have generated several statements regarding a vision for the Initiative. Among these:

- *“Our Aspiration: To propel NC Animal Agriculture to the next level of productivity and sustainability through teaching, research and extension across the agriculture, life science, veterinary and engineering fields.”¹⁹*
- *“To do even more to propel the advancement of the industry, we are creating a Food Animal Initiative. The goal is to assist industry to economically increase the production of healthy animals and animal products that meet consumer demands for food, animal welfare, and environmentally-friendly, sustainable farming.”²⁰*
- *“The Food Animal Initiative can greatly enhance the current , successful collaborations between CALS and CVM and place NCSU as a leading institution in the field of food animal research and innovation that supports the animal production industry and stakeholders in North Carolina. , the United States and Globally, The initiative would also be good for the general public, consumers, the economy and the environment.... We will have reached success when NCSU is a major provider of information to these groups and are who they turn to find information, solutions to current problems, assistance with sudden emergencies and look to for innovations and solutions to future problems.”²¹*
- *“There was universal agreement that the most important/valuable product of a successful program at NCSU would be the production of a skilled workforce of professionals who can support and propel advancement of the industry.”²²*

In the above descriptions, and in other documents and deliberations for the FAI, certain terms and themes repeat:

- A need for relevance to North Carolina food animal agriculture
- A need to “propel” industry to a higher level of performance
- Multidisciplinary/transdisciplinary and multi-college collaborative
- Incorporate both research and higher education missions.

19 January 25, 2018. “Preparing for the NC Food Animal Initiative” PowerPoint Presentation.

20 Food Animal Initiative – growing Talent, Solutions, Opportunities and Economies.

21 Food Animal Initiative – Description of a Successful Program.

22 Ibid

B. Strategies Overview

Five primary strategies, with a series of potential actions associated with each strategy, are proposed for the Food Animal Initiative. The five strategy areas are:

Strategy 1	Develop a “ <i>Forefront Farm</i> ” ²³ as a high visibility, signature development that will provide the modern R&D, education and production environment infrastructure required to propel NC State to the forefront of food animal science and veterinary medicine.
Strategy 2	Build transdisciplinary teams and infrastructure to advance NC State food animal agriculture and veterinary sciences work in the primary development platforms: <ul style="list-style-type: none"> • Integrated Systems for Food Animal Health and Food Safety • Protein Innovation • Digital Animal Agriculture
Strategy 3	Recruit faculty to reinforce strengths, address skills gaps relevant to the platforms and create opportunities for collaborative research.
Strategy 4	Develop undergraduate, graduate and certificate programs that are focused in the three platforms and developed with input from industry
Strategy 5	Develop a proactive Food Animal Agriculture Communications program

C. Strategies and Associated Actions

The development of the Food Animal Initiative is quite rightly being undertaken using an input process involving multiple stakeholders. A committee comprising CALS and CVM leadership is guiding the process and it is evident that care has been taken in providing an inclusive process that engages faculty, students, industry and other stakeholder groups. TEconomy puts forward the following strategies and actions not as a rigid prescription, but rather as conceptual strategies and actions recommended for further discussion and consideration within the FAI planning process.

The strategies and actions have been developed using a series of assumptions:

- The FAI seeks to be world-class signature program for NC State, equivalent in stature to the PSI
- The University will be successful in securing sufficient funds, potentially in the order of \$200+ million to build the infrastructure necessary to realize the Initiative’s vision
- Structures and policies will be put in place within CALS and CVM that require faculty collaborations and transdisciplinary research and education program engagement
- The FAI will have a strong orientation towards meeting the applied and prioritized needs of food animal production and processing industries of relevance to North Carolina and will be designed to facilitate industry/university collaborations.

Each strategy and its associated recommended actions are outlined below:

²³ At a recent presentation by TEconomy to CALS and CVM faculty the term “Farm of the Future” was noted to not necessarily be the right term to use. What is needed is a farm, and associated research and teaching facilities, that is at the forefront of today’s production technologies and designed to be reconfigurable and flexible for upgrading as frontiers in animal research, production and education change and evolve. Farm of the Future was felt to be terminology that implies results that might not be realized for a considerable period of time, whereas producers and other stakeholders for the Food Animal Initiative need to see results and applications in the near-term. As such “Forefront Farm” is used herein as a placeholder name indicative of the vision for this infrastructure development, but TEconomy recommends that branding specialists be consulted for assistance with final naming options.

Strategy 1 focuses on a signature investment in infrastructure for livestock and poultry housing (to an advanced industry standard) designed to facilitate fundamental and applied R&D programs and provide environments reflective of industry practices for student education.

STRATEGY 1: Develop a Forefront Farm as a high visibility, signature development that will provide the modern R&D and education infrastructure required to propel NC State to the forefront of food animal science and veterinary medicine.²⁴

Action	Description
Action 1.1	Establish a Forefront Farm Development Committee (FFDC), comprising representatives of the University (CALs, CVM, and the College of Engineering), NCDA, and industry (including inputs, primary production and value-added processing industry representation). Expertise in communications and marketing/business development should also be incorporated.
Action 1.2	The FFDC should develop a profile of the facilities required to match industry best practices and meet the research and education needs of the FAI recommended platforms (see Strategy 2). It may be advisable to form development platform specific facilities sub-committees to examine current NC State infrastructure for “fitness to purpose” for individual platform needs and advise as to new and enhanced infrastructure and facilities requirements to be integrated into the Forefront Farm.
Action 1.3	Inventory current Lake Wheeler Road facilities, TAU and other core sites and field stations used in livestock and poultry programs and score against an established rating criteria for “keep as is”, “renovate and upgrade”, “expand”, “replace.”
Action 1.4	Retain an architecture and planning firm with experience in science and technology facilities, BSL2/3 construction, and production agriculture and processing facilities, to lead design preliminary design charettes and workshops based on information from Actions 1.2 and 1.3. (see Appendix E for typical planning and design processes for major projects of this type).
Action 1.5	Incorporate a digital operations center into the farm to coordinate network/IoT operations (on the farm and connected to TAU and other NC State research stations/facilities), cyber-security, data storage, etc. The ops center will work with researchers and industry representatives in integrating sensors, technologies etc. into the Forefront Farm system.
Action 1.6	Encourage connectivity of the Digital Operations Center to industry sites for integrated data capture and storage. Assure the FF becomes a hub for the secure storage and confidential analysis of big data relevant to animal agriculture. Access to data is key for advancements across multiple avenues of research, and the FF may be designed to encourage contributions of data from industry as well as internal programs.
Action 1.7	Incorporate space at Forefront Farm for industry co-labs – spaces able to house industry and university joint research teams. Support with an industry concierge position to facilitate access to facilities and equipment, and linkages with faculty and students for teaming projects.
Action 1.8	Incorporate maker space and fabrication facilities, and new business development incubation space, to encourage applied R&D leading to commercialization of new technologies and innovations. Link to existing NC State initiatives in support of research commercialization and business development.

24 It should be noted that the Forefront Farm does not imply a single location. While NC State’s expansive Lake Wheeler Road site is well-suited for development of much of the envisioned new and modernized infrastructure, it will also be important to connect the CVM Teaching Animal Unit (TAU) site and other research station sites of relevance. Major livestock and poultry operations typically operate across multiple sites, and by forming the NC State Forefront Farm as a networked system of sites, the Farm will allow development and testing of systems that work remotely or otherwise are suited for spanning multiple locations.

STRATEGY 1: Develop a Forefront Farm as a high visibility, signature development that will provide the modern R&D and education infrastructure required to propel NC State to the forefront of food animal science and veterinary medicine.²⁴

Action	Description
Action 1.9	Assure development of the Farm as a site that encourages formal and informal interactions between stakeholders, students, researchers and industry representatives. This requires incorporating meeting space and flexible classroom space into the design but also informal gathering and dining spaces conducive to encouraging informal “collisions”. A goal should be to produce a dynamic community environment at the FF and development of the Lake Wheeler Site as an animal agriculture innovation district with diverse programs and supporting amenities.
Action 1.10	Examine opportunities to have major industry stakeholders leverage their equipment and supplier relationships to help secure infrastructure, equipment and supplies at discounted cost to equip the Forefront Farm. Some companies may select to supply equipment and keep it updated as a partnership with the Forefront Farm

Strategy 2 focuses on advancing recommended Development Platforms, comprising transdisciplinary teams.

STRATEGY 2: Build transdisciplinary teams and infrastructure to advance NC State food animal agriculture and veterinary sciences work in the primary development platforms:

Action	Description
Action 2.1	Appoint co-chairs for each platform – with CVM and CALS co-chairs for Integrated Systems for Food Animal Health and Food Safety and Digital Animal Agriculture.
Action 2.2	Use previously conducted faculty survey to identify current faculty who expressed interest in joining teams relevant to each platform. Expanding evaluation to examine faculty outside of CVM and CALS that should be approached for inclusion (e.g. engineering faculty, computer science faculty, communications, social science and business faculty, etc.)
Action 2.3	Bring teams of existing faculty together in a series of group work sessions for each platform to have them identify gaps or weaknesses that need to be addressed through: <ul style="list-style-type: none"> • Faculty and research staff recruitment • Infrastructure and facilities improvement • Changes to policies or procedures.
Action 2.4	Review and address barriers (e.g. promotion and tenure barriers, funding barriers, publishing credit, etc.) that may negatively impact transdisciplinary collaborations that span multiple departments and colleges.
Action 2.5	Leverage the experience of leadership within the Plant Sciences Initiative and the Food Manufacturing Initiative in terms of what has worked well or less-well in terms of advancing platform development under those Initiatives.
Action 2.6	Sustain a seed grant program to support transdisciplinary teams in early research program development and for progressing innovative research towards readiness for major external grant applications. Require participation of faculty from at least two colleges for each seed grant.

Strategy 3 works towards strengthening the intellectual capacity of the university to plug gaps in faculty capabilities and assure that the research community at NC State is robust across each of the three platforms. It also seeks to enhance collaborations between CALS and CVM.

STRATEGY 3: Recruit faculty to reinforce strengths, address skills gaps relevant to the platforms and create opportunities for collaborative research.

Action	Description
Action 3.1	Use previously conducted faculty survey, together with deliberations performed by working groups under Action 2.3, to identify priority recruitment positions. Develop a basic profile for the desired faculty positions and seek to develop a prioritization list for these positions.
Action 3.2	Use the publishing intelligence from the Latent Topic Analysis to identify faculty external to NC State who have robust publishing records in areas relevant to recruitment targets.
Action 3.3	Establish an endowed professorship for each of the platforms and recruit a high profile faculty member, with strong industry connections, to each position. The Integrated Systems for Food Animal Health and Food Safety platform endowed professorship should be joint between CVM and CALS.
Action 3.4	Budget for provision of adequate technician and administrative support for faculty research programs. Additional support for teaching assistants (TAs) for classes and student labor for staffing new facilities.
Action 3.5	Examine opportunities for joint CVM/CALS faculty appointments to naturally serve as bridges between the colleges. Consider a joint position with the College of Engineering for Digital Animal Agriculture.
Action 3.6	Develop multiple adjunct faculty positions with senior researchers and leadership from within North Carolina food animal and associated industries to enhance university-industry relationships and encourage industry connections for faculty, students and research programs.

Strategy 4 focuses on education and the associated workforce development pipeline to meet the anticipated need of industries across the food animal agriculture value chain (from inputs, through primary production and value-added processing).

STRATEGY 4: Develop undergraduate, graduate and certificate programs that are focused in the three platforms and developed with input from industry.

Action	Description
Action 4.1	Conduct undergraduate and graduate food animal curriculum assessments to align educational plans to support and leverage the FAI. Consider adjustments to current curriculum and/or create new programs to best meet the needs of students for future employment in the food animal value-chain?
Action 4.2	Form joint faculty/industry planning groups to advise on required training focus areas across certificate, two-year, bachelors (majors and minors), graduate and professional degree programs relevant to the platforms.
Action 4.3	Examine benefits of developing stackable badge/certificate qualification programs as an education pathway for industry professionals to engage with the FAI.
Action 4.4	Develop plan to coordinate stackable certifications in the Digital Animal Agriculture platform so that they may accumulate to the level of a master’s degree in combination with a requirement for a capstone project.

STRATEGY 4: Develop undergraduate, graduate and certificate programs that are focused in the three platforms and developed with input from industry.

Action	Description
Action 4.5	Continue to support and advance the Food Animal Scholars Program, with consideration of additional numbers of scholars dedicated to each platform and develop financial support programs and scholarships to encourage further student engagement in food animal industries and associated training.
Action 4.6	Develop and sustain an active intern placement program serving each of the three development platforms. Place an emphasis on internship placements in North Carolina, but not to the exclusion of other opportunities.
Action 4.7	Consider development of a “Digital Agriculture” cohort education program, spanning animal and plant agriculture application areas, that can incorporate not only CALS students, but students from across the university with interests in the application of digital/advanced analytics skills. Review the residential “Data Mine” program at Purdue University as a potential model.
Action 4.8	Consider development of an “Agriculture Issues and Communications” education program spanning animal and plant agriculture that can incorporate not only CALS students but provide educational experiences at the “Forefront Farm” to K-12 school students.
Action 4.9	Develop frequent series of industry seminars and guest lectures to take place at the Forefront Farm.
Action 4.10	Examine opportunities to increase output of students with expertise in regulatory affairs relating to animal agriculture and associated food processing.

Strategy 5 specifically addresses the high priority, given by industry, to NC State being engaged in proactively communicating the realities of modern animal agriculture, areas of progress being made, and actively combatting misinformation or disinformation pertaining to animal agriculture and associated industries.

STRATEGY 5: Develop a proactive Food Animal Agriculture Communications program.

Action	Description
Action 5.1	Assure that Forefront Farm is designed to be a showplace for modern animal agriculture that is accessible for public tours and events
Action 5.2	Form an agricultural industry communications advisory board, comprising industry communications and public policy professionals
Action 5.3	Develop a memorandum of understanding with CAST and other similar organizations, such as The Center for Food Integrity, for promotion and use of their research findings and associated publications and materials.
Action 5.4	Get ahead of developing technology spaces in terms of contemplating positive nomenclature and consumer-facing branding around emerging theme areas such as: gene editing, digital agriculture, waste utilization, etc. Will require collaborations with experts in multiple fields including areas such as communications, marketing, psychology, education, etc.
Action 5.5	Canvas NC State for relevant expertise in non-CALS/CVM departments of relevance, including communications, applied psychology, political science, sociology and the College of Natural Resources.

STRATEGY 5: Develop a proactive Food Animal Agriculture Communications program.

Action	Description
Action 5.6	Assure the expertise of Extension is integrated into the Food Animal Agriculture Communications program and leverage Extension Specialists and County Agents as hubs for communications dissemination and engagement.
Action 5.7	Integrate student curricular learning in “Agriculture Issues and Communications” into public and community education opportunities.
Action 5.8	Develop an annual Food Animal awards program to promote and celebrate positive industry practices and progress. Consider awards in categories for: advancing animal welfare; innovative production practices; new technology commercialization, and industry/university engagement.

D. Additional Considerations

As with the Plant Sciences Initiative and the Food Manufacturing Initiative at NC State, the Food Animal Initiative, to realize its full potential, requires a long-term commitment of faculty and staff resources, and considerable investment in facilities, equipment and personnel. Driven by investment in the Forefront Farm, which will involve the upgrading of facilities and construction of new facilities (e.g. BSL facilities, protein processing center, classrooms and meeting space, digital infrastructure integration, etc.), and by investment in new faculty lines and associated support costs, TEConomy would anticipate this being a circa \$200+ million project commitment. In return, however, North Carolina will have a unique state-of-the-art research and education resource performing work directly relevant to one of the state’s largest industries – an industry with a large geographic footprint across the state and sustaining both rural and urban employment. Engagement with North Carolina industry across the Initiative will serve to connect students with industry, helping to anchor skilled human capital in the state post-graduation, providing the workforce needed to sustain North Carolina animal agriculture and associated industries at the forefront of productivity. Applied R&D performed through the Initiative will further support development of solutions to current and anticipated industry challenges, develop innovations to enhance production efficiencies and improve animal health, and advance new products and technologies for commercialization.

E. Conclusions

As envisioned herein, the Food Animal Initiative is proposed as a multi-college NC State initiative focused on advancing research of relevance to prioritized food animal industry challenges and education to meet the needs of livestock and poultry production and processing sectors. It is recommended that the Initiative feature a signature investment in a Forefront Farm and Protein Innovation Center, providing the state-of-the-art infrastructure, research and training environments required to support ongoing work of CALS and CVM in food animal agriculture and veterinary sciences, and advance four specific transdisciplinary R&D, education and extension development platforms in Integrated Systems for Food Animal Health and Food Safety, Digital Animal Agriculture, Protein Innovation, and Food Animal Agriculture Communications. By working in these platform areas, the FAI will have high visibility in areas of substantial importance to North Carolina and national food animal sectors – addressing animal health and food safety (two issues at the forefront of challenges expressed by industry), enhanced production efficiencies through improved animal health, enhanced production efficiencies through the application of digital technologies and data science to food animal agriculture, and innovations to advance the value-added protein processing and food products manufacturing sector for the state.

The FAI's unique infrastructure and platform focus will provide a competitive advantage for North Carolina in applications for external research funding, and serve as a signature attractor for joint R&D programs with industry, and a world-class hub for attracting and training high quality students who will be well prepared to lead future advancements in food animal agriculture and be highly attractive to employers in food animal production and processing industries.

Appendix A. Benchmarking Analysis

A. Benchmark Summaries and Lessons

Background

To assist in drawing lessons for program design of the FAI, TEconomy Partners conducted a benchmarking exercise targeting four programs that emerged from discussions with the FAI steering committee at NC State. In some cases, we were aware of a formal initiative that seemed relevant to the goals of the FAI, but in other cases faculty at NC State were interested in the function of an activity that seemed to have very significant and impressive assets, possibly without a formal initiative. The four initiatives are:

- Kansas State University Beef Cattle Institute (BCI) and also its connections if any with the Kansas City Animal Health Corridor initiative (KCAHC) and the K-State Innovation Campus at Olathe
- Michigan State University’s Michigan Alliance for Animal Agriculture (M-AAA)
- University of Georgia’s programs addressing the poultry sector, in both the College of Agriculture and Environmental Sciences and the College of Veterinary Medicine, and addressing also the agglomeration of assets in the USDA ARS facilities just off campus
- University of Saskatchewan’s Livestock & Forage Centre of Excellence (LFCE), a joint university/industry/government initiative that involves both colleges

With introductions from faculty in the respective colleges at NC State, TEconomy reached out to deans, associate deans, and program directors at the targeted institutions and conducted semi-structured telephone interviews of up to one hour each, supplemented by background research on the respective programs. Following are tabular summaries of our findings, organized according to the primary topics of interest as agreed with the FAI steering committee.

Our primary finding is that none of these institutions is doing exactly what is contemplated by the FAI. However, all the benchmark programs offer insights into best practices and challenges that can be anticipated.

Primary Thrust/Elements

The following table provides quick summaries for reference of the benchmarked programs and elements.

Benchmark program	Primary thrust/elements
K-State Beef Cattle Institute & Animal Health Corridor	BCI is an interdisciplinary program at K-State, supported primarily by the CVM and project fees, designed to discover and deliver useful information to cattle producers AHC is an economic-development marketing initiative to reinforce the region’s existing strengths in animal health providers The two interrelate as points of connectivity up and down the supply chain

Benchmark program	Primary thrust/elements
Michigan (State University) Alliance for Animal Agriculture	A regrant program administered by Michigan State that takes a state appropriation and allocates it via competitive RFP to short-term, applied research projects of interest to the state's primary animal industries
University of Georgia	There is no formal interdisciplinary or intercollege food animal initiative at UGA, but the two colleges collaborate at the faculty-to-faculty level in the poultry area, which enjoys the benefits of decades of federal investment in ARS facilities
University of Saskatchewan Livestock & Forage Centre of Excellence	A large capital project under joint management of the colleges of Agriculture and Veterinary Medicine, designed to combine and modernize formerly separate experimental facilities, and equip them for unique experimental projects

Origins

The following table summarizes the origins of each of the benchmark program elements. There is great diversity in their origin stories.

