FINAL REPORT

Battelle
The Business of Innovation

OARDC 2004–2008:

Accomplishments and Growth Strategies for Economic Development

Prepared For: Ohio Agricultural Research & Development Center
The Ohio State University

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Highlights

Since 2004, OARDC has been highly proactive in developing new programs, funding streams, infrastructure and relationships that drive progress and expanding economic impacts in Ohio's agbioscience economy.

By focusing on areas of R&D excellence and strategic importance, OARDC has directed its resources in new and innovative ways to generate technology-based economic development for Ohio. Today, OARDC is positioned to focus on three "signature R&D focus areas": Food Security, Production and Human Health; Advanced Bioenergy and Biobased Products; and Environmental Quality and Sustainability. Within these focus areas, multiple R&D centers and collaborative R&D programs have been established—working to progress research from discovery to application and commercialization.

The dynamic work of OARDC in targeting agbioscience growth is paying significant dividends, both for the institution and for the State of Ohio:

- OARDC sponsored research grew 23.2% between 2004 and 2008 (increasing from $19 million in 2004 to $23.4 million in 2008).
- Achieving a 64% growth rate in funding in the applied and commercially oriented "non-federal research funding" category between 2004 and 2008.
- Producing innovations that generated 57 invention reports and 22 patent applications since 2004.

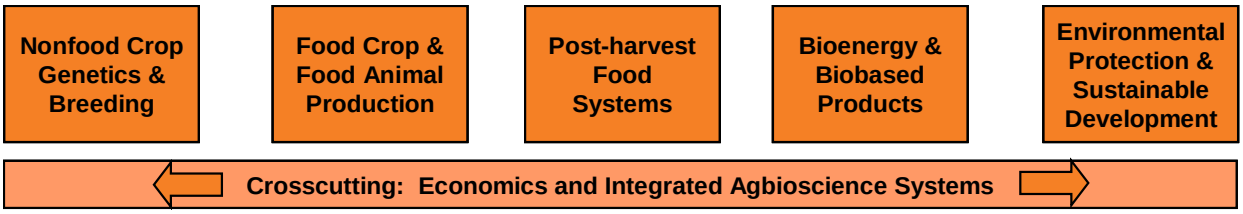
OARDC has also grown its basic expenditure impacts on the State of Ohio. OARDC Ohio spending impacts in FY2008 generated 1,609 jobs; $156.3 million in economic output; $59.2 million in personal income for Ohio residents, and $5.5 million in state and local taxes.

More importantly, OARDC scientific research, innovation and technology development is providing large-scale and widespread functional economic impacts across Ohio—both in terms of the generation of positive impacts (through the development, for example, of high-value crops, bio-based materials and technologies) and significantly reducing negative impacts (such as crop losses or disease impacts).

With over 600 R&D projects performed per year, it is impractical to measure the impact of every project, but some examples serve to illustrate the range of functional impacts being generated:

Generating a potential $22 million savings in the Ohio horticulture industry from biocontrol fungicides versus chemical fungicides.	Development of fundamental growing media technology leading to the growth of the $2.8 billion Ohio nursery industry, employing 96,000 personnel.	Safeguarding poultry and egg production in Ohio via multiple technologies. Securing an $861 million Ohio industry supporting 8,700 jobs.
Reducing Ohio's exposure to $65 million in negative impacts attributable to annual livestock disease losses.	Leading collaborations in the development of a new natural rubber industry for Ohio with projected economic impact of $130 million and 165 jobs.	Sustaining growth in Ohio's $11.1 billion food processing sector via the development of new functional food products, advanced ingredients and packaging technologies.
Protecting Ohio from between $9.3 and $46.6 million in foodborne illness health costs associated with *Salmonella*.	Providing feedstock and process development to drive Ohio's emerging position in the multi-billion dollar biofuels and bio-based products industry segments.	Creating value from waste streams through their conversion into value-added biofuels and bioproducts.

Battelle's reassessment of OARDC's R&D core competencies finds the Center to be well-positioned for future progress in primary agbioscience opportunity areas. OARDC's R&D core competencies segment into five principal technology platforms, and one crosscutting support platform, in which OARDC has significant opportunity to capitalize upon R&D excellence for technology commercialization and economic development:



Each of these core competency-based technology platforms fits well within the OARDC and College's three signature R&D focus area structure.

Moving forward, OARDC is extremely well-positioned to expand its already substantial economic impacts in Ohio. Agbiosciences in the 21st Century *BioEconomy* will be a central driver of economic progress and technology-based economic development for U.S. States. Because of OARDC and the support of multiple stakeholders across the state, Ohio has moved into an early leadership position in supporting agbioscience R&D as driver for economic development.

Executive Summary

The past five years have seen significant growth in public awareness of the economic benefits of agriculture and agbiosciences. In 2004 Battelle found it necessary to explain the direct relevance of agricultural research to a modern 21st century economy, but today there is much greater knowledge of the critical importance of agbiosciences to our economic future. Agbioscience innovations are driving new, high visibility economic opportunities for American states, and the State of Ohio has been an early mover in recognizing the economic development potential of biobased resources.

For Ohio, the foremost in-state driver of agbioscience R&D is The Ohio State University's *Ohio Agricultural Research and Development Center* (OARDC). In 2004, the Battelle Technology Partnership Practice (TPP) undertook a detailed evaluation of the economic impact of OARDC on the State of Ohio finding "*OARDC to be a substantial economic engine for the State of Ohio."* The 2004 analysis showed that OARDC provides a high-return investment for Ohio with impact from OARDC scientific and technological innovations counted in the billions of dollars.

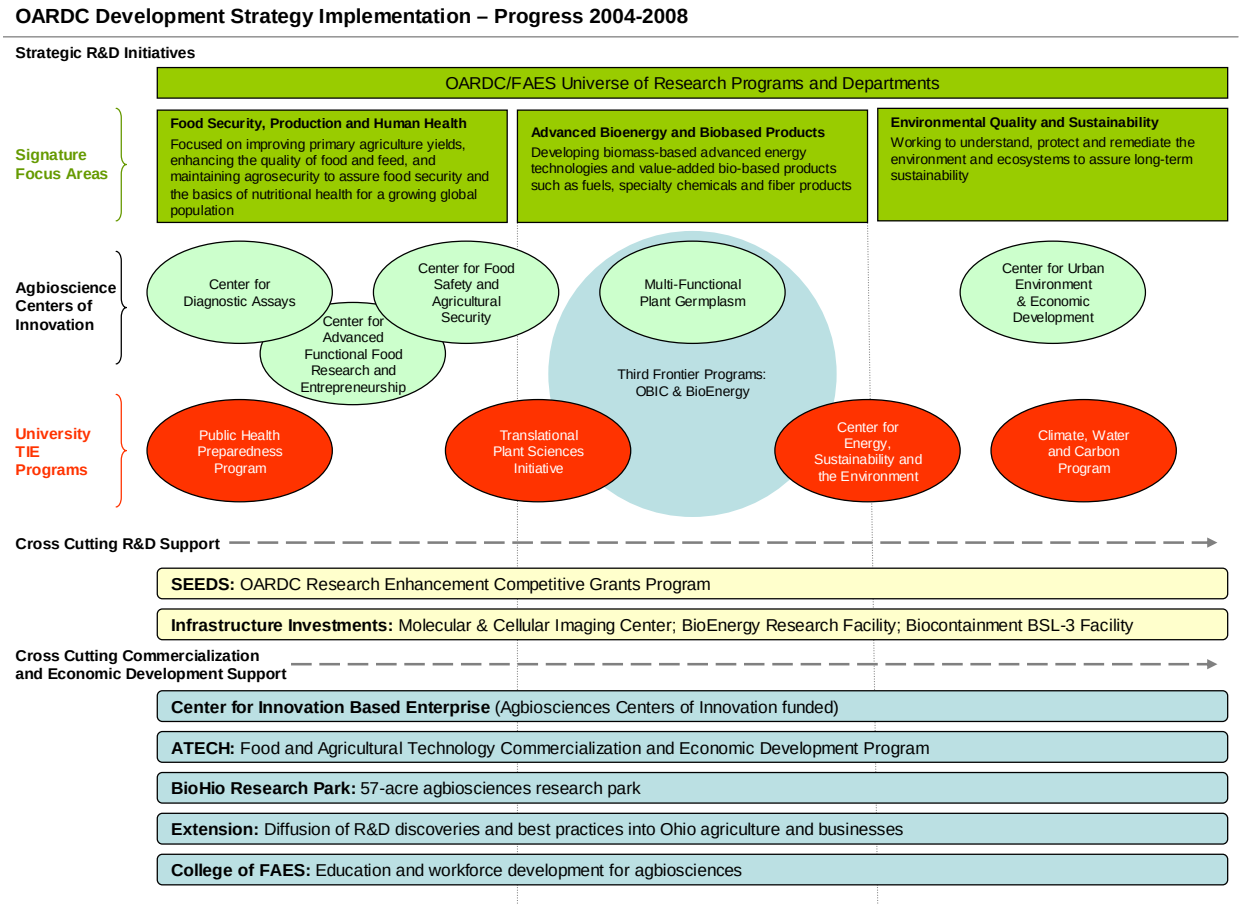
Upon completion of the 2004 impact analysis TPP also conducted a detailed review of the R&D core competencies of the OARDC and identified clusters of research expertise at the Center that could form robust platforms for applied innovation and technology-based economic development. OARDC used Battelle's findings and recommendations to put in place a series of programs and initiatives designed to leverage the Center's identified core competencies and spur technology-based economic development in the state. Now, five years on from the original 2004 evaluation, OARDC has asked TPP to undertake a review of the initiatives and programs that the Center has initiated and evaluate progress being made towards agbiosciences-based economic development in the state. The results of this evaluation are the subject of this report.

OARDC: Implementation of Previous Recommendations and the Generation of Economic Benefits for Ohio

Battelle's 2004 report identified multiple opportunities for OARDC to build-upon its already significant economic benefits for Ohio. In particular, recommendations were made for initiatives that would encourage collaborative academic/industry R&D, early stage investigations of commercial viability for OARDC technologies, and proactive work in bringing new discoveries to the market through business development activities and licensing to Ohio entities.

Evaluation of OARDC today, shows an organization that has taken these recommendations and built upon them. OARDC, in collaboration with the College, the University and key stakeholders (such as the State of Ohio and its Third Frontier Initiative) have made significant organizational and financial commitments—forming a system that boosts R&D capacity in strategically focused areas and seeks to leverage R&D discoveries to build Ohio's agbioscience industry base. As shown in Figure ES-1, OARDC has adopted model centers on three "signature focus areas" plus it has funded distinctive R&D Agbioscience Centers of Innovation within these. OARDC has also leveraged the multi-disciplinary power of the University through participation in OSU Targeted Investments in Excellence (TIE) programs.