Benchmark program	Origins
K-State Beef Cattle Institute & Animal Health Corridor	All program elements discussed in the profile emerged as part of community mobilization to help K-State compete to host the National Bio and Agro Defense Facility
Michigan (State University) Alliance for Animal Agriculture	M-AAA was intended to remedy lack of operating grants in a prior infrastructure initiative, and was modeled on Michigan State's success with an applied research initiative in the plant sector
University of Georgia	Not applicable, but the profile discusses the history of the USDA's investments in ARS facilities at Athens, and also the transition of a state experimental lab into the CVM's PDRC
University of Saskatchewan Livestock & Forage Centre of Excellence	Driven by opportunities to replace two facilities, one of which was obsolete and the other too remote from campus, though replacement required agreement of provincial government and producers that had had a heavy influence on older setup

Governance

Not surprisingly, initiatives within university structures tend to avoid formal governance structures. Most are managed by deans, advised but not governed by boards including industry and government representation.

Benchmark program	Governance approach and components
K-State Beef Cattle Institute & Animal Health Corridor	BCI is a unit of the CVM, but the operating team includes faculty from other colleges AHC is a project of the leading regional civic and economic-development groups K-State campus in Olathe is governed by a not-for-profit corporation
Michigan (State University) Alliance for Animal Agriculture	M-AAA, which includes multiple industry and agency partners, is managed on an ad hoc basis by CANR, serving as custodian for state money and facilitator of project selection – minimal formal structure or titles related to the Alliance

Benchmark program	Governance approach and components
University of Georgia	Not applicable – the CVM and CAES are not integrated in a formal initiative
University of Saskatchewan Livestock & Forage Centre of Excellence	Day-to-day management reports to the two deans of CVM and CABR. A Strategic Advisory Board includes representatives of the industry partners, federal and provincial government, the university assistant VP for research, and the Dean of Engineering

Industry Collaboration

The following table summarizes the approaches of each of the benchmark programs to its primary audience of producers, upstream suppliers of feed or medicine, and downstream audiences like institutional kitchens or restaurants.

Benchmark program	Primary audience and approach
K-State Beef Cattle Institute & Animal Health Corridor	<p>BCI considers its prime audience to be in-state participants including producers and veterinarians and to promote this approach collocated itself just off campus with Kansas Department of Agriculture, and stresses provision of practical tools such as calculators and apps</p> <p>AHC considers its prime audience to be animal health companies up the supply chain from producers – some of these companies see BCI as a helpful intermediary between them and their ultimate customers, the producers</p> <p>BCI has an initiative aimed downstream in the supply chain to food users, attempting to foster better communication between institutional users and producers</p>
Michigan (State University) Alliance for Animal Agriculture	<p>M-AAA has a predefined set of industry groups and statewide farm organizations in the Alliance, and does not have an open-door policy regarding adding regional groups or other producer organizations</p> <p>One entity, the Milk Producers Association, has an applied research fund that will “add-on” to a selected project, by mutual agreement with the PI. Most of the producers do not have check-off capacity to fund research</p>
University of Georgia	<p>Interaction with poultry producers occurs through workshops at the level of middle management and below. Where there are health or epidemiological issues, CAES faculty are joined by CVM clinical faculty or students in the masters in avian medicine program. Exception: parasitology remains in CAES by tradition</p> <p>CVM PDRC has especially strong relationships with all the large animal-health companies, not necessarily based in the region, for vaccine testing. Few startup companies can afford the necessary protocols</p> <p>Interactions downstream on the supply chain are generally handled by Food Science and its Center for Food Safety, which is in Griffin, not Athens</p>
University of Saskatchewan Livestock & Forage Centre of Excellence	<p>The vision for LFCE will require collaboration with both beef ranches, animal-health suppliers, and some large companies including restaurant chains that have sponsored the project – there is often tension between and among these subsets, but at least the Advisory Board puts them at the same table</p>

Intercollege Collaboration

The benchmark set includes a wide range of collaboration types – one owned by CVM, one owned by the Ag college, one in which there is no formal collaboration, and one (LFCE) which is highly structured according to a written charter to be completely joint between the two colleges.

Benchmark program	Ways in which intercollege collaboration is made operational
K-State Beef Cattle Institute & Animal Health Corridor	The director is a CVM faculty member, but supported by a core team of four including two faculty from CVM, two from College of Agriculture Sponsored projects that Ag faculty run through BCI return overhead to Ag
Michigan (State University) Alliance for Animal Agriculture	CANR is the program custodian, but funded projects have included two from departments in CVM and one diagnostic laboratory at CVM
University of Georgia	There is one 50-50 joint appointment between CAES Poultry Science and CVM Both colleges have active relationships and occasional cooperative agreements with the ARS laboratories on site
University of Saskatchewan Livestock & Forage Centre of Excellence	The initiative is owned completely and exclusively by both deans acting together on behalf of the university VP for research – delegation in writing There have been operational challenges making this work within existing university systems for budgeting and control of fund-raising

Facilities

Of the benchmark programs, only University of Saskatchewan’s Livestock & Forage Centre of Excellence puts facilities at the center of the activity.

Benchmark program	Nature of role of new facilities connected to the program
K-State Beef Cattle Institute & Animal Health Corridor	None
Michigan (State University) Alliance for Animal Agriculture	None, though the prior incarnation of the program did fund facilities, and the current program expects the need to become urgent again soon.
University of Georgia	There have been major parallel investments by the federal government over decades in USDA/ARS facilities across the road from the CVM, which have drawn increased attention to the critical mass of poultry assets.
University of Saskatchewan Livestock & Forage Centre of Excellence	The LFCE is fundamentally a facilities play, a replacement of worn-out and inconvenient facilities by new, highly instrumented sites clustered together.

Incentives

The benchmark set includes one example each of a research-grant program used as an incentive to the kind of collaborative work that might not otherwise be undertaken (M-AAA) and of a newly constructed facility acting and its unique capacities as the incentive (LFCE). Incentives play no significant role in the other two.

Benchmark program	Role of incentives in encouraging intercollege or industry collaboration
K-State Beef Cattle Institute & Animal Health Corridor	Minimal
Michigan (State University) Alliance for Animal Agriculture	Regrant program itself is the incentive
University of Georgia	None
University of Saskatchewan Livestock & Forage Centre of Excellence	The new, highly instrumented facilities and what they enable are themselves the incentive

Lessons

Following is a summary of lessons offered by, or that can reasonably be deduced from comments made by, deans and other interviewed.

Benchmark program	Select lessons offered by or implied by interview subjects
K-State Beef Cattle Institute & Animal Health Corridor	<p>Industry partners will seek out established expertise organically, as long as it is provided non-exclusively</p> <p>Graduate and professional students from industry are interested in programs more like Professional Science Masters that can be accomplished easily in non-work time</p>
Michigan (State University) Alliance for Animal Agriculture	Applied research projects that are attractive to industry need also to be budgeted high enough to support graduate students through a complete program
University of Georgia	Initiatives such as the FAI “always cost more than you think” – personnel can be the easiest component, but then there is infrastructure and long-term structural support that cannot be raised through formula or competitive federal funding
University of Saskatchewan Livestock & Forage Centre of Excellence	<p>Introducing collegial governance to producers used to having their own way on research means that not every battle can be one by the university, but some principles require fighting for</p> <p>Having a project director with ranching experience not someone directly out of graduate school can be a plus</p> <p>Routine university accounting systems can interfere with the best-intended efforts to foster intercollege collaboration – while the founding deans may trust each other, the system must be structured to deal with new entrants/actors</p>

B. Kansas State University Beef Cattle Institute (and the Animal Health Corridor initiative)

Description

For the purposes of this benchmarking profile, the initiative of primary interest is the Beef Cattle Institute (BCI)²⁵ at Kansas State University (K-State) in Manhattan. However, also discussed is the Kansas City Animal Health Corridor (KCAHC), an initiative based in the Kansas City metropolitan area that reaches far into both Kansas and Missouri.²⁶ These two initiatives were created at about the same time but for differing reasons and operate independently. Finally, this profile also includes brief discussion of an industry-oriented presence that K-State has established in Olathe, two hours by car from Manhattan, but much closer to the center of mass of the animal-health industry base.

The KCAHC was created first, in the mid-2000s, as K-State was competing to host the National Bio and Agro Defense Facility (NBAF) on the main campus.²⁷ With the NBAF now nearly open, the KCAHC operates mainly as a networking organization and event host, sponsoring an annual OneHealth Symposium, an Investment Forum for animal health business concepts,²⁸ and an annual Homecoming Industry Dinner, at which both industrial and academic partners buy tables. KCAHC is not primarily programmatic. That role is played by BioNexus KC,²⁹ another regional initiative which collects dues payments from participating institutions and regrants them to seed multidisciplinary collaborations and/or to demonstrate proofs of concept for new discoveries in human or animal health.³⁰ Both KCAHC and BioNexus KC also sponsor educational activities of interest to the animal-health industry at the K-State Innovation Campus in Olathe (discussed further below under “facilities”). To Dean Rush, the major benefit of the KCAHC is to put her “at the table” with the animal health industry both through her service on the advisory board and at the once-a-year dinner, which can attract up to 1,800 participants. To the animal health companies, the KCAHC provides an additional way to reach producers.

The Beef Cattle Institute was founded a year or two later, in 2007. Its mission statement (recently revised) currently reads: “The Beef Cattle Institute . . . utilizes collaborative multidisciplinary expertise to promote successful beef production through the discovery and delivery of actionable information and innovative decision support tools.” About half the BCI budget is funded by the CVM, and the other half is sponsored projects split between state, federal, and industry, and some fee-for-service. There is no core, dues-supported program. Project sponsorship is rising, and so the CVM contribution to the budget, while steady in absolute dollars, is declining as a percentage of the whole. The largest current project is a Cattle Trace Pilot Program, a multistate RFID tagging initiative that BCI coordinates on behalf of the U.S. Department of Agriculture, the Kansas Department of Agriculture, and industry partners.³¹ The pilot project is designed to be limited, collecting from 55,000 head of cattle over two years the minimal data necessary for tracing disease outbreaks, spanning ranch to slaughter across a multistate region. It will conclude in 2020 and inform further federal policy development.

The last of the initiatives considered here is the Innovation Campus³² that K-State opened in 2009 in Olathe, a small city in the southwest suburbs of Kansas City. On 40 acres donated by the city, and using funds raised through a regional sales-tax increment, the university constructed what it calls the International Animal Health

25 <https://ksubci.org>. TEconomy Partners LLC also gratefully acknowledges interviews with Dean Bonnie Rush of the K-State College of Veterinary Medicine and with Dr. Brad White, Director of the Beef Cattle Institute. They have not reviewed drafts of this profile, and TEconomy Partners retains full responsibility for any errors.

26 <http://kcanimalhealth.thinkkc.com/about>.

27 <https://www.usda.gov/nbaf>.

28 <http://kcanimalhealth.thinkkc.com/events/investment-forum>.

29 <https://klifesciences.org/about/> or <https://bionexuskc.org/about/>.

30 <https://bionexuskc.org/grant-programs/>.

31 <https://www.cattletrace.org>.

32 <https://olathe.k-state.edu/about/our-story/history/>

and Food Safety Institute. Despite its name, this is not a conventional university institute nor a specialized research facility, but mainly a convenient location for continuing education and other activities connecting K-State to its industry partners in the animal health sector. It is far enough away from Manhattan (2 hours' drive) that most faculty from the main campus cannot easily teach there, but close enough to Kansas City that most industry participants can engage at Olathe more easily than in Manhattan (2 hours' drive for them). It is constrained by state government not to offer any educational programs that compete with those already taught by the University of Kansas, and so its educational offerings have evolved to very applied programs that resemble Professional Science Masters, taught by faculty being specially recruited for this purpose.

Origins

The creation of KCAHC coincided with efforts by the Kansas City Civic Council (the regional CEO leadership group) and its operating partner the Kansas City Area Development Council (the economic-development marketing group) to better exploit the region's R&D assets in both human and animal medicine. The region stretching from Manhattan southeast to the Kansas City metropolitan area and then eastward to Columbia was already known to host the nation's largest concentration of animal-medicine developers. The Civic Council designed KCAHC to help this geographically sprawled cluster better cohere and thereby build the case for the NBAF. The Council also sought to attract funding that would be necessary for the NBAF's full operation and to leverage it effectively (for example, through K-State's own academic research units) as a tool for regional economic development. The Civic Council had already convened regional stakeholders into a Kansas City Area Life Sciences Institute (now BioNexus KC). These two affiliated efforts work together on events and programmatic support relevant to the animal health sector.

The BCI was founded 2007 with \$200,000 in initial funding from a Targeted Excellence Initiative at K-State that was designed to foster multidisciplinary science. Director Dr. Brad White of the BCI recalls that the intent was to create a collaborative group that breaks down silos among departments and colleges in order to give partners in the beef producing industry the best advice. He adds:

"Most people in the industry look at us as K-State, not whether we're in the College of Vet Med or Agriculture, so our goal is to give them an answer to their question, not just from our own perspective. We want not just health but economic implications, so we need interdisciplinary expertise. That was the impetus and that's what we've held through over the years."

Governance

The BCI is a unit of the College of Veterinary Medicine, and Director White reports to the dean, though assisted by a diverse team (see below under "Inter-College Collaboration) and advised by a board of producers.

KCAHC is strictly a project of the two regional economic-development and civic groups, and its board is advisory only. The Dean of CVM (but not of Agriculture) is on the advisory board along with the vet dean at University of Missouri. Corporate members of the advisory board include representatives from Nestle Purina PetCare; Bayer Animal Health; Norbrook; Ceva Animal Health; and Hill's Pet Nutrition.³³ This represents only a share of the overall population of animal-health companies, which also includes major firms such as Boehringer-Ingelheim, Zoetis, and others. (BioNexus KC is more formally structured as a 501(c)(3) not-for-profit, but is not the primary focus of this profile.)

The K-State Innovation Campus in Olathe (see below) is governed by a not-for-profit corporation organized as a supporting organization for the university.³⁴

³³ <http://kcanimalhealth.thinkkc.com/about/advisory-board>.

³⁴ <https://olathe.k-state.edu/about/our-story/governance/index.html>.

Industry Collaboration

To Dean Rush, industry relationships in animal health are always about content-matter experts who make themselves broadly available to industry collaborators on a non-exclusive basis. As an example, she cites a faculty expert in insect parasitology who developed a repeatable model for testing anti-flea products and found that “for 25 years it rained money from the sky from pharma companies who want to get their product tested in his lab.” Director White of the BCI sees the relationship with the KCAHC very similarly and said his focus is on fostering relationships with the larger animal health providers that clarify where the BCI can add value to these larger firms’ relationships with in-state producers and veterinarians.

The BCI considers its prime audience to be the in-state beef industry participants – that is, both producers and veterinarians. The director tries to structure a dialogue that discovers the information needed by these industry participants, and then delivers it. Over time, Director White expects that the value BCI delivers to these in-state participants will transition from purely technical data or advice toward an additional emphasis on new knowledge and on graduating students who are trained in laboratories doing state-of-the-art research funded by external sources.

To make itself more friendly to its industry partners, the BCI is situated not in the CVM building but instead collocated with the Kansas Department of Agriculture in a building situated on the university’s 25-acre Research Park, just off campus. (The park also houses the university’s research foundation, its technology commercialization office, and its office of corporate engagement.³⁵) As a service to producers, the BCI also

- publishes a series of Excel calculators³⁶ and also mobile apps,³⁷ authored mainly by senior faculty in Food Animal Production Medicine in the CVM;
- supports two-way communications efforts between producers and state government (both KDAG and the state Legislature) on Veterinary Feed Directives;³⁸
- regular conferences for veterinarians and symposia on topical issues such as anaplasmosis in beef cattle;³⁹
- an effort in “Value Chain Alliances,”⁴⁰ a farm-to-fork initiative in which a registered dietician works with restaurant chains, retailers, hospitals, non-commercial food services, as well as packers and processors, to feed downstream insights back to producers.

In some cases, this latter value-chain initiative has yielded results that have pleased the producers. Director White notes that in hosting tours by producers, large food users – including at one on-campus dining hall where beef consumption had been declining due to student resistance – have heard the producers’ own views on contentious issues such as antibiotic-free production. Producers, many of whom are K-State alumni, found that this specific interaction was useful and heightened their sense that the university cared about their businesses.

The university’s building at Olathe was intended originally to anchor a larger 92-acre research park, but the only other facility constructed to date is a standalone bioscience business incubator,⁴¹ and there is no long-term industry presence in the park despite the city’s offer to give away land. Dean Rush says the most effective fee-generating industry-related coursework offered at Olathe has included:

35 <https://www.k-state.edu/maps/buildings/KSRP/>.

36 <https://ksubci.org/portfolio/calculators/>.

37 <https://ksubci.org/portfolio/pregnancy-analytics-mobile-app/>.

38 <https://ksubci.org/portfolio/vfd/>.

39 <https://ksubci.org/conferences/>.

40 <https://ksubci.org/value-chain-alliances/>.

41 <https://www.bizjournals.com/kansascity/news/2015/05/28/kansas-bioscience-park-kba-olathe-future.html>.

- A parasitology boot camp offered to the sales forces of KCAHC members (such as Boehringer-Ingelheim, Elanco, Zoetis, etc.) by the faculty member referenced above
- an Executive Veterinary Program in beef management, offered collaboratively with the University of Illinois. It charges tuition and is also sponsored by all the major participants in the KCAHC.⁴²

Inter-College Collaboration

Although the BCI director is a faculty member of the CVM and reports to Dean Rush, he relies on a core team of four including two faculty from CVM and two from the College of Agriculture (agricultural economics and animal science). Sponsored projects that College of Agriculture faculty run through the BCI return a share of overhead charges to their college and home departments as incentive to collaboration. Director White sees the question of finding the right incentives as very challenging even after a decade of operation.

More broadly, Dean Rush sees the College of Agriculture as a resource for CVM students. Since the CVM does not have its own working farm, the best way to ensure students are in contact with animals owned by the university is through a strong collaborative relationship. She has taken steps first as animal-hospital director and now as dean ensure that services rendered to the College of Agriculture by cattle, horse, and small-ruminant units are rendered at cost, so the CVM is not perceived as profiting off the College of Agriculture.

Facilities

There are no specialized facilities which undergird any of the initiatives discussed here.

Incentives

Although the BCI owes its existence to an internal university incentive for excellence, and while BioNexus KC does incentivize multidisciplinary collaborations through its grant programs, neither the BCI nor the KCAHC is driven by state or other incentives. The Kansas Bioscience Authority is no longer active, having converted into a venture capital fund. The BCI is working on building enough industry support outside specific projects to serve as an incentive pool.

Lessons/issues

- Dean Rush believes strongly that industry partners will seek out established academic expertise and that these industry relationships can and should grow organically – so long as it is not perceived that a given faculty is being devoted exclusively to one company as their “mouthpiece.” Even worse is if that kind of lab seeks three or four different sponsorships, but doesn’t tell them about each other. Valued most highly by industry are transparent, openly accessible laboratories and functions.
- A lesson learned at the Olathe campus is that graduate and professional students from industry are not motivated the same way as those enrolled in traditional programs on campus. The interest of those who are studying with support from their employers is more in what might be described as a Professional Science Masters. They want coursework that can be completed after work hours without undue effort, which has practical industry-relevant content, and which leads to career advancement opportunities within their employer.

⁴² <https://vetmed.illinois.edu/evp/beef/>.

C. Michigan State University Michigan Alliance for Animal Agriculture (M-AAA)

Description

The Michigan Alliance for Animal Agriculture (M-AAA)⁴³ is a five-year-old program that takes a targeted state appropriation – an amount that now stands at \$2.9 million – and regrants it via competitive RFP⁴⁴ to faculty members across Michigan State University (MSU), where the principal partners are the College of Agriculture and Natural Resources (CANR), AgBioResearch,⁴⁵ the College of Veterinary Medicine (CVM), and the CANR Extension division. The M-AAA operates with strong industry guidance, and with active participation from the state’s Department of Agriculture and Rural Development (DARD), but entirely under university stewardship and with as little formal structure as possible.

The RFP solicits proposals for short-term, applied research or extension projects that directly address needs identified by the state’s main animal-agriculture industries (which are not solely food animals). M-AAA focuses on projects of industry interest that would not ordinarily be funded through formula funds (possibly because the resource commitment is too high or the need too short-term) or through competitive sources (possibly because they are too applied). Each year’s RFP is issued along with a statement by each of the participating industry stakeholder groups⁴⁶ of its two or three top research priorities.⁴⁷

Funds are available to support research (up to \$75,000 a year for a maximum of two years), extension (up to \$30,000), and seed projects (up to \$25,000). Selection criteria include short-term and ongoing industry relevance, technical merit, feasibility, contribution to the sector’s growth and sustainability, leverage, and a plan to communicate results back to the industry (even in projects that are not in the extension category). Projects in the seed category are judged also according to their ability to advance the development of industry-relevant grant proposals to competitive external funding sources including the USDA AFRI and others.

In the current year, the M-AAA funded 13 projects in applied research, four in extension, and three seed projects.⁴⁸ The most frequent grantees (see table in appendix) are faculty members of all ranks in the Department of Animal Science (including one with an adjunct appointment in Human Medicine), followed by: extension personnel of diverse titles; faculty in the CVM; and one grantee each in the Department of Biosystems & Agricultural Engineering and the Department of Plant, Soil and Microbial Sciences.⁴⁹ Over the lifetime of the M-AAA, the primary focus has been on animal production. However, it has also funded some work on environmental issues.

Origins

The origins of M-AAA date back to 1994. Recognizing that the diversity of Michigan’s animal-agriculture base was impeding the development of consensus on funding priorities, a grassroots effort first called simply the “Animal Agriculture Alliance” organized itself, approached the Legislature, and successfully obtained funding for new faculty lines and investment in animal infrastructure on the main campus and at various experiment

43 <https://www.canr.msu.edu/maaa/index>. TEconomy Partners LLC also gratefully acknowledges an interview with Dr. George Smith, Associate Dean for Research, College of Agriculture and Natural Resources, and Associate Director, MSU AgBioResearch. He has not reviewed a draft of this profile, and TEconomy Partners retains full responsibility for any errors.

44 <https://www.canr.msu.edu/maaa/rfp>.

45 The entity responsible for all Hatch Act experiment stations and all College and station-based research programs.

46 Participating stakeholders are Michigan Allied Poultry Industries; Michigan Cattlemen’s Association; Michigan Horse Industry; Michigan Meat Association; Michigan Milk Producers Association; Michigan Pork Producers Association; Michigan Sheep Breeders Association; the Michigan Farm Bureau; and the Michigan Department of Agriculture and Rural Development. Additionally, the Michigan Soybean Promotion Committee is a non-voting associate member. (The Michigan Allied Poultry Industries lists two over-arching priorities and then two more under each of its egg-layer and turkey/broiler subsets.)

47 https://www.canr.msu.edu/research/animal-agriculture/industry_priorities.

48 <https://www.canr.msu.edu/maaa/projects>.

49 Funded jointly with another source, as described below

stations around the state. However, this original effort did not include any ongoing funding for research over and above the core state budget.

In 1998, however, MSU successfully lobbied for a new budget line in plant agriculture that eventually became the template for M-AAA. Project GREEN (Generating Research and Extension to Meet Economic and Environmental Needs)⁵⁰ was budgeted first under Michigan DARD to support applied research and extension in partnership with the state's commodity-crop organizations. Eventually, Project GREEN was moved into the state's higher-education budget for MSU, where it remains as a specifically defined and recurring item to this day.

In 2014, MSU decided that the time had come to reconvene the earlier grassroots Alliance and try to obtain the same kind of funding for animal agriculture. It was a moment when state budgets were being cut, commodity prices were low, and the animal industry groups typically did not have "check-off" funds available for research (as had been more common in the plant sector). To get the M-AAA off the ground, and attract the animal-industry groups back to the table to work collaboratively on fundable priorities, the then-dean of CANR reprogrammed \$600,000 of existing budgetary resources.

Observing the initial results and the excitement of the industry stakeholders, in 2016 the Legislature appropriated \$1.5 million over and above the university's contribution, then \$2.5 million in 2018, and \$2.6 million in the current year. MSU believes this increasing level of state support was possible only because of the support of the industry groups and could never have been achieved through university lobbying alone. The M-AAA makes an annual report to the Legislature in the name of all its academic and industry partners.

This year, for the first time (see table in appendix) one project was cofunded by M-AAA and Project GREEN together, since it ties addresses both industries, led by a faculty member in Plant, Soil and Microbial sciences.

Governance

In order to create the sense among stakeholders that they own the process, the M-AAA is never presented as an official MSU entity, but rather as an industry alliance that MSU manages and facilitates. It has no bylaws or formal organizational structure, and the key MSU personnel do not have formal titles related to their coordination duties in the alliance. The M-AAA formerly met quarterly, in part to keep up momentum during the years when state funding was appropriated one year at a time. However, as of this year, the funding is expected to enter the "recurring" budget category, and it is not yet clear whether quarterly meetings will still be necessary.

Proposal review is done once a year on an ad hoc basis, managed by the Associate Director of MSU AgBioResearch and the Director of the Agriculture and Agribusiness Institute of MSU Extension. Each proposal is reviewed by two non-conflicted MSU faculty members and by one industry participant. The faculty reviewers' names are not made available to the M-AAA committee as a whole. Critically, the industry participants are asked to review proposals not from their own industry, which encourages faculty to write proposals in plain language that can be understood by laypeople. When the reviews are in, the M-AAA as a whole convenes to discuss and make final allocations. The M-AAA has built a culture of focusing on impact, return, benefits, growth, and sustainability, and therefore has not had any difficulty with special pleading by one sector or another for its "own" proposals.

Aside from the three funding categories specified in the RFP, the M-AAA does hold aside some money each year for emergencies that cannot be met through an annual proposal cycle, such as a need several years ago to respond to a horse diarrhea virus that had become endemic statewide. Decisions on these rapid-response grants are made by the MSU administrators in consultation with a designee from the industry groups. This ad

⁵⁰ <https://www.canr.msu.edu/project-green/>.

hoc group functions somewhat as an executive committee when decisions must be made rapidly between formal meetings of the alliance.

Industry Collaboration

Somewhat in contrast to Project GREEN, which has an open-door policy with regard to industry participation, M-AAA has not defined specific rules for new industry groups entering the alliance or actively recruited any new members. One issue that has arisen stems from a request by certain regional groups to join the M-AAA. At present, the sense is that the broad spread of animal agriculture in the state is already well represented if not by one of the statewide industry groups then by the Farm Bureau, and no additional invitations have been issued to these regional groups. However, the Soybean Promotion Committee remains a non-voting affiliate.

Another point of difference with Project GREEN is that while some of the 40-odd plant commodity groups have “check-off” funds that Project GREEN can match, this is typically not the case under current law or custom for the animal-industry groups. However, the Applied Dairy Research Fund of the Michigan Milk Producers Association may, at its option, supplement any single one of the awards in the dairy category by \$50,000. This external award does not offset the M-AAA grant, but is offered only after the faculty investigator explains and agrees to certain additional tasks.

It is possible that MSU and the industry stakeholders may return to the challenge of developing broad community support for applying check-off funds to these research projects, but there might be differences in receptivity between, for example, the beef cattle industry and the cow/calf industry. At any rate, getting permission to use check-off funds does not seem to be a pressing priority as long as the state budget is healthy and growing

There is no targeted effort to reach up the supply chain to involve technology (or biotechnology) providers, or downstream to processors or value-added producers. However, the program administrators are watching closely the opening of new pork-processing facilities in the state.

Inter-College collaboration

Over the first five years of operation, the CVM units most commonly involved in funded projects have been the Department of Large Animal Clinical Sciences; the Department of Pathobiology and Diagnostic investigation; and the Veterinary Diagnostic Laboratory. The program’s founder, the Associate Director of MSU AgBioResearch, believes that inter-college collaboration has gotten better as a result of the M-AAA process and funds, especially since one of the research directors involved in M-AAA’s early years himself had had appointments in both colleges and eventually became Dean of the CVM.

Facilities

The current iteration of the M-AAA is a mirror image of the grass-roots effort in 1994. It is purely for research funding, and includes no funding for faculty lines or infrastructure.

However, M-AAA sees infrastructure as an issue of increasing urgency, both for producers in the face of continued low commodity prices, and for the university itself. In fact, the M-AAA has set aside some small amounts to meet state requirements that are phasing in this year for housing of swine and poultry. While the university is technically exempt, failure to improve its own facilities would have set a poor example, and would have meant that research findings would be less relevant to actual working producers, who will have no choice.

Incentives

Since there are no special facilities under the exclusive control of the M-AAA, the availability of the regrant program is itself the primary incentive for participation by both industry stakeholders and by faculty members. The grant can be particularly valuable to those faculty whose interests are too applied for the needs of many external funding sources, which are looking for long-term, fundamental projects. The M-AAA concedes that \$75,000 is not a large grant, but believes that over time these grants have increased the number of graduate students trained and have supported research that would be difficult to fund from federal sources. Notwithstanding, the program directors do not want faculty to think they can fund their entire research program from M-AAA, and they encourage faculty to look elsewhere when an idea has run its course.

Lessons/issues

- Associate Dean Smith says MSU learned early on that it needed a higher limit than originally envisioned for applied research proposals, because \$50,000 for one year would not properly fund a graduate student, and faculty were having to raid other projects to complete their M-AAA projects. Accordingly, applied research proposals now may be funded up to \$75,000 a year for a maximum of two years, a time frame that is better matched to actual needs.
- The M-AAA knows that its funded projects are leveraged more than 3:1 by other sources, but the initiative has not yet closely examined the leveraged outcomes of its seed projects. Program administrators believe it will be important to explain to the commodity stakeholder groups why they should care about having leveraged research projects that may be more foundational than applied.

M-AAA PROJECTS FUNDED IN 2019⁵¹

Applied research	Department/Title/Rank of grantee
Saturated buffers: A water conservation practice for reducing phosphorus loss from manure sources - Ehsan Ghane	Biosystems & Agricultural Engineering, Assistant Professor and Extension Specialist
Comparison of duration and antibiotic choices for treatment of non-severe gram-positive bovine mastitis - Pamela Ruegg	Animal Science, Professor & Chair
Can nutritional supplementation improve transition cow health by mitigating oxidative stress? - Lorraine Sordillo-Gandy	Large Animal Clinical Sciences (CVM), Professor and Chair in Farm Animal Health and Wellbeing
Enhancing healthfulness and demand of Michigan produced beef - Jason Rowntree	Animal Science, Associate Professor
Solving floor egg laying in aviaries: Can temporary litter restriction restrain hens without impacting welfare? - Ahmed Ali	Animal Science, Visiting Scholar
Increasing the use of non-forage fiber sources in mid and late lactation dairy cows to improve milk production and feed efficiency - Adam Lock	Animal Science, Associate Professor
Impact of carcass reduction and composting mixing on potential for aerosol dispersion of virus and the expediency and effectiveness of the composting process in destroying the virus - Zachary Williams	Animal Science, Extension – Poultry Academic Specialist

⁵¹ Based on <https://www.canr.msu.edu/maaa/projects> with additional departmental lookups by TEconomy Partners.

Applied research	Department/Title/Rank of grantee
Categorizing joint damage associated with circular exercise to prevent injuries to horses - Brian Nielsen	Animal Science, Professor
Integrating Lamb Grazing Systems with Crop Production for Michigan - Kim Cassida	MSU Extension – Forages and Grazing Educator
Food safety control methods for uncured reduced oxygen packaged meat products - Jeannine Schwehofer	MSU Extension – Meat Quality, Food and Animal Systems Educator, Food and Animal Systems
The welfare of laying hens in non-cage aviaries: Effects of inter-bird distances and flock synchrony on hens’ ability to perform key behaviors across 4 different strains of laying hens - Ahmed Ali	Animal Science, Visiting Scholar
Enhancing maternal recognition of pregnancy in lactating dairy cows to enhance profit on dairy farms - James Pursley	Animal Science, Professor
Integrated management of ear rot and associated mycotoxin contamination of corn in Michigan - Maninderpal Singh ⁵²	Plant, Soil and Microbial Sciences, Assistant Professor of Cropping Systems Agronomy
Extension	
Workforce development through competitive judging opportunities - Taylor Fabus	MSU Extension, Equine Educator
Creation of web-based poultry education center - Zachary Williams	Animal Science, Extension – Poultry Academic Specialist
Building relationships and identifying the needs of Michigan horse industry stakeholders - Christine Skelly	MSU Extension, Associate Professor
Emergency response preparedness and training resources for first responders for accidents and/or emergencies that involve livestock - Elizabeth Ferry	MSU Extension, Swine Production Educator
Seed	
Impact of late gestation maternal metabolic stress on neonatal dairy calf immunity and disease susceptibility - Angel Abuelo	Large Animal Clinical Sciences (CVM), Assistant Professor in Cattle Health and Wellbeing
Mechanism and possible mitigation of effect of body condition loss on dairy cow fertility - Keith Latham	Animal Science, Professor; Obstetrics, Gynecology and Reproductive Biology (College of Human Medicine), Adjunct Professor; Reproductive and Developmental Sciences Program of CANR, Co-Director
Identification of biomarkers associated with bovine leukemia virus (BLV) in dairy cattle - Tasia Taxis	Animal Science, Assistant Professor

52 Co-funded by Project GREEN.

D. University of Georgia

Description

There is no formal food-animal initiative at University Georgia (UGA), and only informal, faculty-to-faculty collaboration between the College of Agriculture and Environmental Sciences (CAES) and the College of Veterinary Medicine (CVM) in Athens. Because the initial nomination and referral from NC State was made to the Department of Poultry Science at CAES, TEconomy Partners LLC assumes that NC State's interest is primarily in the concentration of poultry-related assets at UGA, counting not only relevant research programs and facilities at both CAES⁵³ and CVM⁵⁴ but also the very significant investment over decades by the USDA Agricultural Research Service (ARS) in a National Poultry Research Center (NPRC)⁵⁵ and especially its Southeast Poultry Research Lab (SPRL) unit. There was wide agreement among TEconomy Partners' several interviewees at UGA that a key reason for the campus's dominance in poultry science is simply that "it got there first" and that early availability of specialized facilities and expertise brought in turn successive waves of recognition and investment.

Considered together, these assets have made collaboration with UGA and/or ARS significantly attractive to large vaccine developers, animal-medicine suppliers, and other industrial actors up the supply chain. The sense of asset aggregation over decades is well captured in remarks made by U.S. Secretary of Agriculture (also former Georgia Governor and CVM graduate) Sonny Perdue at the 2017 groundbreaking for a major \$160 million renewal and expansion of the ARS facilities: "For over 55 years on this campus taxpayers and the world have gotten their money's worth. [Foreign] producers can't compete because of the integrated research, whether it be in the Department of Agriculture, Poultry Science, Veterinary Medicine, or the Agricultural Research Service, which make our producers the best, most efficient, and most productive in the world."⁵⁶

Origins and Facilities

Much of the campus's success at building poultry assets stems from actions first taken by state government nearly a century ago to test for the bacterial strain *H. pullorum* and thereby maintain the overall health of poultry raised in-state. At least since the 1930s, when the USDA rolled out its National Poultry Improvement Program, the Georgia Department of Agriculture has contracted with the Georgia Poultry Improvement Association to maintain an officially recognized Poultry Laboratory Network.⁵⁷ This network once included two major centers: a research and testing center headquartered in Gainesville (Georgia), some 45 miles distant, and several satellite experiment stations, including one at Athens that then did a small amount of research. At that time, the Athens center was completely independent of the university, and considered a province of the state Agriculture Department. However, research on Marek's Disease led to a vaccine commercialized in Athens by Select Labs (1971),⁵⁸ and after that the state laboratory was transitioned from the state to the university as the Poultry Diagnostic and Research Center (PDRC) – first reporting to a standalone Department

53 <https://www.caes.uga.edu/research/focus-areas/poultry-science.html>. TEconomy Partners LLC also gratefully acknowledges a group telephone interview with Dr. Samuel Pardue, Dean of CAES; Dr. Todd Applegate, Head of Poultry Science at CAES; and Dr. Allen Moore, Associate Dean for Research at CAES. They have not reviewed a draft of this profile and TEconomy Partners regains full responsibility for any errors.

54 <https://vet.uga.edu/pdrc>. TEconomy Partners LLC also acknowledges separate telephone interviews with Dr. Lisa Nolan, Dean of CVM, and Dr. Mark Jackwood, Head of the CVM's Poultry Diagnostic and Research Center. They have not reviewed a draft of this profile and TEconomy Partners regains full responsibility for any errors.

55 <https://www.ars.usda.gov/southeast-area/athens-ga/us-national-poultry-research-center/>. Under this ARS organizational unit there are two physical complexes next door to each other: the National Poultry Research Center and the Southeast Poultry Research Laboratory.

56 https://www.redandblack.com/athensnews/sonny-perdue-visits-athens-for-groundbreaking-of-new-usda-research/article_9465a936-c130-11e7-9802-0f671383c182.html.

57 <http://www.agr.georgia.gov/georgia-poultry-laboratory-network.aspx> and more detail including history at <https://www.gapoultrylab.org/about-us/>.

58 Subsequently acquired by Rhône Mérieux (1988), now part of Boehringer-Ingelheim.

of Avian Medicine in the CVM, but now a unit of the Department of Population Health.⁵⁹ It has gradually added both research and diagnostic capacity and is now a multibuilding site.⁶⁰

Meanwhile, the federal ARS complex across the road from PDRC had been growing as well. In 1962, in response to then-pressing problem of air sacculitis in broilers, the USDA established at Athens the Southeast Poultry Research Laboratory (SPRL), which now conducts research in three areas: 10 exotic and emerging viruses in poultry; oncogenic viruses; and pathogens endemic in U.S. poultry production that cause enteric and respiratory disease.⁶¹ The SPRL also includes a six-person unit reporting to the Avian Disease and Oncology Laboratory (ADOL) that had been established even earlier at Michigan State University as the national custodian for chicken lines bred for usefulness in research.⁶² Although it is also under the NPRC organizational unit, the contemporaneously constructed Richard Russel Agricultural Research Center (RRC), serves an entirely separate function: it is USDA's primary facility for food safety research, addressing a number of animal and plant issues including but certainly not limited to poultry.⁶³

Within the last 10 years, based on consensus that the unique national facility of SPRL was very outdated, Congress has appropriated \$160 million funding to add a new research facility at SPRL, and the RRC is also due for upgrades.⁶⁴ There are now also commercial contract research organizations specializing in avian issues located just outside Athens, described by the CAES as good partners.

Governance

There are no governance issues raised by the kind of informal collaborations that exist at UGA.

Industry Collaboration

With 10 faculty who have extension appointments, the Poultry Science Department leads interaction with producers, engaging through workshops at the level of middle management and below. Where there are health or epidemiological issues of interest to the workshop participants, CAES faculty are joined by clinical track faculty (or Masters in Avian Medicine students) from the PDRC. The scope of PDRC visits is often across multiple states in the Southeast. One exception to this division of work is that issues of parasitology have historically been the responsibility of Poultry Science in CAES rather than of the PDRC.

Faculty from the two colleges generally share the same kind of funding agencies, except that the CVM cannot access Hatch Act formula funding. In addition to competitive funding through USDA, NIH and other federal agencies, one important source of competitive funding is U.S. Poultry & Egg Association, which issues competitive calls twice a year for very practical research. TEconomy Partners' search of the association's database of funded projects shows 452 records with the keyword "Athens," presumably including both colleges, and 14 with the keyword "PDRC." In contrast, the state-level Poultry Federation has no research funding, but supports both colleges in lobbying efforts.

The PDRC head also cites contract arrangements with nearly all the large animal health companies: Merck, Elanco, Boehringer-Ingelheim, Zoetis, etc. There is some consideration being given to allocating space to these partners, but nothing concrete yet. The PDRC head finds that startup companies generally do not have the

59 <https://vet.uga.edu/populationhealth>.