Figure ES-1: OARDC Development Strategy Implementation – Progress 2004 through 2008



It is evident that the investments made by OARDC and the University in collaborative R&D centers have been a direct match to the three original platforms recommended in Battelle's 2004 report.

7In addition to strengthening its focused R&D infrastructure, OARDC has also invested in a series of cross-cutting supports for progressing research discoveries towards commercialization. As shown on Figure ES-2, these cross-cutting supports, in combination with the targeted research programs, provide a thorough series of supports across the technology-based economic development (TBED) spectrum.

Taken together, the system that OARDC has put in place provides a continuum of support including:

- Support for early stage basic science investigations in areas with potential signature platform linkages.
- Development of applied R&D programs focused on translating basic science discoveries into practical innovations. This is accomplished with both OARDC solo-developed discoveries, and via sponsored research with industry in jointly targeted areas.
- The testing of applied R&D discoveries for true market potential through scale-up and piloting projects, demonstration projects and market feasibility assessment.

- Transfer of proven viable technologies and intellectual property into commercial application along multiple paths including new start-up business development and licensing of technology to existing agbioscience business enterprises.

Figure ES-2: OARDC Programs in Support of Agbioscience Economic Development Chain

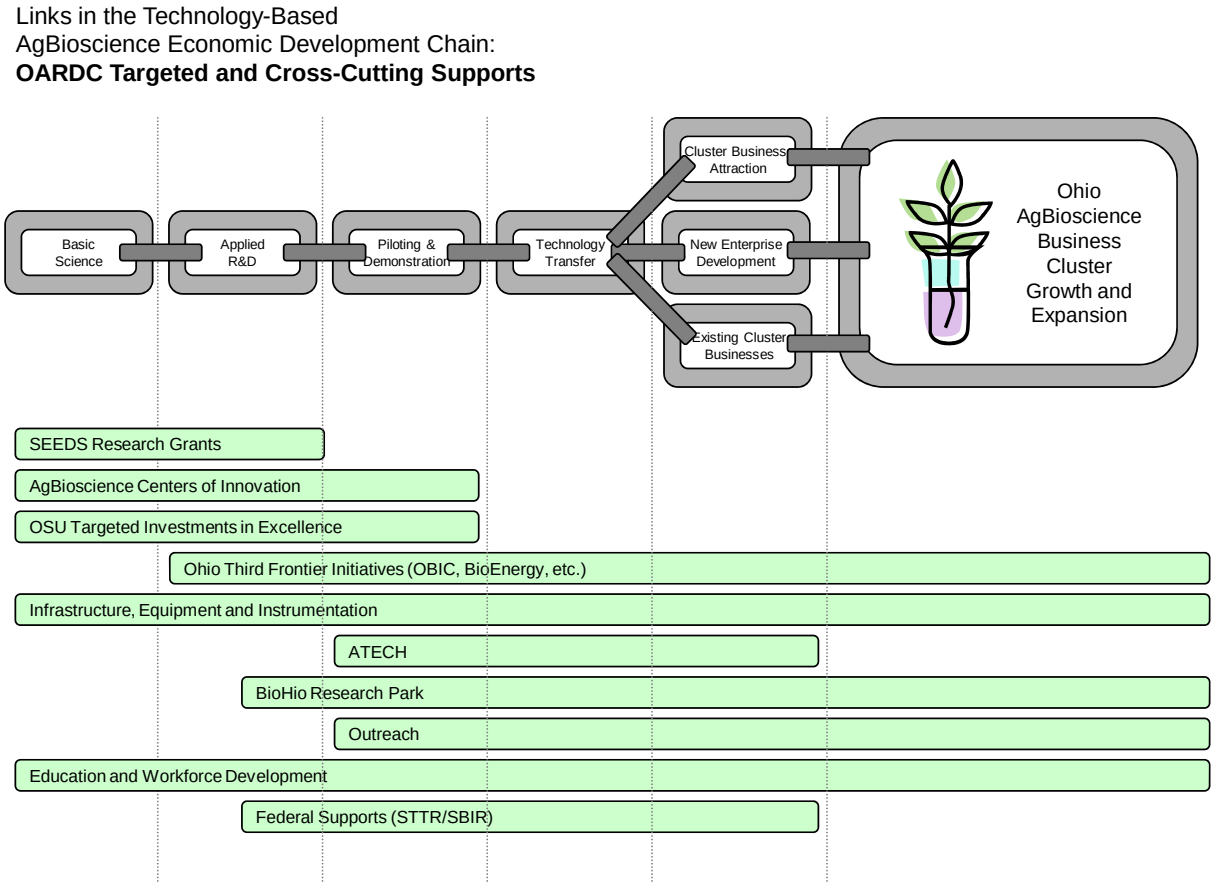
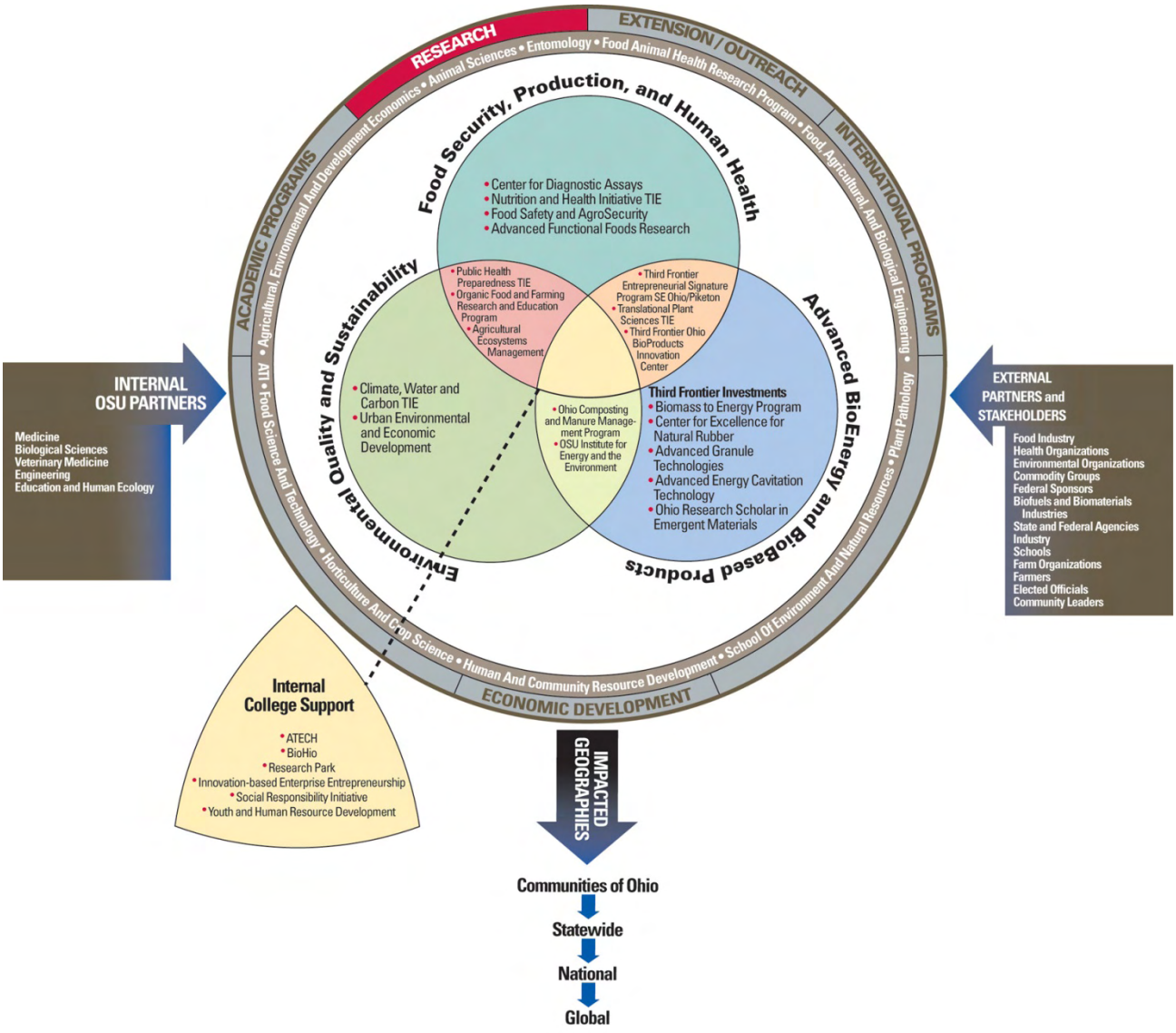


Figure ES-3: OARDC Research Initiatives in the FAES Three Signature Focus Area Model

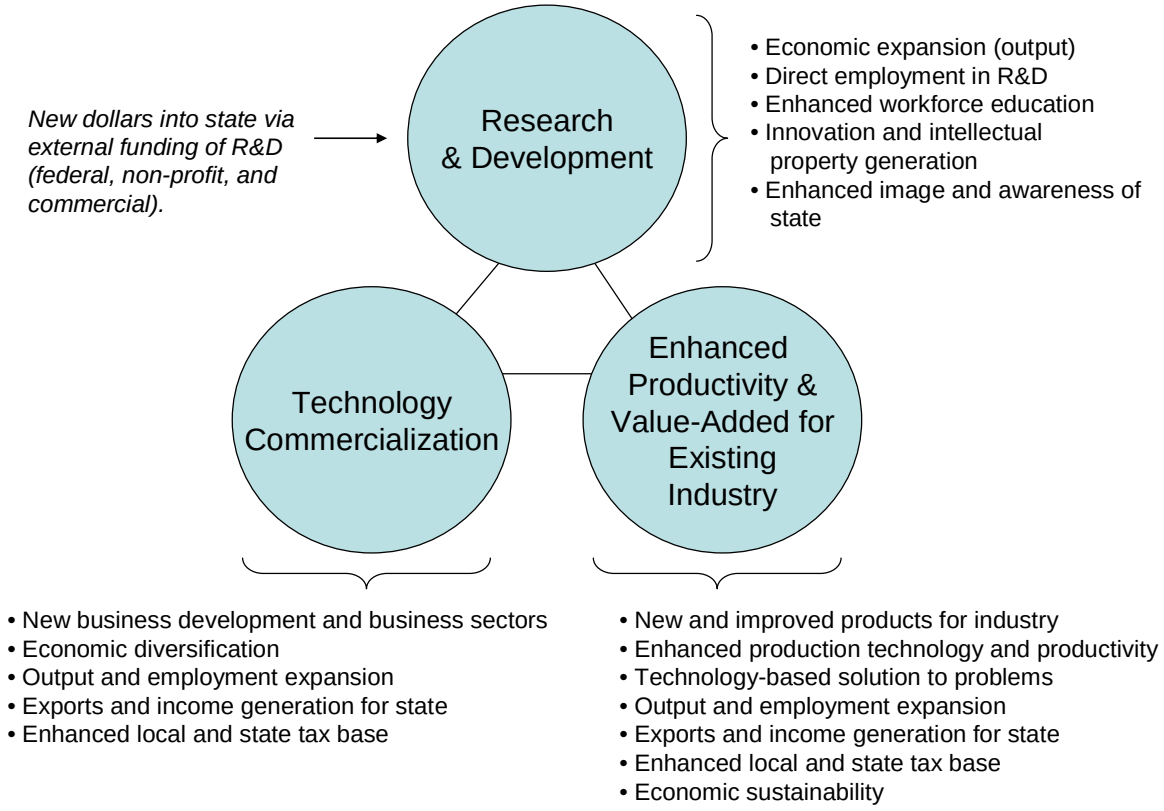


A number of OARDC research programs fall within the intersection of two signature focus areas, indicative of the multidisciplinary nature and broad application of agbioscience innovations to multiple opportunity areas. OARDC is also working to integrate internal OSU partners (in the colleges of Medicine, Veterinary Medicine, and Engineering for example) to bring further multidisciplinary expertise to agbioscience opportunities and applications.

Because of the history of service and collaboration embodied in OARDC and Extension, agbiosciences at OSU also benefit from linkages to many external stakeholders and partners. These external relationships are likely to continue to grow in importance as OARDC focuses on applied and translational research, collaborative research with industry, and the commercialization of innovations to spur technology-based economic development across Ohio.

Technology-based economic development (as shown in Figure ES-4) generates economic benefits along multiple dimensions. Science and technology R&D itself is a major economic sector and benefits from large-scale out-of-state funding in the form of federal, non-profit and commercial funding streams. Academic and associated commercial R&D generates direct jobs and income within Ohio. R&D-based innovations generate opportunities for new business development (in commercializing new innovations and technologies), and enhancements to the existing state economic base through innovations and technologies that enhance productivity or generate new business opportunities for existing industry.

Figure ES-4: Technology-Based Economic Development – Primary Pathways to Ohio Economic Benefits



Growth in Research and Research Outputs

Concentrating on areas of research strength has resulted in growth in OARDC R&D activity. The primary success story for the Center between FY2004 and FY2008 comes via non-federally funded sponsored research. Non-federal research funding totaled $7.6 million in FY2004 and has risen every year since, reaching its current peak in FY2008 with $12.4 million (a 64% increase). Gains in this regard have come through research sponsored by non-profit associations and commodity groups (FY2005 funding = $1.5 million, FY2008 funding = $2.3 million), but most notably through state agency funding which increased from $2.1 million in FY2005 to $5.3 million in FY2008. The state funding increase comes primarily through large scale increases in funding to OARDC by the Ohio Department of Development (ODOD)—which provided less than $0.2 million in FY2005 rising to over $3.3 million in FY2008.

OARDC sponsored research grew 23.2% between 2004 and 2008

2004 = $19 million

2008 = $23.4 million

The major increase in ODOD funding for OARDC research programs testifies to the State of Ohio's recognition of agbiosciences as a major R&D core competency for the state. Specifically, ODOD funding demonstrates that the state recognizes agbiosciences as a principal driver for future economic development in the state and has come forward to fund specific R&D initiatives designed to realize this potential.

In Battelle's opinion, further research growth will be challenging unless faculty numbers at OARDC increase. OARDC's research volume has leveled-off in the last three years—likely indicative of faculty reaching their research capacity limits. With 108 research faculty, the current year $23.4 million in research funding averages to $217,000 per faculty member.

OARDC research, between 2004 and 2008, generated 57 invention reports and 22 patent applications.

The R&D performed by OARDC faculty has resulted in 57 invention reports received by the OSU Office of Research (Technology Licensing and Commercialization) between 2004 and 2008. In turn 22 patent applications have been submitted on these technologies and innovations.

Economic Impacts of OARDC's Institutional Spending

As an operating entity, irrespective of the benefits of its scientific discoveries, the OARDC generates a significant economic impact in the State of Ohio. The Center receives funds from the federal government, extramural funding sources, industry contracts and allocations from the State of Ohio—and it invests these funds in infrastructure, resources and human capital to benefit the state and the agricultural sector. In turn, the expenditures of the OARDC and its faculty and staff within Ohio, in and of themselves, become a significant generator of economic impacts. Analysis by Battelle of the OARDC's direct and indirect expenditure impacts, using input/output analysis, shows that the FY2008 expenditures of OARDC in Ohio generated the following impacts:

- **$156.3 million in total Ohio economic output (sales)**, comprising $78.3 million in direct economic output and $78.0 million in indirect output.

OARDC Ohio Spending Impacts FY2008

1,609 jobs

$156.3 million in economic output

$59.2 million in personal income for Ohio residents

$5.5 million in state and local taxes

- The operations of the OARDC also support **1,609 jobs in Ohio**, comprising 786 direct jobs and a further 823 jobs generated in the Ohio economy via the employment multiplier effect.
- OARDC direct and indirect employment generates **personal income for Ohio residents amounting to $59.2 million annually**. This is divided between direct OARDC income at $33 million and $26.3 million in indirect income.
- While state government is an important funder of OARDC operations, it also receives revenue cycled back to the State through OARDC generated taxes. The OARDC directly and indirectly generates **$5.5 million in annual tax revenues**.

Functional Impacts of OARDC Research and Innovation

The above numbers simply represent the impacts realized by the FY2008 expenditures of OARDC and its associated faculty and staff, plus the follow-on multiplier effect of these original direct expenditures. **The full impact generated by the Center's scientific discoveries, production enhancements and practical solutions for farmers is, of course, far larger resulting from the functional impacts of OARDC research and development.**

In FY2008, the OARDC research complex has worked on several hundred research contracts with sponsored research totaling $23.4 million. Not surprisingly, given this volume of research, it is impractical to quantify the economic benefits of every one of these research projects. It is feasible, however, to examine individual examples of specific research outcomes to illustrate the scale of individual impacts being generated—especially via targeted research support programs such as those initiated through the OARDC *Agbioscience Centers of Innovation Program.* **When such analysis of examples is performed, what is found are large-scale economic impacts generated for Ohio through positive impacts (such as the development of new high-value crops, bioproducts and technologies) and negative impacts averted (such as monetary losses attributable to agricultural pests, plant and animal diseases, and foodborne illnesses).** Some examples of such functional impacts include:

Development of a Real-Time PCR Assay for Rapid Detection of Very Virulent Infectious Bursal Disease Virus (vvIBDV)

Very Virulent IBDV is a disease that has significant negative economic impact for the global poultry industry. OARDC has developed, through its Center for Diagnostic Assays (CDA), the only validated tool for detection of vvIBDV. The development of the CDA's vvIBDV real-time assay is providing a front-line tool for monitoring and controlling the spread of this highly destructive immunosuppressive poultry disease.

The assay is patent pending and builds upon OARDC's existing strengths and technologies in the field of food animal diseases and diagnostics. The institution already holds the patent on molecular-based diagnostic assays for infectious bursal disease virus (Patent #6,114,112).

What does this mean for Ohio? According to Battelle's analysis, the poultry and egg production industries have a total economic impact on Ohio of over $861 million annually and generate almost 8,700 jobs in the state. Because IBDV is able to rapidly produce mutated viruses that are resistant to vaccines the vvIBDV strain causes unusually high morbidity and mortality. Early diagnosis is central to protecting this industry from one of the most economically significant diseases of the poultry industry and is critically important to sustaining this important agricultural industry for the state.

Development of Diagnostic Assays for Infectious Diseases of Plants and Animals

Food animal health is an important economic consideration for Ohio where livestock comprises a substantial

component of agriculture in the state. **Research performed in 2008 by Battelle, sponsored by the Ohio Soybean Council, shows the livestock sector having the following Ohio economic impacts:**

- **$3.6 billion in Ohio economic output.**
- **45,692 jobs in the state directly or indirectly related the livestock sector**
- **Generation of more than $396 million annually in personal income for Ohioans.**

With so much economic value on the line it is imperative that livestock producers have access to the latest in advanced animal disease diagnostics in order to prevent outbreaks and spreading of contagions.

OARDC research has resulted in the development of molecular-based diagnostic for multiple infectious agents including *Mycobacterium*, prion proteins, *E. coli 0157*, *Bovine torovirus* (BToV), *infectious bursal disease virus* (IBDV) (Patent #6,114,112) as well as biological control agents *Trichoderma hamatum 382*, and *DAPG* producing *Pseudomonas fluorescens*. Diagnostic assays in development include those for *Mollicutes* (phytoplasma species), soybean rust pathogen, soybean root pathogens, *Bacillus subtilis* strains with plant disease biocontrol activity, *Enterobacter sakazakii* which causes meningitis in humans, and monoclonal antibody based BToV and vvIBDV assays.

USDA statistics show food animal disease outbreaks reducing annual livestock revenues by 1.8%. **Reducing Ohio livestock revenues by this normative amount, and extrapolating the impacts across the full livestock value chain, equates to almost $65 million in Ohio economic output at risk to livestock disease outbreaks.** Diagnostics technologies, therefore, not only have intrinsic value as direct technologies for sale, their application also brings significant benefits in terms of potential negative impacts prevented.

A "New" Natural Rubber for Ohio's Tire Industry

Natural rubber is a strategically important global commodity—a commodity in high demand because of growth in vehicle use across the globe. Access to natural rubber is especially important in Ohio, home to a large base of tire companies and industrial rubber using industries in the Akron area.

OARDC is playing a central role in the cultivation, development and domestication of a promising latex rubber producing alternative crop. The Russian dandelion, Taraxacum kok-saghyz (TKS), produces high-quality natural rubber in its taproot—a rubber that compares well in performance characteristics with rubber from traditional sources. A Program of Excellence in Natural Rubber Alternatives (PENRA) has been created to coordinate work between OARDC and partnering organizations in the project. The PENRA is housed at OARDC and includes the participation of Ohio State, the University of Akron, Oregon State University, Cooper Tire, Bridgestone Americas, and Veyance Technologies (formerly Goodyear Engineered Products). Each of the corporate partners produces tires and industrial rubber products in Ohio and has its corporate R&D center in the state. The research collaborators have now been supported with a $3 million Third Frontier Wright Projects Program grant to accelerate the development of a new crop and processing industry for Ohio.

Projections indicate that the new industry will generate over $130 million in revenues and produce 165 jobs in Ohio—but, more importantly the availability of secure domestic natural rubber supplies will help reinforce Ohio's major tire and industrial rubber products sector with its multi-billion dollar economic impact on the state. Polymer Ohio notes that 247 Ohio companies depend on rubber as a component of their manufactured products.

High Value Functional Foods Development

With the global market for functional foods estimated to reach $90.5 billion by 2013, there is potential for significant functional foods based economic development to occur in Ohio. This is not just hopeful thinking. Ohio already has a food processing sector accounting for $11.1 billion in gross state product[1] so, rather than trying to introduce a new sector for the state, functional foods represent enhanced product opportunities for an existing sector—thereby leveraging infrastructure and distribution channels that already exist in the state.