60 The name PDRC is used on campus in three distinct meanings: (1) an academic unit of CVM (formerly a standalone avian medicine department, but now a unit of with traditional missions in research, teaching, and service/outreach); (2) a complex of five buildings housing that unit, situated on College Road, just off campus, and just across the road from the ARS complex; and (3) a very specific building within the multi-building complex that is the main diagnostic laboratory rather than office or ancillary lab space.

61 <https://www.ars.usda.gov/southeast-area/athens-ga/us-national-poultry-research-center/docs/seprl/>.

62 <https://www.ars.usda.gov/southeast-area/athens-ga/us-national-poultry-research-center/adol/docs/history-of-adol/>.

63 <https://www.ars.usda.gov/southeast-area/athens-ga/us-national-poultry-research-center/docs/main/>.

64 <https://www.onlineathens.com/article/20160114/NEWS/301149969>.

financial resources to support full-scale animal medicine research. There appear to two vaccine companies and one antibacterial company listed in the portfolio of the UGA “Innovation Gateway”⁶⁵ incubator that are clearly based on research from the lab of a faculty member in the CVM, but in those cases the inventor comes from the CVM Department of Infectious Diseases rather than from the PDRC.

Interaction with downstream actors in food processing may take place informally through faculty who also hold adjunct appointments with the Department of Food Science, but most structured interaction is left almost entirely to UGA’s Center for Food Safety⁶⁶ and the Food Product Innovation and Commercialization Center,⁶⁷ both based 90 miles away at the UGA campus in Griffin, south of Atlanta. Together those two facilities are similar in mission to the value-added food-processing initiative under development at NC State.

Inter-College collaboration

CAES Poultry Science has 20.5 faculty, including 10 with extension appointments; the PDRC will soon have 14 including several in the clinical track; the ARS SPRL has about 45 PIs. With generational turnover in both colleges, leaders are now finding that younger recruits are very much interested in joint seminars and other forms of collaboration between colleges and with the ARS.

For the last several years, a faculty member who had gotten his degrees in CAES but did a postdoc in PDRC has been split as a 50-50 joint appointment between the two colleges. This person has carved out a niche where issues of poultry management and husbandry cross over with veterinary issues. For example, it may be that a disease pathogen has been identified, but its effects are clearly being made worse because of other things the producer is not paying attention to, such as lighting, ventilation, litter conditions water quality, etc. On occasion grants have funded ad hoc collaborations, such as studies of how vaccination practices and settings may be as important as vaccine choice in determining efficacy. The PDRC leadership would like to replicate the formal joint appointment model in two or three other cases if funding can be identified.

Generally, ARS is budgeted top-down according to current agency priorities, and when it “claims” an area, this can make it more difficult for university faculty to obtain competitive funding in that area. However, ARS may itself seek competitive grants and often enters into cooperative agreements with the university, involving placement of graduate students or postdocs in its own facilities. University faculty are not joint-appointed with ARS or vice versa.

Proximity to such a large, specialized presence by ARS clearly conveys some benefit to UGA, although not as targeted as might be expected. The list of current ARS collaborations significantly over-represents UGA relative to other universities.⁶⁸ However, most of the current ARS/UGA collaborations are in food safety, presumably more with the RRC than with the SPRL, although it is difficult to say for certain from the listing. On the other hand, many of the collaborations currently listed on vaccine development are with other federal agencies or directly with vaccine manufacturers.

65 <https://research.uga.edu/gateway/researchers/startups/startup-portfolio/>.

66 <https://cfs.caes.uga.edu/about.html>.

67 <https://foodpic.uga.edu>.

68 <https://www.ars.usda.gov/research/collaborations/?modeCode=60-40-10-00>.

Facilities

See above under “Origins”

Incentives

Aside from the joint-appointed faculty member mentioned above, first funded through a university-wide interdisciplinary initiative, there are no state or university incentives provided for cross-college or industrial collaboration. There have been no animal-agriculture investments by the Georgia Research Alliance at UGA. There are two GRA-supported Eminent Scholars on campus, one in crop and soil science and the other appointed in animal science (Dr. Steven Stice) but whose focus is human medicine through a stem cell institute that is independent of CAES. The CAES has not pursued a GRA eminent scholar in animal agriculture because raising the matching endowment required by GRA would likely prove daunting for the college.

Lessons/issues

- The CAES Dean and his team caution that initiatives such as those contemplated by NC State “always cost more than you think.” They believe that personnel are the easiest component to afford, but there can be significant challenges to financing infrastructure and long-term, structural support for such an activity. It is often very difficult to fund these through formula funding, or to demonstrate ROI-relevance to the producers.
- The CVM Dean, who came from Iowa State, recommends that NC State examine ISU’s swine diagnostic efforts as a possible model for the FAI.

E. University of Saskatchewan Livestock and Forage Center of Excellence (LFCE)

Description

The Livestock and Forage Centre of Excellence (LFCE)⁶⁹ is a C\$38 million+ capital project on lands owned by the University of Saskatchewan and managed jointly by the College of Agriculture and Bioresources (CABR) and the Western College of Veterinary Medicine (CVM). The focal points of the LFCE are cow-calf production; intensive livestock production; and forage, pasture, and grazing management.⁷⁰ The LFCE has been in development for more than half a decade, achieved its grand opening in 2018, and is still fund-raising for certain components of the capital plan.

The LFCE combines, rationalizes, expands, and extends under single management and unified branding several facilities formerly operated separately by the two colleges of the university and by the provincial Ministry of Agriculture in partnership with the Saskatchewan Cattlemen's Association. By moving an existing cattle feedlot and testing unit out of downtown Saskatoon, the LFCE was able to build a new facility combined with a provincially supported cow-calf facility that had previously been much more distant. The LFCE also provided an upgrade path for a large, nearby veterinary research farm. In all its promotional material, the university expresses the firm conviction that "there is nothing quite like the LFCE anywhere in the world" and states its intent to take advantage of this uniqueness to promote research "across the commercial supply chain," to introduce new techniques to producers, and to increase public awareness. While the initiative itself is a capital program rather than a research agenda or pool of funding, it is expected to open new possibilities for interdisciplinary research that may be funded variously by federal, provincial, or industrial sources.

The University of Saskatchewan hosts an important federal laboratory that has helped make it and the provincially supported research park Innovation Place a center of oilseed crop research, and additional federal investments that have advanced the university's profile in human medicine, biotechnology, and industrial biotechnology; however, the LFCE represents the first significant federal investment directly in animal agriculture, which has always been a campus strength, but until now with only provincial support.

The LFCE capital program was co-funded by multiple sources, including to date: internal university and college funds (C\$11 million); the Growing Forward 2 Program⁷¹ operated jointly by the agriculture ministries of the federal and provincial governments (totaling C\$10 million between both levels of government); Western Economic Diversification, a geographically targeted federal development agency (C\$4.5 million); the Saskatchewan Cattlemen's Association (C\$1 million); Farm Credit Canada; A&W Food Services of Canada (C\$5 million – C\$3 million for capital and C\$2 million for operations); Boehringer-Ingelheim Canada (C\$250,000 for combined facilities and operations); and Merck Animal Health (C\$250,000 in research funding over ten years).

69 <https://lfce.usask.ca>. TEconomy Partners LLC also gratefully acknowledges interviews with Dr. Mary Buhr, Dean of the College of Agriculture and Bioresources, and Dr. Douglas Freeman, Dean of the Western College of Veterinary Medicine. They have not reviewed drafts of this profile, and TEconomy Partners retains full responsibility for any errors.

70 The CABR also has important activities in feed research. Much swine research, however, is in the hands of the Prairie Swine Centre, a non-university nonprofit intermediary also located in Saskatoon.

71 <http://www.agr.gc.ca/eng/about-us/key-departmental-initiatives/growing-forward-2/?id=1294780620963> and as renamed the Canadian Agricultural Partnership <https://www.saskatchewan.ca/business/agriculture-natural-resources-and-industry/agribusiness-farmers-and-ranchers/canadian-agricultural-partnership-cap>

Origins

The LFCE was driven by opportunities arising from problems with two important facilities, each of which posed a separate challenge to interdisciplinary and collaborative research.

The most pressing need was to replace the College of Agriculture's Beef Research Unit, a 50-year-old and rapidly obsolescing 700-head feedlot that was located quite near campus but in a rapidly redeveloping residential section of Saskatoon along the riverbank. Not only was this an increasingly inappropriate use in the eyes of the university's neighbors, but the facility no longer met the Canadian Council on Animal Care Standards due to poor site drainage conditions. As long as a decade ago, faculty were already agitating for a replacement.

The second challenge was posed by the remoteness of the former Western Beef Development Centre (WBDC),⁷² a cow-calf and forage research unit formerly operated on university land by a provincially supported intermediary organization in Lanigan, 120 kilometers east of Saskatoon. While the WBDC was structured as a collaboration of the Saskatchewan Ministry of Agriculture, provincial cattle producers, and the university, the substantial distance to this site made participation difficult for both faculty and students in both colleges. Moreover, this site was also considered in need of upgrade and repair.

Together, these constraints and challenges presented the university with the opportunity to work with larger numbers of animals, and tighten its connections with a broader range of producer groups. Initially the university asked the provincial government to support a new feed lot and research unit. The province conducted a lengthy study of the needs of the sector, and concluded it no longer needed to fund a separate facility so remote from the university. At this point, the problem was expanded to include the needs of the CVM research farm, and a large task force was convened among all relevant producer groups, both colleges, central university administration, and all levels of government – leading to the vision for the LFCE.

This vision could not have been achieved without the provincial government's agreement to cease research operations at the WBDC site in Lanigan and eventually fold the entire budget into new facilities at the LFCE. According to an archived website, cattle producers and other industry groups covered 30 percent of WBDC costs, and sales of progeny from the herd covered another 13 percent, leaving the vast majority of funding the responsibility of the provincial Ministry of Agriculture. The ministry agreed to roll its operating funding (20 percent of the WBDC budget) and its strategic research program (another 17 percent) into the LFCE Forage and Cow-Calf Research and Testing Unit, and also to allow university faculty eligibility to compete for project support through the competitive Agricultural Development Fund⁷³ (which accounted for the final 20 percent of the old WBDC budget). As a final component, both colleges agreed to commit operating funds at least equal to what they already spent on their own existing facilities.

Governance

While the university was technically a partner in the former WBDC, its remoteness meant that the cattle industry was used to very heavy involvement. The Cattlemen's Association generally picked research projects and micromanaged many facilities issues down to what kind of wire to use for fencing. After its commitment of \$1 million to the LFCE, the Cattlemen's Association felt no less entitled to a strong voice in the new project. This created a significant governance challenge for the two deans, who have responsibility for scholarly and educational activities as well. To make the LFCE work, the deans had to convince the producers (and the provincial Agriculture Ministry) that they could trust the university to select appropriate projects and operating procedures.

⁷² <http://westernbeef.org>.

⁷³ <https://www.saskatchewan.ca/business/agriculture-natural-resources-and-industry/agribusiness-farmers-and-ranchers/agricultural-research-programs/knowledge-creation/agriculture-development-fund>.

As funding fell into place, the university created a new LFCE Strategic Advisory Board (SAB), which gives a voice to all stakeholders but dilutes the producer representatives with senior representatives from the participating provincial and federal agencies and from the university itself, including the Assistant Vice President for Research and also the Dean of Engineering. One of the first tasks of LFCE governance was to introduce a more collegial process to the SAB. This task is being facilitated by involvement of a faculty member from the business school whose expertise is in board-level governance.

To manage the new unified center operations and also day-to-day relations with the industry, LFCE hired as its director a beef cattle specialist who (1) had earned a Ph.D. but also (2) grew up on a ranch himself and (3) had direct experience as an operations manager for North Dakota State University's Dickinson Research & Extension Center.

Industry Collaboration

The Cattlemen's Association includes sophisticated and politically active businesspeople who have experience in both grant-making and fund-raising. Many have a public presence on Twitter, serve on local boards and commissions, and can easily obtain meetings with relevant government ministries at the provincial or federal level and even with large companies. They are active participants in fund-raising for the facility, although they are not as focused on multi-disciplinary and multi-sectoral partnerships as is the university itself.

On occasion there have been tensions with some major sponsors such as A&W, which is promoting antibiotic- and hormone-free beef as alternatives to traditional ranching product. Ultimately the cattle producers understood that fund-raising was more important to securing the long-term future of the LFCE than their comfort level with any individual corporate sponsor, and in any case A&W is now "at the table" and part of a dialogue with the traditional ranchers. There is always a percentage of producers that are actively innovative, but it may not represent the majority.

Inter-College Collaboration

The two participating colleges already had a record of collaboration. There are many bench-to-bench collaborations between faculty in Department of Animal and Poultry Sciences and those in the CVM, organized around various research topics, specialized facilities, or curricular matters (since the College of Agriculture's undergraduate degree in animal biosciences is in part directed toward those who are thinking of applying to a school of veterinary medicine).

Unlike VIDO-InterVac⁷⁴ center – a OneHealth initiative whose origins were in the College of Veterinary Medicine but which now operates as a university-level center reporting solely to the central Vice President for Research – the LFCE is a variant of a college-based center. Nominally it also reports to the Vice President for Research, but the latter has delegated in writing nearly all authority to the two deans jointly. This hybrid structure has posed a variety of challenges.

For example, during early fund-raising, each college had to raise C\$1.5 million to match the C\$1 million per college committed by the university Board of Governors. While some of the leads that came were unique to one college or the other – such as the drug companies that were brought on board by the CVM or the producer organizations involved by the College of Agriculture – others were targets of development officers from both colleges. To avoid looking disorganized and so as not to confuse potential donors, it was decided to support development centrally. There is now university-level fund-raiser dedicated to managing the LFCE fund-raising overall, who is supported by the college-level development officers.

74 <https://www.vido.org>.

There have also arisen additional practical difficulties. Under the university accounting system, controls are very linear and hierarchical, proceeding from a vice president down to a dean and so on. Projects like the LFCE have always belonged to and were coded as belonging to either one college or another, and there was no way to code a budget for both at once. In addition, when the LFCE raised a capital donation, there was no way to appropriately allocate it to the fund-raising targets of the college most responsible for the donation. Workarounds are available as long as the two founding deans are in place and know the history, but the deans are worried about what will happen when the first one terms out and institutional memory fades.

One additional issue was posed by differing reporting practices in the two colleges. In the CVM, the Goodale research farm had reported to an associate dean for research, while in the College of Agriculture the research unit reported to the Head of the Animal and Poultry Science Department.

Facilities

The three elements of the LFCE facility plan are now all clustered southeast of the City of Saskatoon and the university campus. The closest is the Goodale Research Farm, a former veterinary college property 17 kilometers from campus that is still being upgraded and currently supports 165 breeding cows, as well as horses, bison, elk, and deer for research in reproductive physiology, infectious disease, and other biomedical topics with translational potential.

At about twice that distance from campus, on land newly developed south of the rural village of Clavet, are a new Beef Cattle Research and Testing Unit – with a feedlot of capacity of 1,500, metabolism barns, multiple experimental pens, and intensive environmental monitoring of ground conditions – and a Forage and Cow-Calf Research and Teaching Unit with room for 300-450 breeding cows. The emphasis of both these facilities is on repeated, genetically controlled measures in varying forage and grazing régimes. The two facilities are separated by 500 meters for biosecurity reasons. The feedlot itself was built on virgin prairie that had never before hosted intensive agriculture. It was heavily surveyed and fully instrumented prior to construction so that environmental impacts can be studied and understood into the future, relative to a 16-month baseline of data already in hand.

With funds raised to date, the feedlot is completed, the cow-calf facility has completed its first phase of construction, and there are remaining “cleanup” issues at the Goodale Farm. It is estimated that the LFCE is now two-thirds complete. Some remaining pasturing of cows is still being done at the old WBDC site.

Incentives

The LFCE initiative itself includes no incentives for collaboration, beyond the ability of university researchers from both colleges to apply to the ADF to support projects that might formerly have been conducted by staff at the intermediary that operated the WBDC. Notably, however, the operational support from A&W Restaurants is used to fund visiting scientists – possibly on sabbatical from another institution – to come and use the LFCE facilities.

More generally, the deans consider that it is the uniqueness of the combined facility that is itself the strongest incentive for collaboration with industry and among academic departments. As the agriculture dean noted,

“Because of the systems we have in the LFCE, you could take the genetics of a new forage variety and grow that variety in different pastures, where we can graze cow-calf pairs in different population densities or different genetics and take some of those calves and put them in the intensive livestock operation and follow their individual digestive patterns and link back to their genetics and the pastures they were raised on and forages grazed on. Then we can look at their responses to health challenges and their growth rates, and when they go to slaughter, we can study the meat quality, and we can relate all that to the environmental costs and challenges. If there’s a rainfall event, we can tell

anyone who asks what the feedlot did to subsurface and soil conditions, and what impact that has had depending on the kind of forage, or genetics, or nutrigenetic interactions. It's because we can do all this, because of the enormous animal capacity to run so many trials simultaneously, that we can study how this vaccine or that one works on a cross-bred animal. Because the feed lot will handle way more animals than we will be producing as calves, we can compare our calves – about which we know everything – from the standpoint of growth, health, and lifetime progeny. And finally because of everything we can do here in a totally integrated fashion, we will be able to tell you the carbon footprint and how your forage variety grew and how it compared."

Additionally, she added: "Because our whole production community is so deeply involved, you can come in as a researcher who has done nothing but lab work in development of vaccines, and all of sudden be touching the whole production line. We've brought researchers into this tight-knit industry wide community that had never been here before."

Lessons/issues

- In introducing collegial governance to an industry used to having its way on research that it co-funds, not every battle can be won by the university. At times, the two deans have accepted the cattlemen's way of doing business, but occasionally they have had to insist that things can no longer work that way, and here is how the university does it. In this delicate task, the deans have been assisted by having a center director who was not a young person directly out of a graduate program, but instead had long and directly relevant experience that gave him credibility with the ranching industry.
- Despite everyone's stated desire to do interdisciplinary work, university structures as routine as accounting systems can make this very difficult and must be considered explicitly. The University of Saskatchewan has had to stitch together an ad hoc collection of two development officers, two finance people, two communications specialists. This has worked as long as the founding deans have a high level of trust between them, but now that the Ag dean is terming-out, these procedures and processes must be agreed on in writing at every level of the university. In any case, no such partnership can form without a strong, trusting relationship to start with.

Appendix B. Publications with NC State Authors in Key Words Analysis Categorized by Field.

Fields	Count of WoS Category	NCSU Pubs Quotient
Agriculture, Dairy & Animal Science	232	1.50
Veterinary Sciences	123	1.34
Food Science & Technology	97	1.09
Biochemistry & Molecular Biology	45	0.52
Genetics & Heredity	23	0.51
Agriculture, Multidisciplinary	17	1.00
Biotechnology & Applied Microbiology	17	0.73
Chemistry, Applied	13	1.00
Nutrition & Dietetics	13	0.38
Cell Biology	12	0.46
Fisheries	11	0.33
Reproductive Biology	9	0.67
Biology	9	0.58
Dermatology	8	9.12
Entomology	8	2.26
Endocrinology & Metabolism	8	1.10
Pharmacology & Pharmacy	7	2.64
Agricultural Engineering	6	0.74
Zoology	6	0.74
Toxicology	5	0.94
Immunology	5	0.64
Evolutionary Biology	5	0.59
Chemistry, Organic	4	2.52
Public, Environmental & Occupational Health	4	1.40

Fields	Count of WoS Category	NCSU Pubs Quotient
Chemistry, Multidisciplinary	4	1.06
Infectious Diseases	4	1.05
Ecology	4	0.57
Marine & Freshwater Biology	4	0.25
Computer Science, Interdisciplinary Applications	3	2.88
Pathology	3	2.04
Pediatrics	3	1.81
Physiology	3	0.85
Microbiology	3	0.32
Water Resources	2	10.69
Education, Scientific Disciplines	2	3.35
Engineering, Chemical	2	1.24
Chemistry, Medicinal	2	1.01
Parasitology	2	0.62
Behavioral Sciences	2	0.40
Biophysics	2	0.27
Cell & Tissue Engineering	1	3.72
Gastroenterology & Hepatology	1	1.14
Polymer Science	1	0.74
Oncology	1	0.56
Plant Sciences	1	0.45
Chemistry, Analytical	1	0.42
Neurosciences	1	0.42
Agronomy	1	0.34
Medicine, Research & Experimental	1	0.21
Biochemical Research Methods	1	0.14

Appendix C. Companies of Relevance or Potential Relevance to the Food Animal Initiative in North Carolina

1. COMPANIES IDENTIFIED BY NC BIOTECHNOLOGY CENTER AS “AGRICULTURAL TECHNOLOGY” WITH DIRECT OR ADJACENT (POTENTIAL) RELEVANCE TO FOOD ANIMALS.

Direct	Adjacent	Sector	Animal/Agricultural Bioscience Company	Focus	Location
x		Diagnostics	Advanced Animal Diagnostics Inc.	Advanced Animal Diagnostics (AAD) develops and commercializes diagnostics to detect and manage disease states, reproductive, nutritional and overall health status of production animals.	Morrisville
x		Nutrition	AgBiome Inc.	AgBiome uses its proprietary Genesis platform to collect, isolate and analyze microbes for use in the discovery and development of biologicals and traits for protecting crops, and is researching probiotic products to address swine gut health challenges.	Research Triangle Park
x		Antibiotics & Antimicrobials	Agile Sciences Inc.	Agile Sciences is developing a technology for the treatment of antibiotic-resistant, life-threatening infections.	Raleigh
x		Vaccines	Applied LifeSciences & Systems Poultry Inc.	Applied LifeSciences & Systems Poultry develops automated bio-system solutions for detecting, targeting and delivering vaccines to poultry. ALS-S technology aims to reduce the need for antibiotics by improving vaccination delivery.	Raleigh
	x	R&D Support	AptaChem Consulting LLC	AptaChem provides chemistry and discovery services to the biotech, pharmaceutical, agricultural, academic and patent communities.	Apex
x		Nutrition	Arbiom Inc.	Arbiom develops technologies that convert residues from agriculture and forestry into a high-protein ingredient for aquaculture and animal feed. The Raleigh office is Arbiom's application center.	Durham
	x	R&D Support	Belleropharm LLC	Belleropharm provides preclinical drug development consulting services, with expertise in toxicology, ADME, pharmacokinetics and the conduct of GLP-compliant animal efficacy studies.	Durham

Direct	Adjacent	Sector	Animal/Agricultural Bioscience Company	Focus	Location
x		Antibiotics & Antimicrobials	BENANOVA Inc.	BENANOVA develops antimicrobial nanotechnology products for the disinfectant, cosmetic and agricultural industries.	Raleigh
	x	R&D Support	BioNarus LLC	BioNarus provides research and development consulting, project management and product differentiation services for the animal health and nutrition sector.	Cary
x		Nutrition	BioResource International Inc.	BioResource International (BRI) designs, develops and manufactures unique enzymes that help poultry and swine producers optimize animal nutrition and gut health.	Durham
x		Nutrition	Biovet S.A.	Biovet develops nutritional supplements, enzymes, pronutrients, digestives, antioxidants, preservatives, mycotoxin binders and flavoring for feed for poultry, ruminants, swine and aquaculture.	Research Triangle Park
x		Antibiotics & Antimicrobials	Boragen Inc.	Boragen is developing a synthetic chemistry platform that leverages the unique characteristics of boron to address life science needs in crop protection and animal health.	Research Triangle Park
	x	R&D Support	Cambrex	Cambrex offers development, analytical services and manufacturing of APIs and small molecule drugs. Its Durham site provides drug substance development and manufacturing, as well as analytical services and microbiology testing services.	Durham
x		Nutrition	Demeter Biosciences LLC	Demeter Biosciences is creating sustainable animal feeds and macronutrients for applications in fish farming and animal husbandry.	Apex
x		Veterinary Medicines	Fleming Laboratories Inc.	Fleming Laboratories manufactures animal pharmaceuticals.	Charlotte
x		Food Safety	FoodLogIQ	FoodLogIQ provides traceability, food safety compliance and supply chain transparency software solutions.	Durham
x		Dagnostics	Galaxy Diagnostics Inc.	Galaxy Diagnostics develops assays and provides molecular and serology testing for flea- and tick-borne infectious disease for physicians, veterinarians and clinical research.	Morrisville
x		Vaccines	Goldsboro Laboratories LLC	Goldsboro Laboratories develops and manufactures vaccines for the swine, poultry and cattle divisions of Goldsboro Milling Company.	Goldsboro

Direct	Adjacent	Sector	Animal/Agricultural Bioscience Company	Focus	Location
	x	Vaccines	Greenlight Biosciences Inc.	Greenlight Biosciences has developed a cell-free bioprocessing method for the low-cost production of RNA for use in research in vaccine development, vector control, pandemic preparation, crop management and crop pesticides.	Research Triangle Park
x		Diagnostics	GTCAllison LLC	GTCAllison researches and develops diagnostic tests for animal pathogens.	Mocksville
	x	Veterinary Medicines	Happy Jack Inc.	Happy Jack manufactures insecticides and pharmaceutical preparations to treat dogs.	Snow Hill
x		Vaccines	HIPRA Scientific USA LLC	Hipra researches and develops vaccines, diagnostics and pharmaceuticals for animal health.	Raleigh
x		Vaccines	Huvepharma Inc.	Huvepharma manufactures Coccidiosis vaccines for in ovo and post-hatch vaccination of poultry.	Maxton
x		Diagnostics	IDEXX Reference Laboratories Inc.	IDEXX Laboratories provides animal health diagnostic products and services for use in small animals, equine, poultry and dairy livestock. It also provides microbiology-based water testing products.	Greensboro
x		Diagnostics	ImmunoReagents Inc.	ImmunoReagents manufactures primary and secondary polyclonal antibodies used in research and in vitro diagnostics for the pharmaceutical and veterinary markets.	Raleigh
x		Food Safety	Imperial Brown Inc.	Imperial Brown manufactures cold storage products for biotechnology, medical, food service and building construction industries. The Salisbury site is Imperial Brown's East Coast factory.	Salisbury
x		Food Safety	JLA International Inc.	JLA International provides testing and analytical services for the food and beverage industry. It also provides technical consulting services.	Edenton
x		Food Safety	Laudiss Labs LLC	Laudiss Labs uses advanced proprietary platform technologies for quantitative DNA and protein testing of GMOs, foodborne pathogens and mycotoxins in food and feed.	Winston-Salem

Direct	Adjacent	Sector	Animal/Agricultural Bioscience Company	Focus	Location
x		Vaccines	Medicago USA Inc.	Medicago develops vaccines based on proprietary manufacturing technologies and virus-like particles. The vaccines are manufactured using a transient protein expression system in <i>Nicotiana benthamiana</i> , a close relative of tobacco.	Durham
x		Mycology	Mycosynthetix Inc.	Mycosynthetix manages a large collection of fungal isolates and discovers novel fungal metabolites for human and animal health and compounds for agricultural applications.	Hillsborough
x		Nutrition	Noah's Inc.	Noah's Inc. develops algal growth systems and cultivates algal biomass for the manufacture of protein, astaxanthin and other derivatives for use as nutraceutical ingredients in food and beverage industries, and for commercial fish/animal feed industries.	Charlotte
x		Nutrition	Novozymes North America Inc.	Novozymes researches, develops and manufactures enzymes, microorganisms and biopharmaceutical ingredients used in industries including agriculture, baking, biofuels, brewing, detergents, food, feed and textiles. The Franklinton site manufactures enzymes.	Franklinton
x		Vaccines	Pharmgate Animal Health LLC	Pharmgate Animal Health develops and markets medicines and vaccines for the control of disease in livestock and poultry in North America.	Wilmington
x		Nutrition	Phytobiotics North America LLC	Phytobiotics produces and distributes botanical and phytogetic supplements and flavors for plant and animal nutrition. Additionally, Phytobiotics provides consultative services focused on intestinal health and increased nutrient bioavailability.	Cary
	x	Veterinary Medicines	Piedmont Animal Health LLC	Piedmont Animal Health develops, licenses and markets animal health therapeutics with a focus on major companion animal categories.	Greensboro
x		Nutrition	Premex Innovation Labs	Premex develops, manufactures and markets nutritional ingredients for animals. This location conducts research on feed additives for animal nutrition.	Durham
	x	Diagnostics	Sentinel Biomedical Inc.	Sentinel Biomedical develops and offers molecular diagnostics for the detection and monitoring of canine cancers. Sentinel also offers CRO services in the areas of molecular biology and genomics.	Raleigh

Direct	Adjacent	Sector	Animal/Agricultural Bioscience Company	Focus	Location
	x	Food Safety	SinnovaTek Inc.	SinnovaTek develops and provides food processing systems to manufacturers.	Raleigh
x		Food Safety	Smithers Viscient LLC	Smithers Viscient provides environmental testing and toxicology services for the pharmaceutical, veterinary, agriculture, chemical and personal-care industries. The company's lab in Snow Camp conducts avian and wildlife toxicology testing.	Snow Camp
x		Food Safety	Spin-Darc LLC	Spin-Darc is developing a rapid digital microbiology testing device usable at point-of-care or in low-resource settings. Applications include infectious disease diagnostics, food testing and water testing.	Raleigh
x		Immunotherapies	Stallergenes Greer	Stallergenes Greer develops and distributes animal and human allergy immunotherapy products and services.	Lenoir
x		Antibiotics & Antimicrobials	Trana Discovery Inc.	Trana Discovery provides an anti-infective discovery platform that enables its partners to identify novel treatments that possess pathogen-focused spectrums of activity for bacterial, viral and fungal infectious diseases in crops, animals and humans.	Cary
x		Vaccines	Zoetis Inc.	Zoetis develops and manufactures vaccines and medications for animal health. The Durham, NC site develops and manufactures high-throughput automation biodevices for the poultry industry, including in ovo vaccination technology.	Durham
	x	Veterinary Medicines	Zoion Pharma Inc.	Zoion Pharma develops drugs for veterinary disorders. Zoion's lead product is an epithelial sodium channel blocker compound to treat canine keratoconjunctivitis sicca (KCS) or dry eye.	Raleigh

2. COMPANIES WITH POTENTIAL RELEVANCE TO PRECISION FOOD ANIMAL AGRICULTURE

Direct	Adjacent	Sector	Data/Analytics Organizations	Focus	Location
x		Ag Analytics	AGDATA Inc.	AGDATA provides data and analytical services to agricultural crop protection and animal health manufacturers, including outsourced database management, marketing program administration, data collection and data analysis services.	Charlotte
	x	Sensors and Precision Tech	AgEye Technologies	Smart Spectrum Technologies develops software and sensor solutions that use artificial intelligence to improve the quality, predictability and profitability of indoor farms through autonomous systems.	Raleigh
x		Ag Analytics	Datu Research LLC	Datu Research offers big data research consulting, supporting projects in food and agriculture, economic development and climate resilience.	Durham
x		Sensors and Precision Tech	Galileo Group Inc.	Galileo Group uses state-of-the-art airborne and ground-based hyperspectral imaging sensors and specialized detection algorithms for informatics purposes in agri-science and biomedical applications.	Research Triangle Park
x		Sensors and Precision Tech	PrecisionHawk USA Inc.	PrecisionHawk develops unmanned aircraft for imaging and data collection, with applications for precision agriculture and environmental monitoring.	Raleigh
x		Ag Analytics	TKXS	TKXS provides data collection, data science, technology and data-enabled marketing, and incentive management capabilities to the agriculture, healthcare, construction and industrial supply industries.	Research Triangle Park
	x	Ag Analytics	Alpha-Gamma Technologies Inc.	Alpha-Gamma Technologies provides consulting services and information technology solutions in toxicogenomics, bioinformatics, data mining and warehousing for government, biotechnology and pharmaceutical industries.	Raleigh
	x	Sensors and Precision Tech	Bennett Aerospace Inc.	Bennett Aerospace delivers innovative scientific solutions and on-site science, technology, and IT services. Bennett also has experience in developing advanced technologies, such as ultrasensitive biosensors, robotics, and materials.	Cary

Direct	Adjacent	Sector	Data/Analytics Organizations	Focus	Location
	x	Sensors and Precision Tech	Blue Wave Labs	Blue Wave Labs provides consulting services in embedded and real-time technologies, for data communications, medical devices, sensors, aviation and military projects.	Rougemont
	x	Sensors and Precision Tech	EAG Laboratories Inc.	EAG Laboratories offers contract research and testing for science and technology companies. Its Raleigh location provides semiconductor and microelectronic services to the medical device, semiconductor and aerospace and defense industries.	Raleigh
	x	Sensors and Precision Tech	MEMSCAP Inc.	MEMSCAP provides products and solutions based on micro-electromechanical systems (MEMS) and MEMS contract manufacturing services. Industries served include medical and biomedical, aerospace and defense, optical communications, and the IT/consumer market.	Durham
	x	Sensors and Precision Tech	NanoTechLabs Inc.	NanoTechLabs develops and produces military and commercial products that have performance benefits through the incorporation of nanotechnology.	Yadkinville
	x	Sensors and Precision Tech	Optoniks Corp.	Optoniks develops optical engineering and precision metrology products with applications in the fields of imaging, optical metrology, security and health care industries.	Indian Trail
	x	Sensors and Precision Tech	QuarTek Corp.	QuarTek develops nanotechnology processes with applications in antimicrobials, advanced textiles, nanosensors, diagnostics and biofuels. The company also provides accelerator services for startup nanotechnology companies.	Asheboro
	x	Sensors and Precision Tech	Redbud Labs	Redbud Labs develops and manufactures microfluidic mixing chips that use micro-electromechanical systems (MEMS) technology called Redbud Posts.	Research Triangle Park

3. Companies Classified by NC Biotechnology Center as Focused in Biosecurity

Direct	Adjacent	Sector	BioDefense	Focus	Location
	x	Vaccines	AlphaVax Inc.	AlphaVax develops vaccine technology with applications in infectious disease, cancer and biodefense threats.	Research Triangle Park
x		Food Safety	Appealing Products Inc.	Appealing Products develops products for forensics and personal protection from toxic materials such as inorganics, gases and poisons in foods, animal feeds and liquids.	Raleigh
	x	Antibiotics & Antimicrobials	BioArmor LLC	BioArmor distributes non-toxic, alcohol-free hand sanitizers, topical antiseptics and disinfectants, and hospital-grade cleaners and disinfectants for the infection control industry, including government, military, schools and long-term care.	Kannapolis
	x	Infectious Disease Surveillance	Chemring Sensors and Electronic Systems	Chemring Sensors and Electronic Systems develops and manufactures chemical and biological agent detection systems, as well as explosive detection systems.	Charlotte
	x	Antibiotics & Antimicrobials	Chimerix Inc.	Chimerix discovers, develops and commercializes broad spectrum antivirals for the prevention and treatment of life-threatening viral infections.	Durham
	x	Vaccines	Global Vaccines Inc.	Global Vaccines is a not-for-profit company that develops vaccines against developing-country diseases such as HIV/AIDS, polio, dengue fever, malaria and viral diarrhea (rotavirus).	Chapel Hill
	x	Vaccines	Greenlight Biosciences Inc.	Greenlight Biosciences has developed a cell-free bioprocessing method for the low-cost production of RNA for use in research in vaccine development, vector control, pandemic preparation, crop management and crop pesticides.	Research Triangle Park
	x	Biodefense Consulting	Gryphon Scientific	Gryphon Scientific is a physical and life science consulting firm that provides technical expertise in the areas of public health, biodefense and homeland security.	Chapel Hill
	x	Biodefense Consulting	KTM Biopartners LLC	KBI Biopartners offers biopharma consulting in the areas of vaccines, anti-infectives, emerging diseases and biothreats.	Chapel Hill

Direct	Adjacent	Sector	BioDefense	Focus	Location
	x	Infectious Disease Surveillance	National Collaborative for Bio-Preparedness	The National Collaborative for Bio-Preparedness is a public-private partnership to develop, test and implement an advanced, nationwide bio-surveillance system.	Chapel Hill
	x	Diagnostics	Xenobiotic Detection Systems International Inc.	Xenobiotic Detection Systems offers patented bioassays to facilitate assessment of environmental and human health risks.	Durham

4. COMPANIES CLASSIFIED BY NC BIOTECHNOLOGY CENTER IN BIOPHARMACEUTICALS MANUFACTURING AND CONTRACT SERVICES

Direct	Adjacent	Sector	Biopharmaceutical Manufacturing	Focus	Location
	x	Pharma Ingredients	Ajinomoto North America	Ajinomoto North America manufactures pharmaceutical-grade amino acids and custom-blended amino acid mixtures.	Raleigh
	x	Contract Pharma Production	Alcami Corporation	Alcami provides contract drug and biologics development and manufacturing services, including formulation development, analytical chemistry, API, solid dose and parenteral drug manufacturing for both clinical and commercial markets.	Wilmington
	x	Contract Pharma Production	Alcami Corporation (Durham)	Alcami provides contract drug and biologics development and manufacturing services, including formulation development, analytical chemistry, API, solid dose and parenteral drug manufacturing for both clinical and commercial markets.	Durham
	x	Contract Pharma Production	Almac Clinical Services LLC	Almac Clinical Services provides clinical trial material manufacturing, packaging and distribution services.	Durham
	x	Contract Pharma Production	Asymchem Inc.	Asymchem offers CMC and CDMO services, focused on developing processes for late-phase to commercial APIs and HPAPIs, and small-molecule manufacturing and development. Asymchem is USFDA- and TGA-inspected.	Morrisville

Direct	Adjacent	Sector	Biopharmaceutical Manufacturing	Focus	Location
	x	Biopharmaceutical Production	Aurobindo Pharma USA Inc.	Aurobindo Pharma is a generic drug manufacturer. Aurobindo develops inhalation and dermatological products from the company's U.S. research and development headquarters in North Carolina.	Durham
	x	Diagnostics Manufacturing	Avioq Inc.	Avioq develops and manufactures FDA-approved and CE-marked immunodiagnostic assays. Products include HIV and HTLV assays, recombinant proteins and synthetic peptides and labware supplies. Avioq also offers contract IVD development and manufacturing.	Research Triangle Park
	x	Botanical Extractions	Avoca LLC	Avoca develops and manufactures botanical extraction products and provides extraction services, and contracts with farmers to grow clary sage.	Merry Hill
	x	Diagnostics Manufacturing	BD Diagnostics (Durham)	BD Diagnostics develops and commercializes molecular diagnostic products for various cancers, including cervical, breast, ovarian and prostate.	Durham
	x	Diagnostics Manufacturing	BD Diagnostics (Mebane)	BD Diagnostics develops and commercializes molecular diagnostic products for women's health and various cancers.	Mebane
	x	Contract Pharma Production	BestCo Inc.	BestCo manufactures over-the-counter drugs and dietary supplements, and offers contract product manufacturing and packaging.	Mooreville
	x	Biopharmaceutical Production	Biogen	Biogen discovers, develops and manufactures therapies for serious neurological diseases. Its Drug Substance Campus in RTP is home to biologics production and a patient services contact center.	Research Triangle Park
	x	Biopharmaceutical Production	Biogen (Oral Solid Dose Facility)	Biogen discovers, develops and manufactures therapies for serious neurological diseases. This site houses oral solid dose and anti-sense oligonucleotide production, packaging and fill/finish operations, as well as a Global Business Services center.	Research Triangle Park
	x	Diagnostics Manufacturing	bioMérieux Inc.	bioMérieux develops in vitro products to diagnose infectious diseases, cancer and cardiovascular disease and to detect microorganisms in agri-foods, pharmaceuticals and cosmetics.	Durham
	x	Enzymes	BioResource International Inc.	BioResource International (BRI) designs, develops and manufactures unique enzymes that help poultry and swine producers optimize animal nutrition and gut health.	Durham