Functional foods represent a distinctive opportunity for Ohio building upon an established and growing R&D capability in the state (from agriculture through food processing and on into human health), clinical testing and trials capability, and commercial product production, packaging and distribution.

The OARDC Center for Advanced Functional Food Research and Entrepreneurship (CAFFRE) has been formed to discover and develop high-value functional foods with special application to the treatment or prevention of major chronic diseases (such as obesity, diabetes, vascular diseases, arthritic and autoimmune conditions, and neurodegenerative diseases). Progress at the center has been significant. **With a total of $20.4 million in total funded projects generated and $14 million in currently active projects, it is clear that CAFFRE has provided a strong leverage and return on the University's original center investment of $300,000.**

CAFFRE has successfully accelerated several functional food technologies along the pathway to market. Some key examples with significant economic development potential for Ohio include:

- **Soy-enhanced Bread Products.** Advancements have been made with soy enhanced bread. The soy bread "Healthyhearth" has moved from lab, to commercial prototype and into limited retailing. The soy protein in the bread gives it the ability to be marketed with the FDA's heart healthy label. With the U.S market for bread constituting an $18.5 billion market in 2007[2], heart-healthy bread presents the opportunity for significant domestic sales.
- **Soy-enhanced Tomato Juice.** Experiments have shown cardiovascular benefits through soy-enhancement in terms of oxidative resistance to LDL and VLDL cholesterol, and for improving the positive ratio between total cholesterol and HDL cholesterol. Further study has been investigating benefits in the prevention of prostate cancer also.
- **Oral Cancer Prevention via Black Raspberries.** CAFFRE researchers have shown both in vitro and in vivo cancer prevention benefits from the consumption of black raspberries. This has resulted in the development and testing of two products—a black raspberry lozenge and an oral gel containing freeze dried blackberries—both designed for topical application against oral cancers.

Patent pending technologies developed by CAFFRE scientists include:

- Methods for enhancing soy-containing foods
- A formula and process for making soy-based bakery products
- Anthocyanin determination in biological specimens using chromatography and spectrometry.

[1] Thomas L. Sporleder. "OHFOOD: An Ohio Food Industries Input-Output Model." Version 9.0, November 2007. The Ohio State University, AED Economics Department.
[2] www.researchandmarkets.com/reports/614538

Case Study: Safeguarding Egg Production in Ohio

OARDC's Center for Food Safety and Security focuses OSU expertise in microbiology, pathogen detection, and packaging technologies to develop technological solutions to the human health threat of food-borne pathogens. One area of R&D, in particular, is supporting strong impacts in the important egg production sector of the Ohio economy.

Producing 7.5 billion eggs per year, Ohio ranks second in the nation in egg production. Production was valued at $279 million in 2006, with a total impact on the Ohio economy of $527 million, and support for over 5,300 jobs in the state.

The economic benefits from *Salmonella* elimination technologies in eggs will be highly significant. Industry efforts to reduce *Salmonella* have already resulted in a halving of cases in Ohio since 1997. Now, the work of the OARDC research teams is targeting a further significant reduction.

The USDA ERS estimates from extrapolation of monitoring system data that 1.4 million cases of *Salmonellosis* occurred in the United States in 1997.[1] On a normative level, this would equate to 56,000 cases in Ohio. A halving of this rate through the food safety initiatives targeting *Salmonella* in Ohio would equate to more than 28,000 *Salmonellosis* illnesses avoided per year. ERS data place the average cost of a *Salmonellosis* case at between $331 and $1,664 (two different methodologies were used to derive the two separate estimates). **On this basis, the estimated cost savings to Ohio through the *Salmonella* reduction initiatives would equal between $9.3 million and $46.6 million.**

The Center has advanced several promising technologies along the pathway towards market and "safe eggs" stand as an important example of this work. Safe Eggs are produced using ozone pasteurization technology and, as a result, scientists within the Center are well on the way to meeting the goal of pathogen free eggs. Eggtech, with three major egg production companies as investors, is working with OARDC in bringing advanced ozone technology to market.

Further upstream, in the earlier stage of commercialization investigation, are two other promising technologies in tamper evident packaging development and a rapid diagnostic test kit development for norovirus.

Building the Ohio Bio-Economy: Developing Crops with High-Value Specialty Traits

Through the ABIG funded Program for Advanced Plant Genetics and Specialty Traits, and OARDC's participation in the Ohio Third Frontier Funded "Ohio BioProducts Innovation Center" (OBIC), **OARDC is focused on the development and production of quality plant biomass which has specialized characteristics for downstream processing and specialized bioproducts manufacturing. This work is fundamental to Ohio achieving a leading position in the new bio-economy based on the production of value-added products from bio-based resources.**

This OARDC program leverages the expertise of OARDC's plant breeders in developing adapted crops (such as soybeans, wheat and maize) with genes for resistance to diseases and having value-added traits involving proteins, sugars, fatty acids, starch gluten, hilum color, pigmentation and processing properties.

As the biobased products economy moves forward, plant biomass will need to be optimized for more specific biobased product applications. The usual issues of yield, disease and pest resistance, etc. will continue to be important, but additional traits will be important such as downstream processability, ease of enzymatic break-down, usability of by-products, compatibility with rotation requirements, etc. Plant scientists will also need to develop expertise in species which have not been traditionally grown in Ohio—crops such as canola, camelina, dandelions and sunflowers, to name just a few. OARDC plant scientists will be at the

forefront of this work for Ohio's emerging biobased products industry.

In addition to supporting the development of optimized feedstocks for biofuels and industrial bio-based products (such as lubricants, polymers, rubber, etc.) OARDC research in plant traits and multi-function germplasm also has relevance to emerging functional food, specialty foods, biopharming and other specialized applications. In soybeans, for example, the OHS 201 "Wyandot" line is optimized for food applications such as tofu, while HC01-289 "Prohio" combines high yield with very high protein content. In maize, OARDC breeders are accelerating development of lines high in carotenoid pigments and Anthocyanin content—valuable functional food traits.

Ohio's Green Industry Impacts and Supporting Projects of OARDC

The green industry in Ohio is a sizeable sector that has seen significant growth over the past 15 years. Battelle's analysis shows that in 2005 the sector in Ohio included 6,682 establishments employing 66,647 personnel. Moreover, the sector has experienced rapid growth in the state, with revenues growing by over 30% between 1990 and 2005 and employment expanding by 28% during the same time period. This green industry growth significantly outpaced Ohio's average private sector employment growth rate which was 11.2% over the same fifteen year period. Data show that the green industry represents $5.9 billion in output ranking the state fifth in the nation.

OARDC's long-standing work in growing media development for the green industry has been complemented by the formation of the ABIG funded Center for Urban Environment and Economic Development (CUEED). This center focuses on the development and commercialization of a series of new organic and biological products designed to meet the fertility, pest control, and pollution mitigation needs of urbanized landscapes and the green industry**.**

Some key impact area examples include:

The Development of Biocontrol Agents for Turfgrass Application

OARDC work in bio-insecticides has multiple economic and environmental benefits for Ohio. **Firstly, it is helping to develop new technologies that can be used as the basis for new commercial products and business development. Secondly, it is finding new cost-effective, non-toxic bio-treatments to enhance the productivity of Ohio's $5.9 billion green industry. Thirdly, it is resulting in the introduction of technologies that prevent environmental and ecological damage through reduction in the build up of toxic chemical pesticide residues.**

Advanced Compost-Based Potting Mixes

The work of OARDC scientists has been internationally recognized for its fundamental importance to the nursery and horticulture industry. Researchers interviewed by Battelle at OARDC noted that the nursery industry would only be a minor player in Ohio agriculture if it were not for the development of disease-resistant potting soils at OARDC. **Prior to the release of OARDC's disease resistant compost technology, up to 75% of potted plants could be lost to disease in production (whereas today advanced potting mix technology has reduced these losses to the 10-15% range).** The large advance in nursery productivity from advanced potting mixes has resulted in nursery production moving into a whole new scale of operations and profitability in Ohio. **As of 2001, when OSU undertook a formal analysis of the nursery industry in the State, the industry employed over 96,000 persons, had sales of over $2.79 billion, and over $275 million in payroll. Without OARDC composting technology and potting mix development there is little doubt that this sector would be far less impactful on the Ohio economy than it is today.**

The production and sales of potting mixes has itself grown into a significant industry. In Ohio, OSU data show that wholesale production, distribution and retail sales of nursery and garden center plants totaled circa $1.37 billion in 2001. Of these, OSU estimates that 75% are produced in containers, thereby requiring the use of potting mix (this would equate to $1.03 billion in sales). Potting mix typically represents between 3% and 5% of the retail value of the plant, so using a midpoint estimate of 4% results **in an estimate of over $41 million in potting mix used at the commercial level in Ohio.**

Bio-Control of Disease in Plant Growth Media

Another fundamental contribution of OARDC research to the economics of the horticulture industry has come through the use of biological agents to stimulate plants to activate natural disease and pest resistance mechanisms. OARDC is at the forefront of work in stimulating plant innate disease resistance and the impact of these new approaches on the Ohio nursery and greenhouse plant industry will be substantial. **The use of OARDC developed biocontrol technologies, versus the traditional application of chemical fungicide, are alone estimated to provide a potential cost savings to the Ohio nursery industry of almost $22 million annually.**

OARDC as a Biofuels Development Driver

Perhaps no other area of agbiosciences has received as much attention in economic development circles as biofuels in recent years. This has been for good reason—biofuels represent a high value-added application for biomass, and hold significant strategic implications for the U.S. in the face of competitive global fossil fuel supplies. **The economic promise of biofuels for Ohio is fourfold:**

- **For Ohio to develop new industry sectors in advanced biomass conversion and energy production technologies**
- **For Ohio to generate valuable electrical energy, renewable fuels and chemical co-products from renewable in-state biomass resources**
- **For Ohio industry and agriculture to achieve significant cost efficiencies through the use of their own waste streams for on-site power generation**
- **For Ohio to achieve enhanced energy security thereby reducing economic exposure to high cost, off-shore supplied fossil fuels.**

Within OARDC multiple R&D initiatives are being pursued in relation to bioenergy and waste-to-energy conversion. Examples include:

Microbial Fuel Cell Technology

Microbial fuel cells show potential as a scalable renewable energy source using both agricultural and industrial biomass waste as the input for conversion. OARDC researchers are investigating the generation of electricity from cellulose in a microbial fuel cell using mixed rumen bacteria as a biocatalyst. The R&D has achieved successful conversion at a laboratory scale, and shows promise for progression into pilot scale tests.