Direct	Adjacent	Sector	Biopharmaceutical Manufacturing	Focus	Location
	x	Contract Pharma Production	Cambrex	Cambrex offers development, analytical services and manufacturing of APIs and small molecule drugs. Its Durham site provides drug substance development and manufacturing, as well as analytical services and microbiology testing services.	Durham
	x	Contract Pharma Production	Cambrex High Point	Cambrex High Point develops and manufactures small-molecule APIs and intermediates for Phase I through III clinical trials. It offers custom organic synthesis, process development, analytical development and cGMP manufacturing services.	High Point
	x	Contract Pharma Production	Catalent Pharma Solutions LLC	Catalent provides drug development and manufacturing services for the pharma, biotech and consumer sectors. Core offerings include biologics, parenterals, oral solids, softgel, inhalation, clinical supply services and analytical services.	Morrisville
	x	Biopharmaceutical Production	CMP Pharma Inc.	CMP develops, manufactures and commercializes specialty pharmaceuticals, focused on niche liquid and topical products that solve unmet patient needs.	Farmville
	x	Vitamins and Minerals	Daily Manufacturing Inc.	Daily Manufacturing manufactures vitamins, minerals and herbals. The company also manufactures products for other supplement companies with their own brand names.	Rockwell
	x	Drug Discovery Tools	EpiCypher Inc.	EpiCypher develops and manufactures novel products and tools for epigenetics and chromatin biology, focused on enabling drug discovery research and development.	Research Triangle Park
	x	Contract Pharma Production	Exela Pharma Sciences LLC	Exela Pharma Sciences develops, manufactures and markets sterile injectable pharmaceuticals, and provides contract manufacturing services. The Lenoir site is a cGMP-compliant sterile manufacturing facility.	Lenoir
	x	Drug Delivery Tools	Fresenius Kabi USA LLC	Fresenius Kabi manufactures medical devices and sterile injection- and infusion-based drug-delivery products.	Wilson
	x	Contract Pharma Production	FUJIFILM Diosynth Biotechnologies USA Inc.	Fujifilm Diosynth Biotechnologies provides biologics contract development and manufacturing. Services include cell line development, process and analytical development, clinical and commercial manufacturing and bioprocess research and development.	Morrisville

Direct	Adjacent	Sector	Biopharmaceutical Manufacturing	Focus	Location
	x	Biopharmaceutical Production	G&W Laboratories LLC	G&W Laboratories manufactures OTC and prescription hydrocortisone, antifungal and permethrin products as creams, ointments, liquids and suppositories.	Lincolnton
	x	Botanical Extractions	Gaia Herbs Inc.	Gaia Herbs grows and produces certified organic herbal products, including liquid extracts, functional powders and herbal teas. All growing, manufacturing, processing, researching, packaging and distribution takes place in its North Carolina facilities.	Brevard
	x	Biopharmaceutical Production	Glenmark Pharmaceuticals Inc., USA	Glenmark Pharmaceuticals discovers small-molecule drugs and biologics in the areas of oncology, respiratory disease and dermatology, and manufactures and distributes APIs and generics. The Monroe site manufactures oral solids, injectables and topicals.	Monroe
x		Vaccines	Goldsboro Laboratories LLC	Goldsboro Laboratories develops and manufactures vaccines for the swine, poultry and cattle divisions of Goldsboro Milling Company.	Goldsboro
	x	Biopharmaceutical Production	Grifols (Clayton)	Grifols' Clayton plant is the company's primary manufacturing facility, producing proteins to treat rare diseases including immune deficiencies and genetic emphysema.	Clayton
	x	Contract Pharma Production	GSK (Zebulon)	GlaxoSmithKline manufactures solid-dose products, including tablets and capsules, at its Zebulon facility. The plant also does granulation, drying and packaging, and contract manufacturing of antibiotics for other companies.	Zebulon
x		Vaccines	Huvepharma Inc.	Huvepharma manufactures Coccidiosis vaccines for in ovo and post-hatch vaccination of poultry.	Maxton
x		Diagnostics Manufacturing	ImmunoReagents Inc.	ImmunoReagents manufactures primary and secondary polyclonal antibodies used in research and in vitro diagnostics for the pharmaceutical and veterinary markets.	Raleigh
	x	Pharma Ingredients	Ingredion Inc.	Ingredion manufactures ingredients for foods, beverages and drugs from corn, tapioca, wheat and potatoes.	Winston-Salem

Direct	Adjacent	Sector	Biopharmaceutical Manufacturing	Focus	Location
	x	Contract Pharma Production	KBI Biopharma Inc.	KBI Biopharma offers contract development and biopharmaceutical manufacturing services such as formulation, analytical method development, stability services, process development and recombinant protein API manufacturing. This site is KBI's headquarters.	Durham
	x	Contract Pharma Production	KBI Biopharma Inc. (Process Development Facility)	KBI Biopharma offers contract development and biopharmaceutical manufacturing services. This site is KBI's process development facility.	Research Triangle Park
	x	Pharma Ingredients	Lonza RTP	Lonza provides bioscience products and services ranging from cell culture and discovery technologies for research to quality control tests and software that ensures product quality. Its RTP site produces hepatocytes for use in drug research.	Morrisville
	x	Biopharmaceutical Production	Mallinckrodt Pharmaceuticals	Mallinckrodt manufactures acetaminophen, the active ingredient in Tylenol, at its pharmaceutical facility in Raleigh.	Raleigh
	x	Biopharmaceutical Production	Mayne Pharma USA (Greenville)	Mayne Pharma manufactures branded and generic oral solid dose pharmaceuticals. The Greenville site is Mayne Pharma's U.S. development and manufacturing facility.	Greenville
	x	Vaccines	Medicago USA Inc.	Medicago develops vaccines based on proprietary manufacturing technologies and virus-like particles. The vaccines are manufactured using a transient protein expression system in <i>Nicotiana benthamiana</i> , a close relative of tobacco.	Durham
	x	Diagnostics Manufacturing	MEDTOX Diagnostics Inc.	MEDTOX Diagnostics manufactures and distributes instant drugs of abuse testing devices for use by the government, hospital and medical centers and workplace markets.	Burlington
	x	Vaccines	Merck & Co. Inc.	Merck manufactures elements of Varivax, a chicken pox vaccine, and other vaccine products at its Durham facility.	Durham
	x	Biopharmaceutical Production	Merck & Co. Inc. (Wilson)	Merck's Wilson facility produces patented prescription products and performs granulation and tableting operations.	Wilson

Direct	Adjacent	Sector	Biopharmaceutical Manufacturing	Focus	Location
	x	Pharma Ingredients	Nitta Gelatin NA Inc. (Fayetteville)	Nitta Gelatin's Fayetteville plant produces 3,000 tons of pharmaceutical and food-grade gelatins per year. Nitta Gelatin provides many different grades of gelatin for a variety of uses in the pharmaceutical industry.	Fayetteville
	x	Contract Pharma Production	Novex Innovations LLC	Novex Innovations is a contract development and manufacturing organization (CDMO) supporting small and startup life science companies in the development of their products, from concept through manufacturing and commercialization.	Winston-Salem
x		Enzymes	Novozymes North America Inc.	Novozymes researches, develops and manufactures enzymes, microorganisms and biopharmaceutical ingredients used in industries including agriculture, baking, biofuels, brewing, detergents, food, feed and textiles. The Franklinton site manufactures enzymes.	Franklinton
	x	Nutraceuticals	Nutra-Pharma Manufacturing Corp. of N.C.	Nutra-Pharma manufactures vitamins, supplements and other wellness products.	Lexington
	x	Contract Pharma Production	Pfizer Inc. (Rocky Mount)	Pfizer's Rocky Mount facility manufactures injectable hospital products. The facility also provides contract manufacturing services such as aseptic filling, lyophilization and terminal sterilization.	Rocky Mount
	x	Vaccines	Pfizer Inc. (Sanford)	Pfizer's Sanford facility manufactures clinical trial and commercial drug substance materials for conjugate vaccines.	Sanford
	x	Contract Pharma Production	PharmAgra Labs Inc.	PharmAgra Labs conducts contract research and development in organic chemistry for industries including pharma/biotech and electronics. PharmAgra also offers cGMP services including clinical trial materials supply and low-volume API manufacturing.	Brevard
	x	Pharma Ingredients	Pisgah Labs Inc.	Pisgah Labs manufactures active pharmaceutical ingredients on a contract basis. Pisgah Labs' cGMP facility includes an aseptic manufacturing suite.	Pisgah Forest
x		Gene Editing	Precision BioSciences Inc.	Precision BioSciences utilizes a proprietary genome editing method called ARCUS to treat cancers and genetic diseases, and enable the development of safer, more productive food sources.	Durham

Direct	Adjacent	Sector	Biopharmaceutical Manufacturing	Focus	Location
	x	Gene Editing	Precision Biosciences Manufacturing Center for Advanced Therapeutics	Precision BioSciences utilizes a proprietary genome editing method called ARCUS to treat cancers and genetic diseases. The MCAT facility produces genome-edited, off-the-shelf CAR T-cell therapy products.	Research Triangle Park
	x	Biopharmaceutical Production	Prinston Laboratories	Prinston Laboratories manufactures generic pharmaceuticals.	Charlotte
	x	Biopharmaceutical Production	Procter & Gamble	Procter and Gamble manufactures Vicks and other over-the-counter products at this facility.	Greensboro
	x	Biopharmaceutical Production	Purdue Pharma Manufacturing LP	Purdue Pharma develops and provides prescription medicines for the treatment of pain. The Durham location is an oral solid dosage manufacturing plant.	Durham
	x	Biopharmaceutical Production	Purdue Pharmaceuticals LP	Purdue Pharma develops and provides prescription medicines for the treatment of pain. The Wilson plant manufactures, packages and distributes oral solid-dose tablets and is the company's distribution center for prescription products.	Wilson
	x	Pharma Ingredients	Qualicaps Inc.	Qualicaps manufactures empty two-piece capsules (gelatin and hypromellose) and encapsulation equipment under cGMP regulations for use by pharmaceutical, OTC and dietary-supplement manufacturers.	Whitsett
	x	Contract Pharma Production	Relion Manufacturing Inc.	Relion Manufacturing provides contract manufacturing and packaging services for the pharmaceutical, medical device and personal care industries.	Asheville
	x	Biopharmaceutical Production	Sagent Pharmaceuticals	Sagent Pharmaceuticals develops, manufactures, packages and markets pharmaceutical products with an emphasis on injectables. Its Raleigh site produces sterile injectables and lyophilized formulations of biosimilars.	Raleigh
	x	Biopharmaceutical Production	Sandoz Inc., a Novartis Division	Sandoz, a Novartis division, develops generic and biosimilar medicines. Its facility in Wilson manufactures oral-dosage generic pharmaceuticals.	Wilson
	x	Vaccines	Seqirus, a CSL Company	Seqirus manufactures influenza vaccines using both egg-based and cell-based technologies.	Holly Springs

Direct	Adjacent	Sector	Biopharmaceutical Manufacturing	Focus	Location
	x	Diagnostics Manufacturing	Southcot Inc.	Southcot prepares biological agents for the detection of tissue hypoxia at the cell level in normal and malignant tissues.	Research Triangle Park
x		Immunotherapeutics	Stallergenes Greer	Stallergenes Greer develops and distributes animal and human allergy immunotherapy products and services.	Lenoir
	x	Vaccines	Takeda Vaccines Inc.	Takeda's Vaccine Business Unit develops vaccines, including norovirus, dengue and seasonal influenza candidate vaccines. The Morrisville location is a manufacturing site.	Morrisville
	x	Contract Pharma Production	Tergus Pharma LLC	Tergus Pharma provides topical and semi-solid development, formulation, analysis and testing services, with expertise in IVRT method development. The company has cGMP manufacturing, phase one through four clinical supplies and logistics capabilities.	Durham
	x	Contract Pharma Production	Thermo Fisher Scientific (Durham)	Thermo Fisher's Pharma Services Division offers drug development and manufacturing. The Durham site provides contract development and manufacturing services for solid and sterile dosage forms, including small-molecule API and biologic drug substances.	Durham
	x	Contract Pharma Production	Thermo Fisher Scientific (Greenville)	Thermo Fisher's Pharma Services Division offers drug development and manufacturing. Its Greenville site manufactures sterile injectables, tablets and capsules. It also offers stability storage and testing, and API and large-molecule development.	Greenville
	x	Contract Pharma Production	Thermo Fisher Scientific (High Point)	Thermo Fisher's Pharma Services Division offers drug development and manufacturing. The company's site in High Point manufactures soft gel capsules.	High Point
	x	Contract Pharma Production	Triangle Compounding Pharmacy	Triangle Compounding Pharmacy is a PCAB-accredited pharmacy, specializing in compounding sterile and non-sterile preparations of study medications, in varied formulations, for individual patients and clinical trials.	Cary
	x	Biopharmaceutical Production	United Therapeutics Corp.	United Therapeutics develops and commercializes products to treat cardiopulmonary diseases, infectious diseases and cancer.	Research Triangle Park

Direct	Adjacent	Sector	Biopharmaceutical Manufacturing	Focus	Location
x		Vaccines	Zoetis Inc.	Zoetis develops and manufactures vaccines and medications for animal health. The Durham, NC site develops and manufactures high-throughput automation biodevices for the poultry industry, including in ovo vaccination technology.	Durham

5. COMPANIES CLASSIFIED BY NC BIOTECHNOLOGY CENTER IN DIAGNOSTICS

Direct	Adjacent	Sector	Diagnostics	Focus	Location
	x	Diagnostics - ID	3i-Nano	3i Nano develops point-of-care devices for disease diagnostics and protein detection.	Greensboro
	x	Diagnostics	AccuGenomics Inc.	AccuGenomics develops and provides gene expression tests to diagnose and monitor cancer treatment. Its technologies include Standardized Nucleic Acid Quantification for quantitative PCR and Standardized RNA Sequencing for NGS platform analysis.	Wilmington
x		Diagnostics - ID	Advanced Animal Diagnostics Inc.	Advanced Animal Diagnostics (AAD) develops and commercializes diagnostics to detect and manage disease states, reproductive, nutritional and overall health status of production animals.	Morrisville
	x	Diagnostics	Aestas Pharma Inc.	Aestas Pharma develops novel diagnostic imaging and disease-modifying therapeutic agents to enable the early treatment and reversal of Alzheimer's and Parkinson's disease when clinical signs are not yet pronounced.	Lewisville
	x	Diagnostics	Affinergy LLC	Affinergy develops peptide-based technologies, including diagnostic products, research tools and therapeutic drug monitoring products for use by clinicians and researchers.	Morrisville
	x	Diagnostics	Alderon BioSciences Inc.	Alderon Biosciences develops point-of-care diagnostics.	Beaufort
	x	Diagnostics	Almac Diagnostics LLC	Almac offers services for biomarker discovery, assay development/validation/testing and companion diagnostic co-development. Testing platforms include NGS, Microarray, qPCR and IHC. Regulatory and bioinformatics services are also available.	Durham

Direct	Adjacent	Sector	Diagnostics	Focus	Location
x		Diagnostics	Antech Diagnostics Inc.	Antech Diagnostics provides clinical and veterinary hematology analysis, clinical chemistry, urinalysis and coagulation testing.	Morrisville
x		Diagnostics	Appealing Products Inc.	Appealing Products develops products for forensics and personal protection from toxic materials such as inorganics, gases and poisons in foods, animal feeds and liquids.	Raleigh
	x	Diagnostics - ID	Avioq Inc.	Avioq develops and manufactures FDA-approved and CE-marked immunodiagnostic assays. Products include HIV and HTLV assays, recombinant proteins and synthetic peptides and labware supplies. Avioq also offers contract IVD development and manufacturing.	Research Triangle Park
	x	Diagnostics	Baebies Inc.	Baebies develops and delivers products and services based on digital microfluidics and other technology to advance newborn screening and pediatric testing worldwide.	Durham
	x	Diagnostics	BD Diagnostics (Durham)	BD Diagnostics develops and commercializes molecular diagnostic products for various cancers, including cervical, breast, ovarian and prostate.	Durham
	x	Diagnostics	BD Diagnostics (Mebane)	BD Diagnostics develops and commercializes molecular diagnostic products for women's health and various cancers.	Mebane
	x	Diagnostics	BD Technologies and Innovation	BD Technologies and Innovation develops technologies for parenteral drug delivery, advanced diagnostics, smart medical devices, genomic research and supports external innovation. The RTP site is BD's corporate technology R&D and innovation center.	Research Triangle Park
	x	Diagnostics	Biofluidica Inc.	Biofluidica is developing novel instrumentation for the isolation and analysis of circulating biomarkers, including circulating tumor cells, in cancer patients.	Research Triangle Park
	x	Diagnostics - ID	BioMedomics Inc.	BioMedomics develops point-of-care (POC) diagnostics, with a focus on immunologically-based disease-specific tests and advanced quantitative POC platforms.	Durham
x		Diagnostics - ID	bioMérieux Inc.	bioMérieux develops in vitro products to diagnose infectious diseases, cancer and cardiovascular disease and to detect microorganisms in agri-foods, pharmaceuticals and cosmetics.	Durham

Direct	Adjacent	Sector	Diagnostics	Focus	Location
	x	Diagnostics	BioZyme Inc.	BioZyme develops and sells substrates for metalloproteinases (MMPs and ADAMs) which can be used in enzyme assays and other diagnostic tests.	Apex
	x	Diagnostics	Cancer Genetics Inc.	Cancer Genetics offers diagnostic products and services that enable precision medicine in the field of oncology. This site performs clinical pharmacogenomic testing and provides biorepository services under federally-designated clinical lab standards.	Morrisville
	x	Diagnostics	Cellex Inc.	Cellex develops, manufactures and markets diagnostic tests suitable for point-of-care use. These tests use a platform technology called Homogeneous Biochemiluminescence Assay (HBA), which enables assays that are highly sensitive and easy-to-use.	Research Triangle Park
	x	Diagnostics	CellSolutions LLC	CellSolutions develops liquid-based preparation and evaluation systems for cytology applications. The company's primary area of focus is women's health, including cervical cancer screening, precancer detection and evaluation of infectious disease.	Greensboro
	x	Diagnostics	Circassia	Circassia develops and markets products to aid in the diagnosis and control of asthma, COPD and allergy.	Morrisville
	x	Diagnostics - ID	Clinical Sensors Inc.	Clinical Sensors (CSI) develops a near-patient test for early detection of sepsis based on nitric oxide measurements from unprocessed blood.	Research Triangle Park
	x	Diagnostics	Countervail Corp.	Countervail develops and commercializes products to diagnose, protect against and treat exposure to chemical weapons and pesticide poisoning.	Charlotte
	x	Diagnostics	Covance Inc. (Morrisville)	Covance, LabCorp's contract drug development arm, develops companion diagnostics at this lab.	Morrisville
	x	Diagnostics	Eastwood Pharmaceutical Consulting LLC	EPC provides consulting and product development services for pharmaceuticals, devices, diagnostics and other health technologies. The company's priority is to maximize efficiency of the development process by eliminating unnecessary expense or work.	Wilmington

Direct	Adjacent	Sector	Diagnostics	Focus	Location
	x	Diagnostics - ID	Endacea Diagnostics Inc.	Endacea Diagnostics is developing EndaTox IVD, an in vitro sepsis diagnostic, and EndaTox Test, an assay to measure LPS endotoxin in biological and non-biological samples.	Research Triangle Park
	x	Diagnostics - ID	f(x) Immune Diagnostics Inc.	f(x) Immune Diagnostics provides advanced testing services to developers of immuno-therapeutics and vaccines using its proprietary technologies. The company's pipeline includes related clinical diagnostics, point-of-care and companion assays and systems.	Candler
	x	Diagnostics - ID	Foenestra Corp.	Foenestra is developing a diagnostic device based on proprietary solid-state nanopore technology that enables point-of-care detection of pathogens.	Winston-Salem
	x	Diagnostics	Foundation Medicine Inc.	Foundation Medicine develops and provides clinical assays that provide a comprehensive genomic profile to identify molecular alterations in a patient's cancer and match them with targeted therapies and clinical trials.	Morrisville
x		Diagnostics - ID	Galaxy Diagnostics Inc.	Galaxy Diagnostics develops assays and provides molecular and serology testing for flea- and tick-borne infectious disease for physicians, veterinarians and clinical research.	Morrisville
	x	Diagnostics	GeneCentric Therapeutics Inc.	GeneCentric Diagnostics develops molecular diagnostic assays to enable oncologists and their patients to make informed, individualized treatment decisions.	Research Triangle Park
	x	Diagnostics	Genetron Health Technologies Inc.	Genetron Health Technologies provides mutation detection assays using its liquid biopsy platform, as well as various genetic assays to support both clinical and basic research. Genetron also offers custom assay development.	Research Triangle Park
	x	Diagnostics	Genome Insights LLC	Genome Insights provides microbiota analysis kits and analyzes samples for health care providers.	Hillsborough
	x	Diagnostics	Genova Diagnostics Inc.	Genova Diagnostics performs diagnostics and molecular genetics testing under federally-designated clinical lab standards to support physicians in personalized chronic disease treatment and prevention.	Asheville