Treatment of Bioenergy Byproducts

Ohio has a significant base of dairies, and these operations can reclaim energy from animal waste via the use of methane digester technology. The economics of the conversion process are helped if the post-conversion waste can be sold as organic fertilizer or used as livestock bedding material. A key problem

associated with this byproduct re-use, however, has been the substantial pathogen load contained within the material. OARDC scientists have analyzed byproducts and characterized the microflora in dairy waste. This has enabled the team to develop approaches to the treatment of this waste to neutralize negative microbial content.

Biomass to Energy, Increasing Biogas Yield

OARDC researchers have been working to significantly increase biogas yield, and resultant energy yield, via the improvement of anaerobic digestion processes. A key approach taken in the OARDC work has been the introduction of enhanced levels of trace elements into waste feedstock and it has been found that this "seeding" with trace elements results in an increase of between 60% and 200% in biogas yield. The commercial potential of this discovery is significant—making a substantial difference to the economics and return on investment of biomass waste-to-energy conversion equipment.

Converting Cellulose Materials into Energy

A key to the future success and viability of much more widespread bioenergy use is the conversion of lignocellulosic material into useable forms—such as fermentable sugars, biogases and ethanol. An OARDC research team has undertaken in-depth study of microbial communities and their function in plant cell wall degradation. Using genomic analysis, OARDC scientists are facilitating deeper understanding of the fundamental mechanisms involved in plant cell wall degradation leading to specific recommendations and potential technologies for improving anaerobic digester operational efficiency and economic viability.

Enhancing Waste-to-Energy Conversion for Sand-Bedded Dairies

Sand is commonly used as a bedding material in Ohio dairies, but the presence of significant quantities of sand in manure causes equipment maintenance problems when the manure is processed in anaerobic digesters. OARDC has been working with industry on approaches to manage and recover the sand within digesters before it causes equipment damage.

Engineering Combustion Systems for Bioenergy

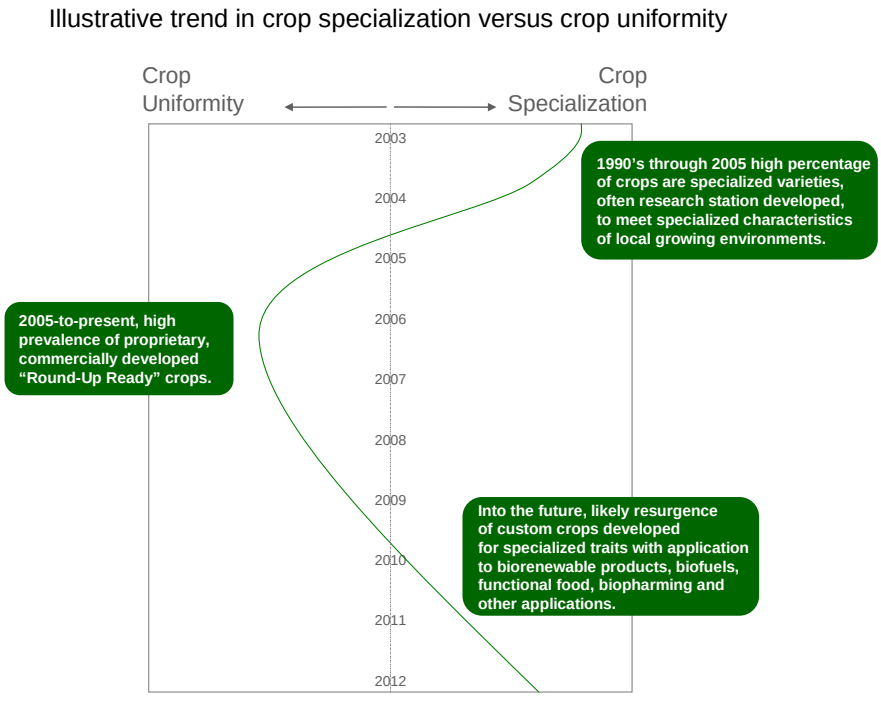
OARDC agricultural engineers are focusing on the development of biomass combustion systems—particularly those using crop and crop residue as the primary fuel. A key goal of the OARDC team's work is the development of high-efficiency and automated combustion systems. A particular emphasis is being placed on fluidized bed combustion processes. Prior work by members of the team resulted in development and commercialization of an 8 million BTU/hr. flex-fuel combustion system, using the fluidized bed technology, which was installed at an Ohio greenhouse. Greenhouse operators found the system to be effective and cost-efficient, reducing overall energy expenditures by a substantial $200,000 annually. Currently the team has developed a fluidized bed combustion unit using shelled corn as fuel with a 65% combustion efficiency. The engineers are working on refining the system with a more advanced third-generation model with goals of reaching 85-90% combustion efficiency.

OARDC Crop Impacts: Resurgence in Economic Impacts Likely to Occur

Historically, the work of OARDC scientists in plant breeding and crop variety development has had strong economic impact benefits for Ohio. In 2004 Battelle's analysis indicated that OARDC's work in developing high-yield, disease-resistant soybeans, optimized for Ohio growing environments, generated a $191 million impact on Ohio economic output and were responsible for the generation of 4,030 jobs in the state. Clearly, OARDC research in plant breeding and trait development can have a significant farm-level impact, and generate specialized varieties of crops with value-added traits.

Since the 2004 study was released there have been dramatic changes in agricultural markets. As the 2004 study predicted, bio-based products (including biofuels) have emerged as a major market for commodity crops (especially corn and soybeans)—thereby increasing demand and commodity prices for these crops. During this time, however, the market for crop varieties shifted away from specialized university varieties in favor of variety standardization led by Monsanto's "Round-Up Ready" brand. As the illustrative figure below depicts, there has been a significant swing away from crop specialization (in which university R&D specialized) towards crop standardization (favored by big industry**). It is likely however, that a new trend will emerge—driven by the previously mentioned bio-based products and emerging functional foods markets. These markets require specialized crop traits—an area of research and development in which OSU and OARDC excels. Therefore, into the future, Battelle anticipates that OARDC will continue to play a critically important role in developing crops with specialized value-added traits for Ohio producers that are suited to production in Ohio growing environments (with impacts measured in the hundreds of millions of dollars).**

Figure ES-5: Crop Specialization versus Crop Uniformity



OARDC Leadership and Participation in Ohio's Economic Development Programs

The Ohio Department of Development (ODOD) has a targeted industry approach to economic development, and is focused on nine primary industry sectors—many of which are directly or indirectly impacted by agbioscience. The nine ODOD target sectors and potential agbioscience linkages are illustrated on Table ES-1 below:

Table ES-1: ODOD Target Sectors and their Agbioscience/OARDC Linkages

Ohio's Statewide Targeted Industry Sectors	Potential Agbioscience/OARDC Linkages
Agriculture and Food Processing	**Direct** – Development of comprehensive approaches to improving and diversifying agricultural production, commodity processing, and value-added product development. Connects to all OARDC signature focus areas.
Bioscience and Bioproducts	**Direct** – Development of biobased industrial products and work in human health and safety aspects pertaining to agriculture and natural products. Connects to all OARDC signature focus areas.
Advanced Energy and Environmental Technologies	**Direct** – Development of bioenergy and environmental technologies. Connects to OARDC Advanced Bioenergy and Biobased Products signature focus area.
Polymers and Advanced Materials	**Direct** – Major focus of work linking OARDC, OBIC and the polymer cluster in Akron. Biocomposite materials for application within other Ohio target industry clusters. Connects to OARDC Advanced Bioenergy and Biobased Products signature focus area.
Distribution and Logistics	**Indirect** – Relevance in emerging issues pertaining to biomass transportation and the location of biomass conversion and value-added manufacturing facilities. Biologistics is an emerging field as are local food networks.
Instruments, Controls and Electronics	**Indirect** – May be relevant work in instruments and controls relating to precision agriculture and improvement of value-added processes. Direct work in technologies with application to food safety and packaging.
Motor Vehicle and Parts Manufacturing	**Indirect** – Application of Biocomposite materials in automotive applications. Direct potential application of alternative rubber sources in tire and rubber component manufacturing.
Aerospace and Aviation	**Indirect** – Relationships in biobased aviation fuels and lubricants, and advanced biobased materials. Work in food product development, nutritional enhancement and packaging for space and long-term environment applications.
Corporate and Professional Services	**Indirect** – May be relevant in terms of services for agribusiness and bio-based corporate enterprises. Specific support through development of the BioHio Research Park.

As Table ES-1 shows agbiosciences has a role to play in every one of the target industries and a major leadership role in four of them:

- **Agriculture and Food Processing**
- **Bioscience and Bioproducts**
- **Advanced Energy and Environmental Technologies**

- **Polymers and Advanced Materials**.

Through OARDC's ABIG funded centers, OSU TIE initiatives, and participation in Third Frontier funded projects, OARDC is a critically important contributor to Ohio's technology-based economic development strategy.

OARDC Cross-Cutting Supports for Ohio Economic Development

Each of the science based Centers of Innovation at OARDC has a goal of moving innovation into commercialization and economic development for Ohio. However, the R&D personnel in these Centers are predominantly research bioscientists with little prior experience in technology acceleration, market assessment or commercialization. Recognizing this challenge OARDC took the important step of funding cross-cutting support for agbioscience innovation commercialization. The Center for Innovation Based Enterprise (CIBE), led by the Department of Agricultural, Environmental and Development Economics (AEDE) within FAES was established to address barriers to product commercialization by providing research into entrepreneurship, contract design, financing, marketing, and risk management for innovation-based and start-up agbioscience enterprises.

The Center for Innovation Based Enterprise supports the other centers, and other groups within OARDC and the university, with market analysis, economic modeling and forecasting, and commercialization assistance. CIBE plays the crucial role of keeping the other centers rooted in reality—helping them to assess technology in terms of market potential and potential for business development success. The analytical expertise within CIBE provides the ability to assess the commercial scalability of R&D based agbioscience innovations and to identify the best pathways to market for those technologies demonstrating process and business scalability. **Through provision of these services CIBE makes important contributions to improving the chance of commercialization success for OARDC innovations. The key economic impact of the Center's work will come though enhanced probability of commercial success for OARDC-based innovations.**

It should be noted that the quality of services and research supports provided by CIBE under its remit is evident in CIBE personnel having significant scholarly success through their CIBE projects. Research findings have been published in several scholarly journals, particularly in food science fields, and CIBE personnel have been active presenters at multiple seminars and events.

OARDC has also been proactive in working to develop the infrastructure necessary to house new agbioscience businesses in close proximity to university research assets. The growth of university research parks around the nation shows the value companies place on proximity to academic institutions that are major R&D and innovation engines. Such research parks host university spin-off companies and the operations of existing companies that recognize the benefits of academic-industry R&D partnerships and enjoy the access to skilled human capital graduating from universities. OARDC has become an active stakeholder in the university research park concept and, with the support of the State of Ohio and Wayne County, is developing the BioHio Research Park. While the research park, being driven by ATECH, is still in its early stages, work is progressing well, and significant milestones include:

Between 2005 and 2007 ATECH has worked with more than 100 business enterprises and has developed commercial partnerships that provide significant sponsored research opportunities for OARDC researchers. ATECH is leading the recruitment of industry operations to the BioHio Research Park.