Direct	Adjacent	Sector	Diagnostics	Focus	Location
	x	Diagnostics - ID	Global Lyme Diagnostics LLC	Global Lyme Diagnostics develops and provides diagnostic solutions specific to Lyme Disease, with the goal of decreasing the number of patients being mis- or undiagnosed.	Research Triangle Park
x		Diagnostics - ID	GTCAllison LLC	GTCAllison researches and develops diagnostic tests for animal pathogens.	Mocksville
	x	Diagnostics	Hemoglobin Diagnostics LLC	Hemoglobin Diagnostics develops diagnostic tests for clinically relevant hemoglobin variants for use in screening, confirmations and point-of-care facilities.	Research Triangle Park
	x	Diagnostics	HemoSonics LLC	HemoSonics is developing an in vitro diagnostic platform that measures the evolving stiffness of forming blood clots within a consumable test cartridge. Its technology assists with the management of coagulation dysfunctions at the point of care.	Durham
x		Diagnostics	HIPRA Scientific USA LLC	Hipra researches and develops vaccines, diagnostics and pharmaceuticals for animal health.	Raleigh
x		Diagnostics	IDEXX Reference Laboratories Inc.	IDEXX Laboratories provides animal health diagnostic products and services for use in small animals, equine, poultry and dairy livestock. It also provides microbiology-based water testing products.	Greensboro
	x	Food Allergy Diagnostics	Immufood LLC	Immufood tests for IgG food allergies, and provides recommended recipes tailored to test results.	Fuquay-Varina
	x	Diagnostics	Indexus Biomedical LLC	Indexus Biomedical designs, develops and manufactures instrument systems, reagents and assays for in vitro diagnostics, initially focusing on the hematology and immunology markets.	Morrisville
	x	Diagnostics	Inivata Inc.	Inivata develops a noninvasive liquid biopsy diagnostic using the precision of circulating tumor DNA (ctDNA) analysis for improving cancer detection and assessing individual response to treatment.	Research Triangle Park
	x	Diagnostics - ID	Jericho Sciences LLC	Jericho Sciences is developing antiviral therapeutics and corresponding personalized diagnostics for the clinical management of HIV-1 infection.	Research Triangle Park

Direct	Adjacent	Sector	Diagnostics	Focus	Location
	x	Diagnostics	Johnson and Johnson Vision	Johnson & Johnson Vision's TearScience division develops and markets technologies to improve the identification, diagnosis and treatment of Meibomian Gland Dysfunction.	Morrisville
	x	Metabolomics	Juno Metabolomics LLC	Juno Metabolomics is developing next-generation metabolomics for precision medicine.	Chapel Hill
	x	Diagnostics	Metabolon Inc.	Metabolon is advancing the science of metabolomics for the clinic and life sciences research. Its technology and data are used for biomarker discovery, diagnostic test development, and genomics and population health initiatives.	Morrisville
	x	Diagnostics	MLSC Inc.	MLSC provides a variety of home health and point-of-care laboratory testing kits online, via their online businesses Home Health Testing and POC Test Supply.	Wilmington
	x	Diagnostics	MoyoMedical Technologies Inc.	MoyoMedical develops home-based early detection tests for pregnancy complications like preeclampsia and eclampsia for use in low-resource settings.	Chapel Hill
	x	Diagnostics - ID	NanoDiagnostic Technology LLC	Nanodiagnostic Technology develops nanotechnology-based portable analytical devices for onsite rapid and sensitive detection of toxic chemical exposure and diseases at the point of care.	Charlotte
	x	Diagnostics	NIRvana Sciences Inc.	NIRvana Sciences is commercializing red and near-infrared fluorescent dyes for use in diagnostics and imaging applications.	Research Triangle Park
	x	Diagnostics	Olfaxis LLC	Olfaxis is developing a system for assessing the human olfactory system's odor detection ability as an indicator of cognitive impairments and other health conditions.	Morrisville
	x	Diagnostics	OncoTAB Inc.	OncoTAB develops and commercializes diagnostic blood tests designed to detect breast cancer and develops an immunotherapy for the treatment of pancreatic cancer.	Charlotte
	x	Diagnostics	Path BioAnalytics Inc.	Path BioAnalytics develops rheological assays for testing trans-mucosal drug delivery systems, mucolytic compounds, inhaled medications for respiratory diseases, antimicrobials and treatments for diseases that impact the body's mucosal layers.	Chapel Hill

Direct	Adjacent	Sector	Diagnostics	Focus	Location
	x	Diagnostics	Qatch Technologies LLC	Qatch Technologies develops microfluidic sensor technology to measure blood coagulation in point-of-care diagnostic tests.	Durham
	x	Diagnostics	Sanesco International Inc.	Sanesco develops clinical tools for healthcare providers, such as neuroendocrine analytical testing, nutritional support formulas and patient-centered clinical review. The NeuroLab division conducts research and development of in vitro diagnostic tools.	Asheville
	x	Diagnostics	Sciteck Inc.	Sciteck provides forensic drug testing services and diagnostic products. Sciteck develops, manufactures and sells products for biotechnology, urinalysis, clinical chemistry, toxicology, pharmaceuticals, treatment and safety applications.	Fletcher
	x	Diagnostics	SenGenix Inc.	SenGenix develops point-of-care blood diagnostic tests using bioengineered fluorescently-responsive sensors. Testing is done with a finger stick, and results are available immediately.	Durham
	x	Diagnostics	Sentinel Biomedical Inc.	Sentinel Biomedical develops and offers molecular diagnostics for the detection and monitoring of canine cancers. Sentinel also offers CRO services in the areas of molecular biology and genomics.	Raleigh
	x	Diagnostics - ID	Spin-Darc LLC	Spin-Darc is developing a rapid digital microbiology testing device usable at point-of-care or in low-resource settings. Applications include infectious disease diagnostics, food testing and water testing.	Raleigh
x		Allergy Immunotherapy	Stallergenes Greer	Stallergenes Greer develops and distributes animal and human allergy immunotherapy products and services.	Lenoir
	x	Diagnostics	Synapse Biosciences LLC	Synapse Biosciences develops biomarker preparations and customized assays for the diagnostic determination of medication compliance. Synapse also provides diagnostic testing services and reporting for medication compliance in clinical trials.	Raleigh
	x	Diagnostics - ID	Vero Diagnostics LLC	Vero Diagnostics offers tick-borne infectious disease testing, including its proprietary lab developed test.	Research Triangle Park
	x	Diagnostics	Xenobiotic Detection Systems International Inc.	Xenobiotic Detection Systems offers patented bioassays to facilitate assessment of environmental and human health risks.	Durham

Direct	Adjacent	Sector	Diagnostics	Focus	Location
	x	Diagnostics	Zenalux Biomedical Inc.	Zenalux Biomedical uses biophotonics to develop diagnostic tools, including an optical system for the clinical detection of cancer.	Durham
	x	Diagnostics	Zymeron Corporation	Zymeron researches and develops nanomaterials and polymer-based biomaterials with applications in in vitro diagnostics, sample collection and drug delivery and formulation.	Research Triangle Park

6. COMPANIES/ORGANIZATIONS OF POTENTIAL RELEVANCE TO FAI LOCATED AT THE NC STATE CENTENNIAL CAMPUS

Direct	Adjacent	Sector	At Centennial - Of Potential Relevance	Focus	Location
	x	Smart Tech	ABB Inc.	ABB is a leader in power and automation technologies that enable utility and industry customers to improve performance while lowering environmental impact.	Venture I
	x	Smart tech	ABB Smart Grid Center for Excellence	ABB Substation Automation Systems Group engineers, integrates, assembles and tests protection relay devices that are a key component of the smart grid.	Poulton Innovation Center
	x	Gene Therapy	Adrenas Therapeutics Inc.	Adrenas Therapeutics is developing a gene therapy for the treatment of a monogenic disease that presents in childhood.	Partners II
x		Antibiotics & Antimicrobials	Agile Sciences	Agile Sciences is a Delaware corporation headquartered in Raleigh, North Carolina. The company was founded in 2007 by Professors Christian Melander and John Cavanagh of North Carolina State University (NCSU) to provide commercial solutions to those industries plagued by the effects of biofilms. Agile Sciences has developed compounds that can disperse colonies of bacteria called biofilms. These compounds have applications in the areas of medicine, agriculture, and industry.	Keystone Science Center
	x	IT	Amphenol Broadband Solutions	All Systems Broadband is a leading North American manufacturer and supplier of central office and customer premise connectivity products.	Keystone Science Center

Direct	Adjacent	Sector	At Centennial - Of Potential Relevance	Focus	Location
	x	IT	Baron Advanced Meteorological Systems (BAMS)	Baron Advanced Meteorological Systems (BAMS) is a team of scientists, mathematicians and engineers dedicated to expanding the frontiers of environmental computing.	Research II
x		Antibiotics & Antimicrobials	Benanova Inc.	Benanova Inc. has developed a cost-efficient, environmentally benign particle system (EbNPs) made of natural materials, which can leverage the functional properties of bioactive agents. This innovative, patent-pending technology can facilitate the development of highly efficient, application-customized and environmentally benign replacements for silver nanoparticle antimicrobials.	Partners II
	x	Infectious Disease Therapeutics	Collaborations Pharmaceuticals, Inc.	Collaborations Pharmaceuticals, Inc. performs research and development on innovative therapeutics for multiple rare and infectious diseases. We partner with academics or companies to identify and translate early preclinical to clinical stage assets.	Partners II
	x	IT	Exostar LLC	Exostar is a leader in identity access management and secure cloud solutions that improve collaboration, information sharing, and supply chain management.	Venture I
	x	Analytics	First Analytics	First Analytics is a professional services firm devoted to Advanced Analytics.	Research IV
	x	Smart Tech	Funxion Wear	Funxion Wear is focused on producing smart textiles, creating clothing with embedded sensors that can measure vitals for personal health and collect other data points as needed.	Partners II
x		Veterinary Medicine	HIPRA	HIPRA is a veterinary pharmaceutical company dedicated to animal health.	Biomedical Partnership Center
	x	IT	IBM Innovation Center	IBM is a global IT product and solutions company.	Research IV
	x	Analytics	InsightFinder	InsightFinder provides machine learning technology, finding root causes for deviations from normal behaviors and recurring patterns, as well as predicting future events and outages.	Partners I

Direct	Adjacent	Sector	At Centennial - Of Potential Relevance	Focus	Location
	x	IT	Juniper Networks	Juniper Networks delivers high-performance IP networking systems built by industry experts with broad experience in high-performance computer and Internet networking applications.	Venture IV
	x	IT	LUMEOVA	LUMEOVA develops innovative opto-electronics modules to meet the growing data communication demands of consumer electronics and wireless infrastructure markets.	Partners I
	x	Biopharmaceuticals	Merck	Merck is a pharmaceutical company that works to create vaccines and drugs that improve people's health.	Venture I
x		Aquaculture	Pentair	Pentair Aquatic Eco-Systems is the global leader in aquatic systems and supplies. Providing unparalleled resources and leading expertise for a variety of industries including: commercial aquaculture and aquaponics, aquatic life support systems, laboratory animal housing, and lake and pond management.	Research IV
	x	IT	Republic Wireless	Republic Wireless is an American mobile service provider that combines fast, nationwide 4G LTE cell service with the power of WiFi to give you better coverage, in more places, for less money.	Venture I
	x	IT	Secmation	Secmation provides engineering, technology and tools to add information security to new and existing products. Specializing in emerging security applications, Secmation's goal is to demystify security design, manage/develop it like any other technology, and keep product teams focused on the success of their product.	Partners I
	x	Diagnostics	Sentinel Biomedical Inc.	Sentinel Biomedical provides canine genetic cancer testing, Genomics, genome mapping and the comparative aspects of canine cancer.	Partners II
x		Animal Science	Smithfield Foods Inc.	Smithfield Foods is the world's largest pork processor and hog producer, committed to providing good food in a responsible way.	Biomedical Partnership Center
	x	Diagnostics	Statera Environmental LLC	Statera offers a unique passive sampling exposure assessment technology that provides an unprecedented comprehensive picture of chemical exposure. Statera also provides related professional services needed to properly design exposure and risk assessment studies, analyze and interpret chemical and toxicological data, and make informed decisions that are scientifically defensible.	Partners II

Direct	Adjacent	Sector	At Centennial - Of Potential Relevance	Focus	Location
x		USDA	USDA-APHIS-Eastern Regional Office	The Administrative Eastern Regional Office of the USDA focuses on plant protection and quarantine, veterinary services, animal care, investigation and enforcement services and wildlife services.	Venture II
	x	USDA	USDA-APHIS-PPQ-CPHST	The Center for Plan Health Science and Technology of the USDA is the scientific support organization for the Plant Protection and Quarantine division of the Animal and Plant Health Inspection Service.	Venture II
x		USDA	USDA-APHIS-PPQ-State Plant Health Directors Office	The Plant Protection and Quarantine (PPQ) division of the USDA safeguards agriculture and natural resources from the risks associated with the entry, establishment, or spread of animal and plant pests and noxious weeds.	Venture II
x		USDA	USDA-APHIS-VS-NC Area Office	This USDA unit helps protects and improves the health, quality and marketability of U.S. animals and animal products.	Venture II
x		USDA	USDA-APHIS-VS-NCIE	The National Center for Import and Export (NCIE) of the USDA plays an integral role in the mission of protecting American agriculture.	Venture II

7. COMPANIES/ORGANIZATIONS OF POTENTIAL RELEVANCE TO INNOVATION AND COMMERCIALIZATION ECOSYSTEM DEVELOPMENT IN FOOD ANIMAL AGRICULTURE

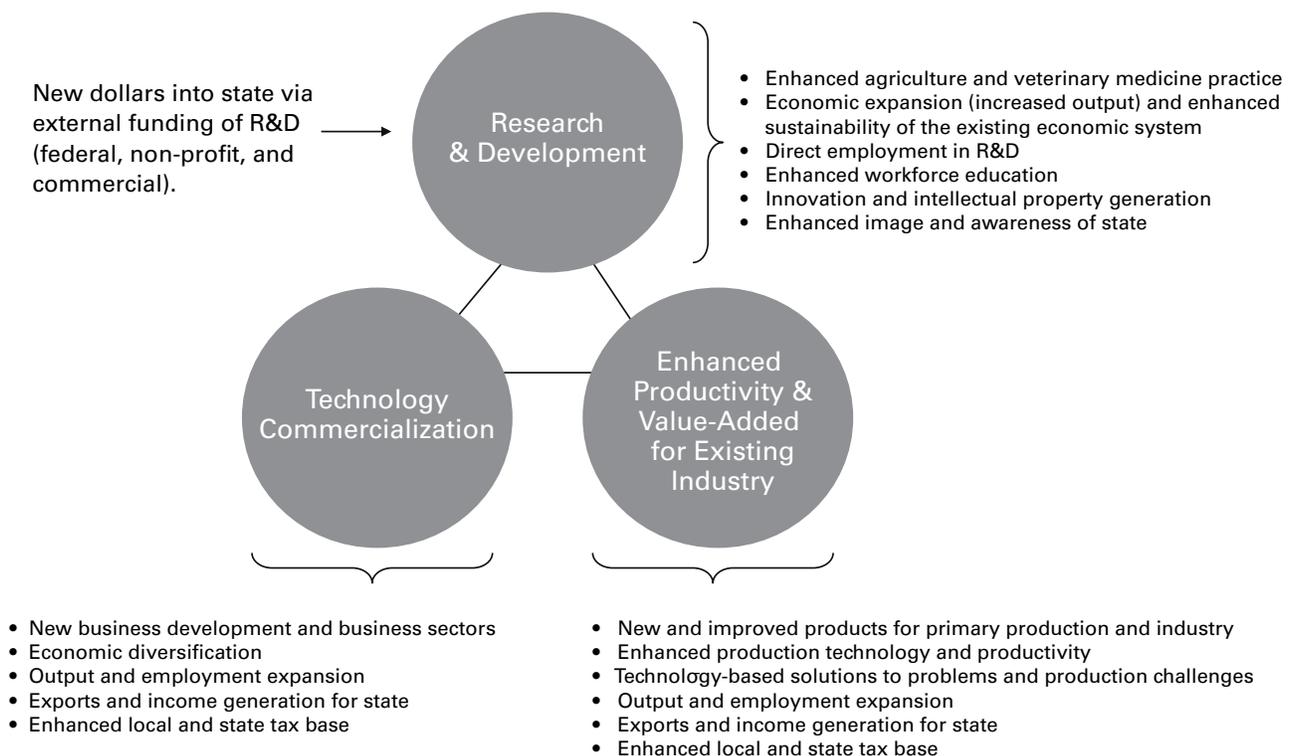
Direct	Adjacent	Sector	Ecosystem Organization	Focus	Location
x		Entrepreneurship & Funding	Ag TechInventures LLC	AgTI develops technologies to form new agricultural spin-offs positioned for acquisition by leading Ag companies.	Durham
x		Entrepreneurship & Funding	AgTech Accelerator Corp.	AgTech Accelerator provides venture funding to early-stage agricultural technology companies.	Durham
x		Entrepreneurship & Funding	Alexandria Center for AgTech- Research Triangle	The Alexandria Center for AgTech is a multi-tenant campus that serves the regional AgTech ecosystem.	Durham

Direct	Adjacent	Sector	Ecosystem Organization	Focus	Location
x		Business Development	Catalyst International LLC	Catalyst International provides market research, brand management and communications, product management, business development and account management within the biotechnology, animal health, nutraceutical, agriculture and dairy industries.	Morrisville
x		Scientific Support	David H. Murdock Research Institute	The David H. Murdock Research Institute (DHMRI) provides collaborators with genomics, proteomics, metabolomics, light microscopy, NMR, clinical chemistry, cellular biology and immunology services. DHMRI focuses on human health, nutrition and agriculture.	Kannapolis
x		Scientific Support	EN-CAS Analytical Laboratories	EN-CAS provides GLP-compliant analytical chemistry contract services for agrochemical, veterinary and bioanalytical research. EN-CAS has experience with preclinical and clinical trials support, pesticides, herbicides and veterinary drugs.	Winston-Salem
x		Nutrition	Eurofins Craft Technologies Inc.	Eurofins Craft Technologies provides analytical and method development services to measure nutritional components in blood, tissues, dietary supplements, food and animal feed.	Wilson
x		Entrepreneurship & Funding	Green Works 2.0 LLC	Green Works 2.0 invests in agtech startups and repurposes industrial property to house its portfolio companies.	Research Triangle Park
x		Business Development	Scullion Strategy Group LLC	Scullion Strategy Group's Life Sciences Division provides consulting services to the animal health and healthcare industries. Services include strategic planning, product marketing, technical development, quality assurance, and commercial operations.	Greensboro
x		Scientific Support	SoBran BioScience	SoBran Bioscience conducts preclinical small and large animal contract research for academic, corporate and government clients. SoBran is GLP-compliant, AAALAC-accredited, OLAW-assured and ISO 9001:2008-certified.	Browns Summit

Appendix D. Potential Economic Impact of the FAI for North Carolina

As noted in Chapter I, there are multiple paths to the generation of economics impacts through major initiatives at research universities. Figure 1 illustrates the major components of impacts likely to be generated through an initiative such as the Food Animal Initiative. Existing industry benefits from the development of R&D based solutions to needs and challenges and the education of a skilled and creative workforce. New industry opportunities are presented through commercialization of new innovations, technologies and production practices developed through university R&D. In addition, the performance of R&D, often supported with federal or other funding from out-of-state sources, itself has a stimulus effect within the economy.