- Renovation of Pounden Hall which is to provide business incubation space with flex labs and co-lab facilities. The building will provide 30,000 sq.ft. of space once renovations are completed. The Pounden Hall renovations have been supported with a $744,000 federal EDA grant.
- Generation of a $3.5 million *Jobs Ready Sites* grant to renovate Secrest Road leading to the 90 acres that will house the research park.
- Recruitment of companies, such as Schmack BioEnergy, to locate operations at the Wooster campus.

It is evident that, since 2004, the OARDC has been proactive in adopting, and building upon, Battelle's recommendations for platform development leading to agbioscience-based economic development. OARDC has formed multiple centers specifically focused on innovation in the three signature focus areas that define agbioscience opportunity in the state. The centers that have been formed are now producing results—results that can be measured via significant leverage of external research funds, a substantive volume of research discoveries and patent applications, a strong and growing base of applied R&D projects with industry, the diffusion of innovations and technologies into existing Ohio industry, and the formation of new commercial entities around agbioscience opportunities.

BioOhio in its 2007-08 Ohio Bioscience Growth Report notes that ***"agricultural biotechnology, the application of bioscience and biotechnology to the processing of agricultural goods and the production of feedstocks and chemicals, including the production of biofuels, is the leading commercial bioscience subsector by output in the state".***

Core Competency Assessment and Technology Platform Identification

Research core competencies are those fields with a critical mass of ongoing activity along with some measure of excellence. Battelle uses both quantitative and qualitative methods to identify research core competencies, including an Omniviz™ cluster analysis of abstracts from grant awards and publications; analysis of publication and citation activities; a review of major competitively funded research grants; and extensive interview with both internal and external stakeholders on the particular strengths of OARDC's research activities, what differentiates them from others, and where they are headed.

The core competency analysis herein finds identification of eleven agbioscience core competencies, shown in Figure ES-6 with key elements and focus areas. Nine of these core competencies are direct descendants of the 2003 core competencies from Battelle's previous study, but two, "economics of agbiosciences" and "biobased products research", are new.

OARDC's research core competencies reflect the wide range and scope of the Center's R&D expertise across the agbiosciences, but the translation of these core competencies into broader technology platforms—expansive, applications-oriented areas that offer the potential to realize significant economic gains—will enable OARDC to exploit existing and emerging market opportunities and to maintain significant agbioscience-based economic impact within Ohio. Technology platforms must draw upon multiple research strengths, align with existing or emerging commercial strengths, have positive outlook for external funding, and build on specific competitive advantages that minimize competition from other states or regions.

Figure ES-6: OARDC's 2008 Research Core Competencies

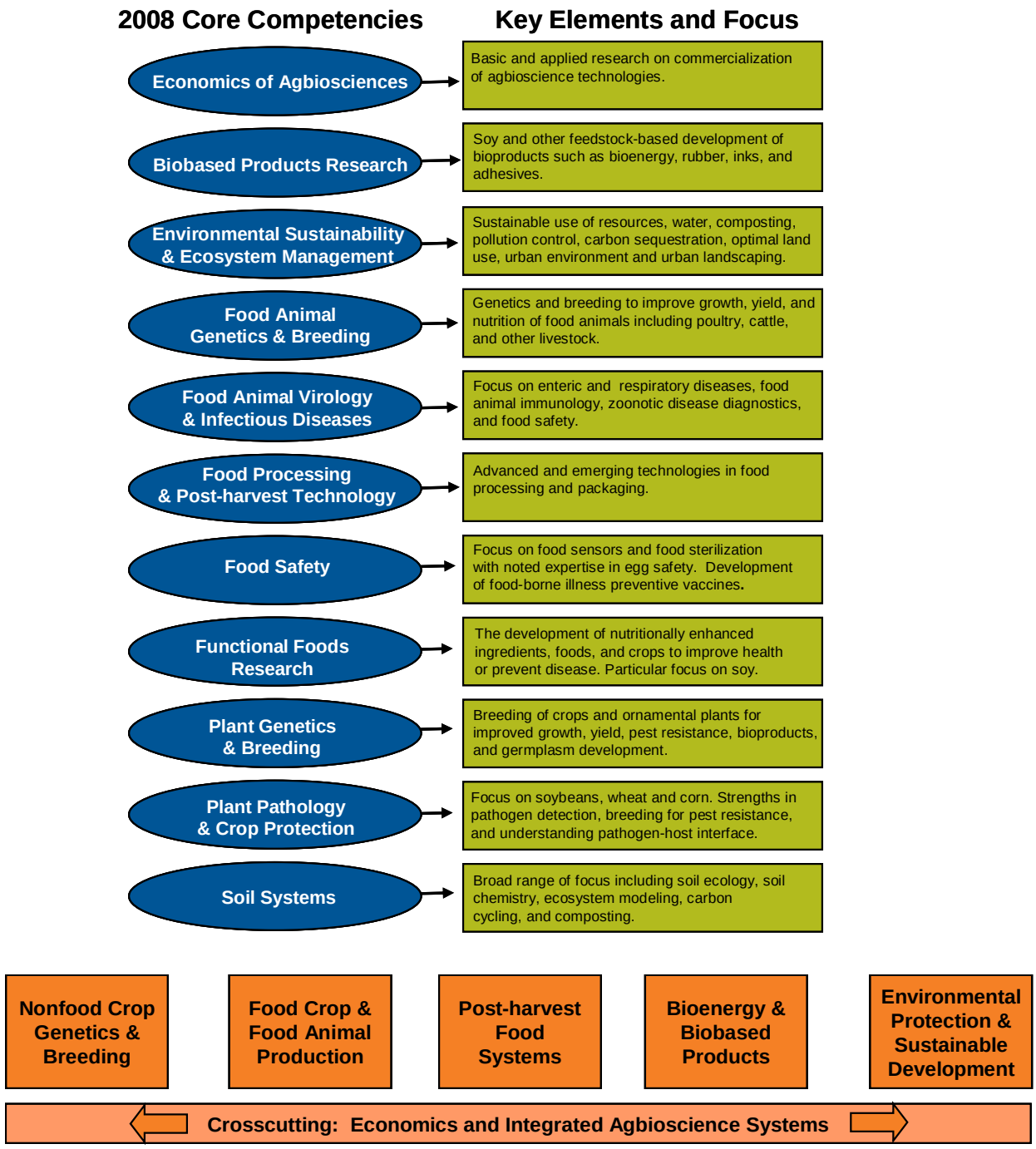


Table ES-2 summarizes the details of each technology platform.

Table ES-2: Summary of Recommended Technology Platforms

Technology Platform		
Food Crop & Food Animal Production & Protection – Genetically engineered food crops that may express beneficial traits, such as higher yield, longer shelf life, or the ability to be farmed without the need for herbicides, pesticides, or other chemicals; genetics and breeding of food animals for nutritional enhancement; and food animal health along with the development of infectious disease diagnostics, vaccines, therapeutics, and biologics		
Specific Opportunities: • Enhanced Food Crops • Enhanced Food Animals • Food Animal Disease Diagnostics & Therapeutics		
Related OSU/OARDC R&D Strengths	**Prospect for External Funding**	**Competition**
Plant Pathology, Horticulture & Crop Science, Entomology, Corn and Soybean Research, Extension, Food Animal Health Research, Center for Diagnostic Assays	Federal funding slipping but non-profit and industry funding for food crop research is increasingly available. Decent opportunities for federal funding for food animal production and animal health research.	Intense competition in food crop research; less so for food animal production and health.

Technology Platform		
Post-harvest Food Systems – The application of technologies to agricultural commodities after harvest for the purpose of loss prevention, preservation, food safety, and quality control or enhancement		
Specific Opportunities: • New Food Processing & Preservation Technologies • Advanced Food Packaging • Food Safety, Biosensors & Rapid Foodborne Pathogen Detection		
Related OSU/OARDC R&D Strengths	**Prospect for External Funding**	**Competition**
Food Science and Technology, Center for Advanced Processing and Packaging Studies, Center for Diagnostic Assays	Increased funding available for food safety initiatives; more limited funding opportunities for packaging and processing. Key federal funding agencies are the USDA and FDA.	Moderately intense.

Technology Platform

Nonfood Crop Genetics & Breeding – Genetic studies of nonfood crops and the development of new or enhanced crops with desirable traits, such as increased yield, oil content, fiber content, carbohydrate content, altered lignocellulosic ratios, insect or disease resistance, temperature tolerance, improved appearance, delayed ripening, or production of high-value industrial or pharmaceutical compounds. Also, improved plant breeding technologies, evaluation of plant germplasm, enhanced seed production, and the development of improved agronomic processes for field and greenhouse systems.

Specific Opportunities:

- Transgenic Plants with Improved Yield, Resistance, or Other Desirable Traits
- Transgenic Plants that Produce Industrial or Pharmaceutical Products
- Germplasm & Germplasm Mining
- Floriculture & Ornamental Plants
- Turf Grass R&D

Related OSU/OARDC R&D Strengths	Prospect for External Funding	Competition
Ornamental Plant Germplasm Center, Plant Pathology, Horticulture & Crop Science, Turf Grass Science	USDA is the primary source for federal funding of nonfood crop genetics and breeding research. Smaller pools of funding—generally from other nonprofit sources—for horticultural, floricultural, and turf grass research.	Extremely high competition on transgenic nonfood crops, almost entirely from other academic R&D centers. Also significant competition in floriculture and turf grass.

Technology Platform

Bioenergy & Biobased Products – Involves research and development of processes that lead to the conversion of biomass feedstock into a wide range of products, from biofuels, biodegradable packaging, and biodegradable plastics to nutritional supplements, soy-based adhesives and lubricants for industrial uses, and compost.

Specific Opportunities:

- Algae-based Biofuel
- Cellulosic Biofuel
- Biorefinery Byproducts
- Biopolymers, Bioplastics & Biocomposites
- Compost and Engineered Growing Media/Soils
- Nutraceuticals & Functional Foods

Related OSU/OARDC R&D Strengths	Prospect for External Funding	Competition
OBIC, Ohio Composting and Manure Management Program, Soil Science/Carbon Sequestration	Excellent opportunity for external funding for bioenergy projects from both federal and nonfederal sources. Smaller but still positive outlook for funding for other biobased products R&D.	Intense competition in bioenergy with a number of major centers nationwide; less competition surrounding R&D on other biobased products.

Technology Platform

Environmental Protection & Sustainable Development – Involves efforts to limit global warming, consider the effects of urbanization and the built environment, safeguard from poor air and water quality, maintenance of biodiversity and ecosystems, protection of natural resource endowments, control pollution, improve energy efficiency, and develop more efficient uses of resources such as recycling and waste management.

Specific Opportunities:

- Urban Land Management
- Soil Quality
- Water Quality
- Bioremediation
- Sustainable Systems

Related OSU/OARDC R&D Strengths	Prospect for External Funding	Competition
Center for Urban Environment and Economic Development, School of Environment and Natural Resources. Entomology, soil science and water resources.	Strong prospects from multiple federal agencies including USDA, DOE, EPA, NOAA, and others.	Increasing number of universities with one or more centers concentrating on the environment and sustainability.

Crosscutting Platform

Economics and Integrated Agbioscience Systems – Involves R&D and program support services relating to agbioscience markets, emerging trends and agricultural/biomass economics. Also includes R&D into integrated systems of biomass production, production of value-added products, and the economic reuse of agricultural and bio-process waste streams and co-products.

Specific Opportunities:

- High efficiency networks and systems for integrated collection and value-added use of waste streams
- Identification of synergistic products, infrastructure and industries for integration into high efficiency systems for biomass use
- Agbioscience product market assessment and modeling

Related OSU/OARDC R&D Strengths	Prospect for External Funding	Competition
Agricultural economics, OBIC, bioenergy R&D and composting and waste utilization expertise	Strong prospects for external funding for basic modeling and integrated network development and simulation. More challenging to raise funding for product specific market research and projections.	Emerging competition in agbioscience economics and its relationship to biomass and associated agbioscience resources. State-by-state variability in the presence of groups and institutions providing market research and new product commercialization support services.

Into the Future: OARDC as an Economic Development Driver for Ohio

Battelle's assessment of the economic impact of OARDC shows the Center to be a high impact driver of economic progress in the State of Ohio. OARDC's traditional legacy of impacts on the agriculture and food production sectors has been added-to, with specific initiatives targeting economic growth through fast growth agbioscience areas in bioenergy and bio-based industrial products, advanced food crops and food systems, highly integrated systems of production and biomass utilization, and environmental quality and sustainability. Both the traditional and emerging applications of OARDC knowledge and R&D place the institution in a strong position as a technology-based economic development engine for Ohio. OARDC has been proactive in organizing to take advantage of its R&D core competencies and their potential for innovation, new technology development and commercialization. Using internal funding, the support of key stakeholders such as the University and state, and major external private and federal government research sponsors, OARDC is clearly focusing its work on the practical application of science to grow the economy. The work of OARDC in building focused R&D expertise is being further leveraged through strategic investments in the supporting infrastructure required to accelerate the progression of innovations from discovery to commercialization. Key infrastructure initiatives such as the BioHio Research Park, biocontainment facility, bioenergy research facility, molecular and cellular imaging center, etc. provide the tangible assets for R&D acceleration, while purpose designed support programs such as ATECH and the Center for Innovation Based Enterprise provide the cross-cutting supports required to move innovation from the bench to commercial application.

The position and promise of agbiosciences as a key driver of future growth for Ohio has been reinforced by the recognition of the sector as a strategic asset by the State of Ohio and the Ohio Department of Development. OARDC is the primary agbioscience research asset for the State—the R&D arm of the only college of agriculture in the state, within the Ohio's only land-grant university. As Ohio seeks to propel its economy forward using agbiosciences as an accelerant, it is clear that OARDC must be considered a prime strategic asset for further state investment and development.

In 2004 OARDC's early work in determining agbioscience strengths and developing strategies for agbioscience-based economic development placed it at the forefront of bioeconomy development. Ohio was one of the first states to recognize and intensively support agbiosciences as a core 21st Century development driver, and was certainly first among major industrialized states. The subsequent work of OARDC and its key stakeholders in structuring programs and operations to leverage strategic opportunities has built a momentum that is generating tangible impacts. That said, other states have likewise seen the opportunity that biobased resource development will bring and are moving fast to develop their own strategies for agbioscience economic growth. Competition for projects and assets will grow, and it is imperative that the State continues to work intensively with OARDC and the agbioscience assets of The Ohio State University to sustain Ohio's current positive trajectory.

I. Introduction

In 2004, the Battelle Technology Partnership Practice (TPP) undertook a detailed evaluation of the economic impact of the Ohio Agricultural Research and Development Center (OARDC) on the State of Ohio. Immediately after completion of the impact analysis TPP was also asked to conduct a detailed review of the R&D core competencies of the OARDC and to identify clusters of research expertise at the Center that could form robust platforms for applied innovation and technology-based economic development. The results of these projects were summarized in two reports[3] released in 2004.

OARDC used Battelle's findings and recommendations to put in place a series of programs and initiatives designed to leverage and build upon the Center's identified core competencies. Now, five years on from the original 2004 evaluation, OARDC has asked TPP to undertake a review of the initiatives and programs that the Center has initiated and evaluate progress being made towards agbiosciences-based economic development in the state. The results of this evaluation are the subject of this report.

The Rise to Prominence of Modern Agbioscience

During the past five years there has been significant growth in public awareness of the economic benefits of agbiosciences. In 2004 Battelle found it necessary to explain the relevance of agricultural research to a 21st century modern economy, but today there is much greater knowledge of the critical importance of agbiosciences. Innovations in agriculture, agricultural sciences, biochemistry, environmental sciences, health sciences and many other associated fields are driving new, high visibility economic opportunities for American states, including Ohio. Many of the most significant issues facing the world are, and will be, directly impacted by new discoveries taking place in agbiosciences and related scientific disciplines. In recent work supporting the strategic plan development of The Ohio State University College of Food, Agriculture and Environmental Sciences (FAES), TPP noted that agbiosciences are at the forefront in developing solutions to many key global challenges including, but not limited to:

Figure 1: Global Issues with Agbioscience Relationships

- **Global Food Production and Security** – With a world population of 6.7 billion, projected to grow to over 9 billion by 2040[4], sustaining growth in food production is of singular importance to human life. Every

[3] Battelle Memorial Institute – Technology Partnership Practice. *"OARDC: A Generator of Positive Economic Impacts for Ohio."* December 2003. Battelle Memorial Institute – Technology Partnership Practice. *"OARDC's Competitive Positioning Strategy: A Development Path for the Future."* February 2004.
[4] U.S. Bureau of the Census. "World Population Information." Online at http://www.census.gov/ipc/www/idb/worldpopinfo.html

day more than 860 million people go hungry worldwide[5]. Agbiosciences focus directly on finding solutions to this problem.

- **Human Health and Nutrition** – Both quantity and quality of diet effect human health and performance. Malnutrition is the leading cause of lagging human capital performance in developing countries, while obesity increasingly plagues developed nations. Agbiosciences research is working to address these needs.
- **Biosecurity and Emerging Diseases** – Whether by natural or terrorist means, the threat of major disease outbreaks and food contamination events is a real and present danger. Agbiosciences researchers are at the leading edge of defenses against these threats.
- **Environmental Sustainability** – Sustaining population growth and economic growth must be balanced with preservation of natural resources and environmental assets. The 20th Century saw unprecedented growth in pollution, natural resource depletion and environmental degradation. Agbioscience researchers are on the front lines of environmental quality and sustainability.
- **Renewable/Green Resources and Products** – Linked hand in hand with environmental sustainability is an urgent need for the development of ecologically benign resources for economic activity. Agbioscience, and associated disciplines, provide the expertise and resources required to develop biorenewable, biomass based materials and products that will contribute to a sustainable, non-polluting future.
- **Climate Change** – The effects of global warming are of worldwide concern. Agbiosciences have an extremely important role to play in multiple aspects of the issue, including carbon sequestration, alternatives to natural-gas based fertilizers and the reduction in the use of fossil-fuel based carbon emissions.
- **Renewable Energy** – With global fossil fuel energy prices at record levels, and legitimate concerns relating to carbon emissions from fossil fuels, the race is on to develop renewable energy sources with nominal environmental impacts. Biofuels have a substantial role to play in the future of global energy supply.

The need for science-based, innovative solutions to these challenges is clear and the market for such solutions of unprecedented scale. Likewise it is clear, that the only College within The Ohio State University, and indeed the entire State of Ohio, structured to address each of these global priorities is FAES, and within FAES the central focus of R&D activity is the OARDC.

There is also a clear need for innovation and new technology development as drivers of economic growth for the U.S. and its constituent states. Global competition among developed and developing nations dictates a need for new high value U.S. innovations and value-added products in order for the U.S. to earn the income required to sustain our quality of life. Agbiosciences offer an important and exciting pathway towards a broad range of new value-added marketable products and technologies.

It is clear that the opening of the 21st Century has brought with it the unveiling of a ***BioCentury***—the coming of an era where rapid advancements in bioscience will provide unprecedented opportunities for economic and societal advancement. OARDC is Ohio's signature research center for realizing progress in all significant aspects of the bio-based economy. OARDC is the R&D hub for agbiosciences research

[5] Food and Agriculture Organization of the United Nations. "State of Food Insecurity in the World 2006." Online at http://www.fao.org/docrep/009/a0750e/a0750e00.htm

in the state, and while there are other institutions contributing to Ohio's growing prominence in agbiosciences R&D (including Battelle, other Ohio universities and some private sector research labs for example), the OARDC is clearly the signature institution in Ohio for driving agbiosciences based development forward in the state.

OARDC: Translating Core Competencies into Signature Platforms for Development

As noted above, OARDC was proactive in 2004 in working with TPP to identify its core competencies and strengths. Subsequent to the release of Battelle's findings and recommendations, the Center has worked to align these strengths with the high priority challenges and opportunities shown in Figure 1. As a result, the OARDC today has its signature R&D initiatives focused in three main areas[6]:

- **Food Security, Production and Human Health –** Focused on improving primary agriculture yields, enhancing the quality of food and feed, and maintaining agrosecurity to assure food security and the basics of nutritional health for a growing global population.
- **Advanced Bioenergy and Biobased Products –** Developing biomass-based advanced energy technologies and value-added bio-based products such as fuels, specialty chemicals and fiber products.
- **Environmental Quality and Sustainability –** Working to understand, protect and remediate the environment and ecosystems to assure long-term sustainability.

Within these signature areas, the OARDC has put in place numerous centers, programs and initiatives designed to foster multi-disciplinary and inter-disciplinary research, collaborative R&D with industry, and translational science programs to move discoveries from basic and applied labs into demonstration and piloting programs and then onwards into commercialization. It is clear that the OARDC, together with the University, the State of Ohio and other key stakeholders, has been working in a focused manner to realize benefits for Ohio from the opportunities contained in agbiosciences. The extent to which benefits are being achieved is the subject of this report.

OARDC 2004: Summary

In order to set the stage for a review of progress made over the past five years it is necessary to revisit some of the key findings and conclusions from the 2004 projects. At that point in time, the OARDC had identified the potential for significant engagement in technology-based economic development, but had not formally structured initiatives to facilitate growth in such development. However, even though not specifically organized to optimize economic development and technology transfer Battelle found that the OARDC was a significant contributor to statewide economic development.