FIGURE 1: PATHWAYS TO FOOD ANIMAL AGBIOSCIENCE, VETERINARY SCIENCE AND TECHNOLOGY-BASED ECONOMIC DEVELOPMENT



In considering the key elements and platforms for the Food Animal Initiative as profiled in previous chapter, it is evident that the initiative will bring economic and functional impacts for North Carolina and North Carolinians as summarized on Table 1:

TABLE 1: PRIMARY FOOD ANIMAL INITIATIVE RECOMMENDED PLATFORMS AND POTENTIAL IMPACT AREAS

FAI Platform	Improved Primary Animal Production	New Products and Innovations for Commercialization	Increased Value-Added Through Downstream Processing	Enhanced Human Health, Safety and Wellbeing
Integrated Systems for Animal Health and Food Safety	<input checked="" type="checkbox"/> Reduced production losses, and increased yield via animal health enhancement	<input checked="" type="checkbox"/> Diagnostics, feed products, therapeutics, vaccines, etc.	<input type="checkbox"/>	<input checked="" type="checkbox"/> Reduction in zoonotic pathogens and associated food safety issues.
Digital Animal Agriculture	<input checked="" type="checkbox"/> Enhanced information to improve production practices and ID challenges at early stage.	<input checked="" type="checkbox"/> Sensors, surveillance and monitoring systems, decision support systems and software	<input checked="" type="checkbox"/> Improved process automation and control, new product innovations	<input checked="" type="checkbox"/> Sensors and surveillance systems to improve food safety, and workplace health and safety.
Protein Innovation	<input type="checkbox"/>	<input checked="" type="checkbox"/> New protein products and processing technology innovations.	<input checked="" type="checkbox"/> Improved process automation and control, new product innovations.	<input checked="" type="checkbox"/> Enhanced food safety and workforce safety.
Food Animal Agriculture Communications	<input checked="" type="checkbox"/> Building and sustaining support for modern production practice implementation and freedom to operate.	<input checked="" type="checkbox"/> Building support and demand for innovative new products and production technologies.	<input checked="" type="checkbox"/> Building and sustaining support for modern processing plant development and freedom to operate.	<input checked="" type="checkbox"/> Building and sustaining support for agricultural products and innovations that meet global demand for safe and nutritious foods.

The Food Animal Initiative, as profiled and structured herein, is designed to achieve meaningful R&D, education and extension-based positive impacts for the food animal agriculture value-chain in the State of North Carolina. While it is unknown what innovations, discoveries, or practice enhancements may occur through the FAI’s research, education and associated activities, it is possible to measure the impact on the North Carolina that could occur through hypothetical increases in food animal agriculture and associated economic activity. TEconomy provides a baseline measure of the impacts that would occur for each one-percent increase in production food animal agriculture and downstream value-added processing of food animal products.

A. Introduction to Impact Measurement

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 commonly 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's food animal industry value-chain 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 food animal industry value-chain company comprise three types of impact:

- **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 food animal agriculture 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 food animal agriculture industry were calculated using the 2017 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 food animal production industries and the associated value-added processing industries in the state. The model incorporates detailed subsectors of the production industry and processing industries and their interrelationships with more than 430 other individual sectors that cover the entire state economy.

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), and **economic output** (the dollar value of sales, goods, and services produced in an economy, which is sometimes referred to as business volume, and represents the typical measure expressed as “economic impact” in a standard economic impact study).

B. Findings from Input/Output Analysis

TEconomy modeled the impact of a one-percent expansion in two value-chain components:

- Production of food animals (farming)
- Food processing (value-added production).

The results are shown on the tables below:

NORTH CAROLINA 1% INCREASE IN FOOD ANIMAL - AG PRODUCTION AND FOOD ANIMAL - FOOD PROCESSING (2019 DOLLARS)

Food Animal - Livestock Production 1% Change

Impact Type	Employment	Labor Income	Value Added	Output
Direct Effect	317.3	\$23,115,795	\$28,750,586	\$80,029,968
Indirect Effect	172.5	\$10,263,098	\$15,908,763	\$41,969,990
Induced Effect	194.8	\$8,645,106	\$15,901,035	\$27,472,522
Total Effect	684.6	\$42,023,999	\$60,560,384	\$149,472,481

Food Animal - Food Processing 1% Change

Impact Type	Employment	Labor Income	Value Added	Output
Direct Effect	338.8	\$15,332,829	\$21,319,755	\$134,259,665
Indirect Effect	430.1	\$27,523,787	\$38,566,736	\$102,523,667
Induced Effect	253.8	\$11,290,708	\$20,760,311	\$35,904,095
Total Effect	1,022.80	\$54,147,323	\$80,646,802	\$272,687,428

Appendix E. Phases for Major University Facility Planning and Development

The following information was provided to TEconomy Partners by colleagues at Flad Architects (the project architects for the Plant Sciences Building at NC State). Flad Architects has deep expertise and considerable experience in planning, designing and construction of advanced research and education facilities for universities and major initiatives. The design and documentation process provided below is what would be expected for an initiative of the size and scope of the Food Animal Initiative.

EXISTING INFORMATION VERIFICATION & PROGRAMMING

Owner Project Kick-Off Meeting with Design Team Participation.

- a. Data Collection
 - i. Gather and review the existing documents, survey information, existing conditions, and other relevant background information.
 - ii. Obtain existing drawings if available.
 - iii. Field verify the existing conditions.
 - iv. Conduct a site analysis and report of existing conditions.
 - v. Analyze the information and prepare an interpretation that will be used to facilitate a user/architect programming workshop meeting.
- b. Kick-off Meeting
 - i. Conduct an interactive meeting and programming confirmation workshop with the designer/Owner core team and stakeholder team.
 - ii. Review project execution plan and schedule.
 - iii. Overview of Program and Objectives.
 - iv. Overview of existing information/site assessment.
 - v. Overview of benchmarking information about similar facilities.
 - vi. Visioning /goals /objectives discussion: identify key adjacencies, operational, maintenance requirements, identify process flow, budget strategy, flexibility requirements, regulatory requirements, sustainability goals, governance issues, etc.
 - vii. Discuss space and aesthetic design principals to develop a common language and vision for the design.
- c. Sustainability Workshop
 - i. Conduct a workshop with key stakeholders to discuss sustainability goals and options.
- d. Program Creation
 - i. Conduct user interviews.
 - ii. Conduct an Owner Facilities group meeting.
 - iii. Review sustainability workshop information and investigate options.

- iv. Review data & workshop information internally.
 - v. Analyze data collected; compare against current Owner standards and agreed upon benchmarks.
 - vi. Tabulate existing facility data, projected staff/research PIs (Principal Investigators), and interdisciplinary information.
 - vii. Assemble data into draft program format.
 - viii. Review draft program and projected staff. Modify as necessary and align with research initiatives.
 - ix. Evaluate regulatory impacts.
 - x. Review research benchmarks discuss programming options.
 - xi. Establish preliminary space typology budget.
- e. f. Site and Systems Review
 - i. Begin site analysis and discuss key issues and proposed approaches.
 - ii. identify adjacencies and site characteristics.
 - iii. Identify/Investigate engineering systems distribution and alternative approaches.
- f. Stakeholder Meeting to Review Program
 - i. Review draft program. Modify as necessary and align with projected research initiatives.
 - ii. Review site information.
 - iii. Review engineering systems distribution and alternative approaches.
 - iv. Review process options.
 - v. Review special requirements, including logistics of shared support/resources.
- g. Internal Refinement and Development
 - i. Refine space needs program and prepare final draft document.
 - ii. Develop adjacency & flow diagrams.

CONCEPTUAL DESIGN

- a. Internal Conceptual Design Development
 - i. Develop conceptual multiple massing and siting options, and description of systems.
 - ii. Develop a conceptual design of the proposed project components.
- b. Stakeholder Meeting to Review Concept and Program
 - i. Review final draft program.
 - ii. Review building siting options & sustainability/LEED.
 - iii. Review multiple massing and site design concept options.
 - iv. Review engineering concept options & greenhouse design options
- c. Internal Refinement and Development
 - i. Refine design concepts into three design options.
 - ii. Develop blocking and stacking diagrams.
 - iii. Review design / material palette options.
 - iv. Refine engineering systems design.
- d. Stakeholder Meeting to Review Finalized Design Concept and Options
 - i. Review final draft program.
 - ii. Review multiple blocking/stacking and design concept options.
- e. Internal Refinement and Development

- i. Refine design concepts into a single option.
 - ii. Create design options for major interior spaces.
 - iii. Modify blocking and stacking diagrams.
 - iv. Refine building systems concept.
 - v. Refine siting and building aesthetic concept.
 - vi. Create concept estimate draft.
- f. Stakeholder Meeting to Review Building Design
- i. Review final building concept and single design option (interior, exterior & site design).
 - ii. Review building systems design.
- g. Internal Refinement and Development
- i. Refine design concept based on meeting comments.
 - ii. Modify blocking and stacking diagrams to match final concept.
 - iii. Refine building systems design.
 - iv. Finalize revisions to program.
- h. Stakeholder Meeting to Review Final Program
- i. Review final program and conceptual design, discuss modifications as needed.
 - ii. Conduct independent meetings with key leadership as required.
- i. Advance Planning Deliverable
- i. Prepare and Submit Final Advance Planning Report and Estimate

OWNER AGENCY REVIEWS

- a. a. Owner/AHJ review
 - i. Provide modifications from Stakeholder review meeting.
 - ii. Print and distribute final draft copies to the Owner.
 - iii. Upload SCO documents.
 - iv. Owner/Design Team review meeting of documentation and sign-off for Schematic Design phase.

SCHEMATIC DESIGN

- a. SD Round 1 User Group Interviews
 - i. Meet with user groups to obtain detailed programming information.
 - ii. Develop initial detailed program draft.
- b. Plan and Design Refinement
 - i. Revise concept design to incorporate comments provided by the Building Committee during the Advance Planning phase.
 - ii. Refine building design concept.
 - iii. Coordinate building MEP systems and concept design/plan.
 - iv. Develop and refine site design concepts.
 - v. Assist CM in developing phasing plan.
- c. Stakeholder Meeting to Review Updated Design Concept
 - i. Review progress of detailed program.
 - ii. Update committee on AP report revisions – high level.
 - iii. Review exterior design and present options for concept aesthetic.

- iv. Review Schematic Design schedule.
- d. Internal development.
 - i. Refine exterior concept and develop floor plan.
 - ii. Develop site plan.
 - iii. Develop special use spaces and relationship strategies.
 - iv. Develop building systems design in coordination with detailed programming information.
 - v. Perform quality assurance design review.
- e. SD Round 2 User Group Interviews
 - i. Meet with user groups for follow-up planning interview information.
 - ii. Refine detailed program draft, space adjacencies, initial concept layouts and create room data sheets.
- f. Stakeholder Meeting to Review Detailed Program
 - i. Present update on refined building program.
 - ii. Review building plan development.
 - iii. Discuss lab/office space and relationship design options.
 - iv. Concept design update.
- g. SD Round 3 User Group Interviews (If Required)
 - i. Meet with user groups to review draft program, preliminary conceptual room configurations and room data information.
 - ii. Refine final program draft.
- h. Internal Refinement and Development.
 - i. Incorporate program developments into building design.
 - ii. Refine plan & design concept based on stakeholder review.
 - iii. Develop site plan and coordinate with building design.
 - iv. Create outline specifications.
 - v. Refine building systems design.
 - vi. Sustainability analysis – update LEED checklist and verify possible points if applicable.
 - vii. Quality Assurance design meeting.
- i. Internal Life Cycle Cost Analysis (LCCA)
 - i. Perform preliminary life cycle cost analysis per SCO requirements.
 - ii. Create energy model.
- j. Stakeholder Meeting to Confirm Design Direction and Present Progress
 - i. Program update.
 - ii. Building design and plan update.
 - iii. Interior design concepts.
 - iv. Building systems update.
 - v. Sustainability update
- k. CM Review, Estimating & Reconciliation.
- l. Internal Refinement and Development.
 - i. Implement modifications from review meeting and chosen path.

- ii. Refine plan concept and prepare schematic design document.
 - iii. Create 3D renderings & physical model of final design if required.
 - iv. Refine building systems design and coordination.
 - v. Refine rough cost (SQ. FT. and infrastructure).
 - vi. Draft LCCA narrative.
 - vii. Conduct quality assurance.
- m. Owner and SCO Schematic Design Review
- i. Prepare document drawing set and presentation to describe the project.
 - ii. Present and participate in Owner review conferences as required.
 - iii. Submit drawing package to the Owner and SCO.
 - iv. Respond to review comments and modify design/documents as required.
- n. Stakeholder Meeting to Present Final Schematic Design
- i. Review history, update from previous sessions.
 - ii. Review Schematic architectural design: exterior and interior.
 - iii. Review basic building systems.
 - iv. Review site design and landscaping concept.
 - v. Review sustainability strategy and provide LEED update.
 - vi. Present Budget and estimates.
 - vii. Outline timeline for QA review process and future phases.
- o. Quality Assurance Document Review
- i. Design team review of document set and Revit model.
 - ii. Flag potential issues for resolution and assign resolutions.
 - iii. Distribute documents to commissioning agent for review.

DESIGN DEVELOPMENT

- a. Development of Building Design.
- i. Provide modifications to design based on feedback from Owner/SCO reviews.
 - ii. Refine building design concept.
 - iii. Coordinate engineering systems with building revisions.
 - iv. Develop site/civil design.
- b. Stakeholder Meeting to Confirm Design Direction
- i. Review updates from Schematic Design.
 - ii. Review exterior building design updates.
 - iii. Review interior design updates.
 - iv. Review sustainability path and LEED update if required.
 - v. Review timelines.
- c. DD Round 1 User Group Meeting
- i. Meet with select user groups to review and obtain additional detailed programming information.
- d. Internal Refinement and Development
- i. Modify design per stakeholder comments.
 - ii. Refine design and prepare design development documents.
 - iii. Update building and wall sections.

- iv. Create enlarged plans of key areas.
 - v. Identify primary building details.
 - vi. Update cost estimate model with CRM and design team estimator.
 - vii. Begin hazardous material assessment per SCO requirements.
- e. Quality Assurance 50% Document Review
- i. Design team review of document set and Revit model.
 - ii. Flag potential issues for resolution and assign resolutions.
- f. Internal Refinement and Development
- i. Make corrections to documentation and design based on QA review.
 - ii. Refine building design.
 - iii. Create detailed building system documents.
 - iv. Develop primary building details.
 - v. Create interior finish plan and material palette.
 - vi. Develop draft outline for early package set.
 - vii. Develop full specifications.
 - viii. Update LCCA narrative.
- g. Stakeholder Meeting to Present Design Update
- i. Review detailed building design development.
 - ii. Review floor plan development.
 - iii. Review finish materials and interior design.
 - iv. Review building mechanical, electrical and plumbing system development.
 - v. Review timelines.
- h. Internal Refinement and Development
- i. Refine building documents.
 - ii. Complete site/civil coordination and draft documents.
 - iii. Complete draft specifications.
 - iv. Update cost estimate.
 - v. Update energy model with alternates per SCO requirements.
- i. Quality Assurance Review of 90% Documents
- i. Design team review of document set and Revit model.
 - ii. Flag potential issues for resolution and assign resolutions.
 - iii. Commissioning agent review.
- j. Owner and State Construction Review of Design Development Package
- i. Complete document drawing set and presentation to describe the project.
 - ii. Present and participate in Owner review conferences as required.
 - iii. Submit schematic design drawing package to Owner and SCO.
 - iv. Respond to review comments and modify design/documents as required.
- k. Stakeholder Signoff to Proceed

CONSTRUCTION DOCUMENTS

- a. Construction Document Development
 - i. Provide modifications to design based on feedback from Owner/SCO reviews.
 - ii. Refine building details, plans, sections and prepare construction documents.
 - iii. Draft furniture design and selection options.
 - iv. Refine building structure and greenhouse design.
 - v. Complete grading/site coordination.
 - vi. Breakout early package specification sections and draft finalized version.
 - vii. Follow-up meeting with code officials as necessary.
 - viii. Conduct follow-up user meetings as necessary to review key design options.

- b. Quality Assurance Review of 30% Construction Documents
 - i. Design team review of document set and Revit model.
 - ii. Flag potential issues for resolution and assign resolutions.

- c. Internal Refinement and Document development.
 - i. Provide modifications from QA meeting.
 - ii. Finalize structural and footing design.
 - iii. Finalize site grading.
 - iv. Complete specifications.
 - v. Complete cost estimate.

- d. Building Committee Meeting to Review CD Progress
 - i. Review design updates.
 - ii. Review draft building renderings.
 - iii. Review furniture selection.
 - iv. Review draft materials pallet selection.
 - v. Review sustainability/LEED if required.
 - vi. Review timelines.

- e. Construction Document 60% Submittal to the Owner & CMR for review.
 - i. Assist CMR in updating cost estimate model.
 - ii. Update design estimate model.

- f. Quality Assurance document review – 60% submission review:
 - i. Design team review of document set and Revit model.
 - ii. Review early bid packages for coordination and completeness.
 - iii. Flag potential issues for resolution and assign resolutions.

- g. Internal refinement and development
 - i. Provide modifications from review meetings.
 - ii. Complete detailing and prepare construction documents.
 - iii. Complete specifications.
 - iv. Update cost estimates.
 - v. Create final building renderings.
 - vi. Furniture selection & interior material selection refinement.

- h. Stakeholder Meeting to Present CD Progress
 - i. Review construction documents with stakeholder group.

- ii. Review final building renderings.
 - iii. Review materials pallet.
 - iv. Review timelines.
 - v. Review updated designer and CMR estimate with stakeholder team.
- i. Internal Refinement and Development
 - i. Complete construction documents.
 - ii. Complete specifications.
 - iii. Finalize cost estimate.
 - j. Quality Assurance Review of 90% Documents
 - i. Design team review of document set and Revit model.
 - ii. Flag potential issues for resolution and assign resolutions.
 - k. Completion of Construction Documents.
 - i. Make revisions based on QA review.
 - ii. Complete documentation set and issue.
 - l. Owner Design Review and State Construction Submittal.
 - i. Provide construction documents to Owner and SCO for internal review process.
 - ii. Modify documents as required and prepare bid set.

PRECONSTRUCTION

- a. Assist the owner in preparing the bid notification and assist in minority bid solicitation.
- b. Attend a Pre-Bid meeting hosted by the Owner.
- c. Prepare and transmit the construction documents to the local code authority for the code review process.
 - i. Respond to the code review comments and amend drawings as required.
- d. Answer contractor questions during the bidding process and issue required Addenda.
- e. Conduct a bid opening in accordance with State Construction guidelines and review bids with owner.

CONSTRUCTION ADMINISTRATION

- a. Attend the pre-construction conference.
- b. Process and approve or take appropriate action in respect to, progress schedules, shop drawings, progress payments and other required submissions of the contractor.
- c. Provide general administration of the performance of the construction contract, including review and liaison of the work to ensure compliance with plans and specifications. The review shall be performed by representatives of the designer's firm bi-weekly while work is in progress; (1) person from Designer and (1) person from respective consultants during the active construction. Site visits are limited as noted in Basic Services, Assumptions and Clarifications below.

- d. Process and approve or take appropriate action in respect of RFI's (Requests for Information) as submitted by the contractor.
- e. Attend regularly scheduled Owner/Architect/Contractor (OAC) monthly meetings for contractors' representatives and a representative of the Owner.
- f. Provide a written monthly report as outlined in the SCO Manual.
- g. Schedule and conduct a final inspection and prepare a punch list of the project, coordinating the date for such inspection.

PROJECT CLOSEOUT DOCUMENTATION

- a. Collect and review contractor's record documentation.
- b. Prepare and submit final report project manual per NC State Construction Manual guidelines
- c. Prepare final stamped as-built drawings per NC State University project closeout guidelines.