In the OARDC economic impact report, TPP drew the following conclusions:

Battelle finds the OARDC to be a substantial economic engine for the State of Ohio. Simply in terms of its expenditure impacts, the OARDC generates $138 million in State output, $52 million in personal income for Ohioans and over 1,600 jobs. These expenditure impacts are, however, eclipsed in their importance by the benefits accruing to the State through the intensive research and development activities

[6] These three signature platforms are also being used by FAES overall to integrate the activities of the College in education and extension, as well as research.

housed within the OARDC's campuses. The OARDC is a scientific institution with a uniquely practical mission—a mission to enhance agricultural and agri-business productivity and sustainability through intensive programs of applied research. In terms of just the OARDC's work in the development of new crops and plant varieties suited to Ohio's environment and resistant to endemic diseases the annual benefit to Ohio is measured in billions of dollars of output, rather than millions. Likewise, OARDC's work in the prevention and response to infectious food diseases saves Ohio's agriculture from the potential of large-scale economic losses, through disease outbreaks, that again have the potential to cause damages in the billions.

Ohio's investment in the OARDC's operations and infrastructure provides a recognizable dividend to the State through the sustainability and enhancement of Ohio's $79.6 billion agriculture and food-related industry sector. On this impact alone, the OARDC represents a high yield investment. Perhaps even more significant, however, are the potential impacts for Ohio that may be realized through the presence of a pre-eminent life-sciences and ag-biotech R&D center as the U.S. economy moves into what has been termed the bio-century. Plant and animal diversity provides a germplasm pool of immense diversity and promise—certainly a pool far beyond that available in the human genome—thus the OARDC's strong position in the new wave of ag-biosciences bodes well for Ohio achieving a prominent, if not leading position in the most promising area of the knowledge economy.

Following release of the Phase I economic impact findings, TPP moved into an assessment of OARDC R&D core competencies and indentified potential platforms for using agbiosciences to generate technology based economic development in Ohio. The Phase II analysis found OARDC to be well provisioned with areas of scientific excellence and technological expertise capable of forming the foundation for significant potential economic progress. Figure 2 (page 30) illustrates the primary areas in which OARDC was found to have demonstrable expertise and the primary focal areas of R&D being conducted within them. Seven technology platforms at OARDC were seen to have significant merit as broad-based platforms for future progress, including:

- *Genetics, transgenics, and breeding of food plants (focus on, but not limited to, soybeans and tomatoes)*
- *Genetics, trait marker identification, and associated breeding of food animals*
- *Enteric and respiratory food animal diseases, including zoonotic diseases*
- *Food decontamination, sterilization, and associated processing technologies*
- *Ornamental plant genetics and germplasm "mining" for functional genes useful in the agbiosciences*
- *Environmental protection and decontamination technologies focused on soil and water*
- *Composting and advanced potting soil/growing media development.*

These technology platforms represented the identified core competencies in which OARDC had a demonstrable track record of R&D success and which showed promise for future development. Battelle noted at the time that the selection of these seven did not mean that OARDC had no other areas of competency, but rather that other areas were smaller or more embryonic in their development and, therefore, had less "launch platform" potential.

TPP, in turn, developed a recommended structure for OARDC to realize the development potential of these core competency platforms. As envisioned, OARDC was encouraged to form an Agbioscience Initiative with three constituent "collaboratories" directed at the following macro opportunity areas:

Battelle Recommended Collaboratories – 2004 Phase II Report

- **Advanced Food Economy Development –** Leveraging OARDC expertise in food science and technology, in combination with advanced R&D skills in plant and animal breeding, nutrition, processing technologies, and food safety.
- **Biobased Economy Development** – Creating progress in biotechnology and biorenewable industrial commodities to generate an enhanced agbioscience economy and new fast-growth business fields for Ohio.
- **Environmental Economy Development** – Using OARDC strengths in environmental sciences, resource management, and environmental remediation to generate new environmental business technologies and promote an enhanced environmental sustainability and quality of life for Ohio.

As noted on page 28 above, the OARDC and FAES have organized under a three part focused structure comprising

OARDC and FAES Signature Research Focus Areas – 2008

- **Food Security, Production and Human Health –** Focused on improving primary agriculture yields, enhancing the quality of food and feed, and maintaining agrosecurity to assure food security and the basics of nutritional health for a growing global population.
- **Advanced Bioenergy and Biobased Products –** Developing biomass-based advanced energy technologies and value-added bio-based products such as fuels, specialty chemicals and fiber products.
- **Environmental Quality and Sustainability –** Working to understand, protect and remediate the environment and ecosystems to assure long-term sustainability.

Clearly, at the macro level, OARDC has adopted a structure very similar to that recommended by the Battelle project team.

In 2004, the TPP project recommended a series of centers to be formed under each of the three collaboratories. The structure that was recommended is shown in Figure 2. The figure also identifies key components of OARDC R&D that were envisioned as contributing to the success of each collaboratory.

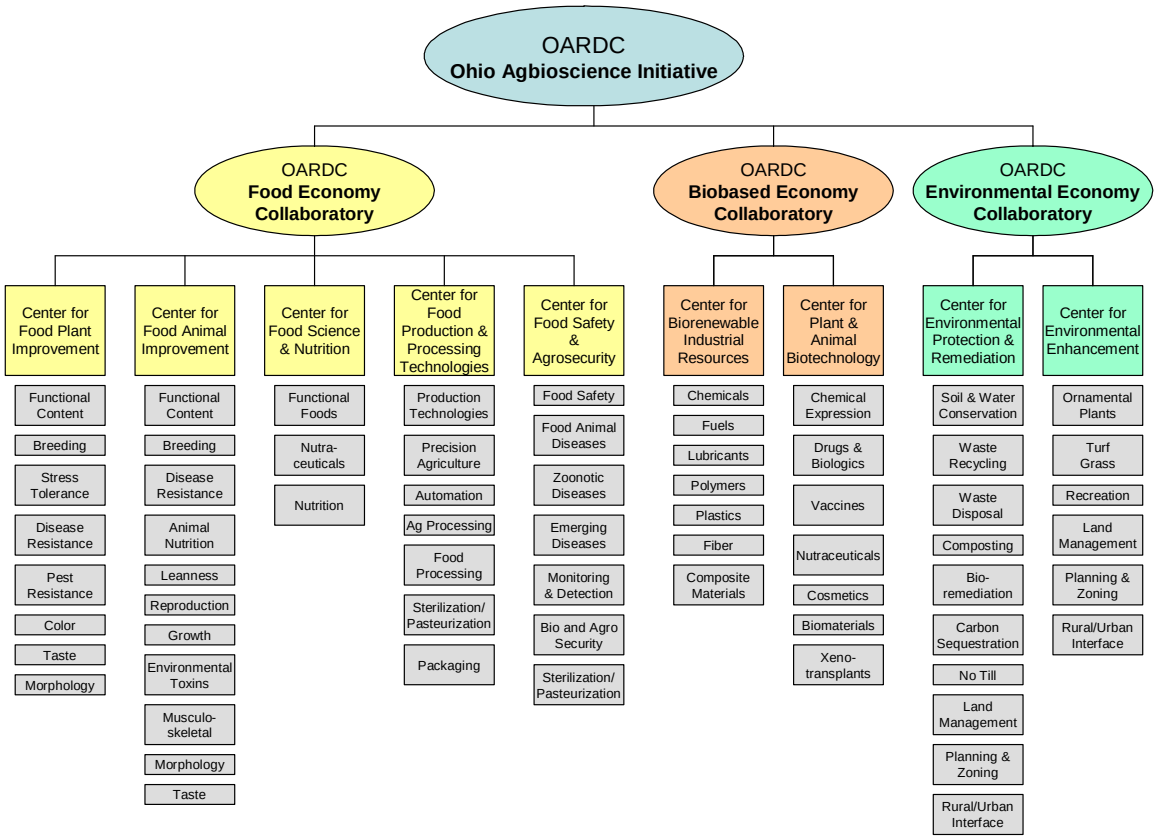
Battelle recommended that the collaboratories be designed to foster both ***internal*** interdisciplinary research among faculty as well as ***external*** linkages and interaction with industry. From an internal OARDC perspective it was recommended that the organization and development of each collaboratory should run concurrently, with faculty and research scientists from multiple OSU/OARDC departments being asked to sign on as members of one or more Collaboratories. From an external economic development perspective TPP noted that it would be critically important to find ways in which to foster linkages with industry and facilitate the commercialization of research discoveries and innovations.

Battelle noted that technology commercialization involves bridging the gap between innovations and discoveries and the commercial development of those discoveries by businesses. Overall, a key mission of the collaboratories was to be the commercialization of OARDC-developed or joint OARDC-Industry developed technology. The collaboratories were expected to foster linkages with industry by:

- Determining its research agendas based on industrial need, with industry driving the process.

- Evaluating research coming out of the technology platforms to determine market opportunities through both technology and market assessments.
- Evaluating commercial potential of patented technologies.
- Forging partnerships with businesses interested in commercializing the agbiosciences.
- Encouraging researchers to commercialize their research through licensing and spin-off opportunities and ongoing collaborations.

Figure 2: Recommended OARDC Agbiosciences Initiative (2004 Phase II Report)



Five years is a short span of time in technologically-driven market sectors. The current attention being paid to biofuels, biorenewables resources and biobased products, for example, is a relatively new phenomenon and was not receiving anywhere near the attention back in 2004. The speed and fluidity of markets, funding streams, and technological progress has meant that some opportunities have become more urgent and others less so in determining the centers, initiatives and programs deployed under the three part macro collaboratory structure.

OARDC has, as evidenced above, put in place a macro structure that follows Battelle's recommendations. The devil though is in the details, and herein TPP examines the specific activities under these collaboratories that have been initiated and evaluates some of the early results being achieved by OARDC. It is at the program and initiative level that individual results are made and positive impacts generated, so it as this level that Battelle focuses much of the evaluation.

The 2008 Review and Impact Update Process

The 2008 TPP review of OARDC progress uses both quantitative and qualitative information to reach conclusions. The following categories of information are presented:

Quantitative Measures

- Current OARDC metrics
  - Organizational Size (budget and staffing levels)
  - Sponsored research trends
  - Intellectual property generation, technology transfer and commercialization
  - Economic impacts of institutional spending

Qualitative Measures

- Formation and operation of focused R&D centers and initiatives
- Activities and progress of focused R&D centers and initiatives
- Conclusions from interviews with internal and external stakeholders
- Initiatives and programs planned for the future

One set of measures examines available statistics and organizational data showing the status of the OARDC, its budget, growth in research and results being achieved in terms of key discoveries and intellectual property generation. The degree to which innovation is being leveraged to achieve commercialization and value-added economic development for Ohio is also examined.

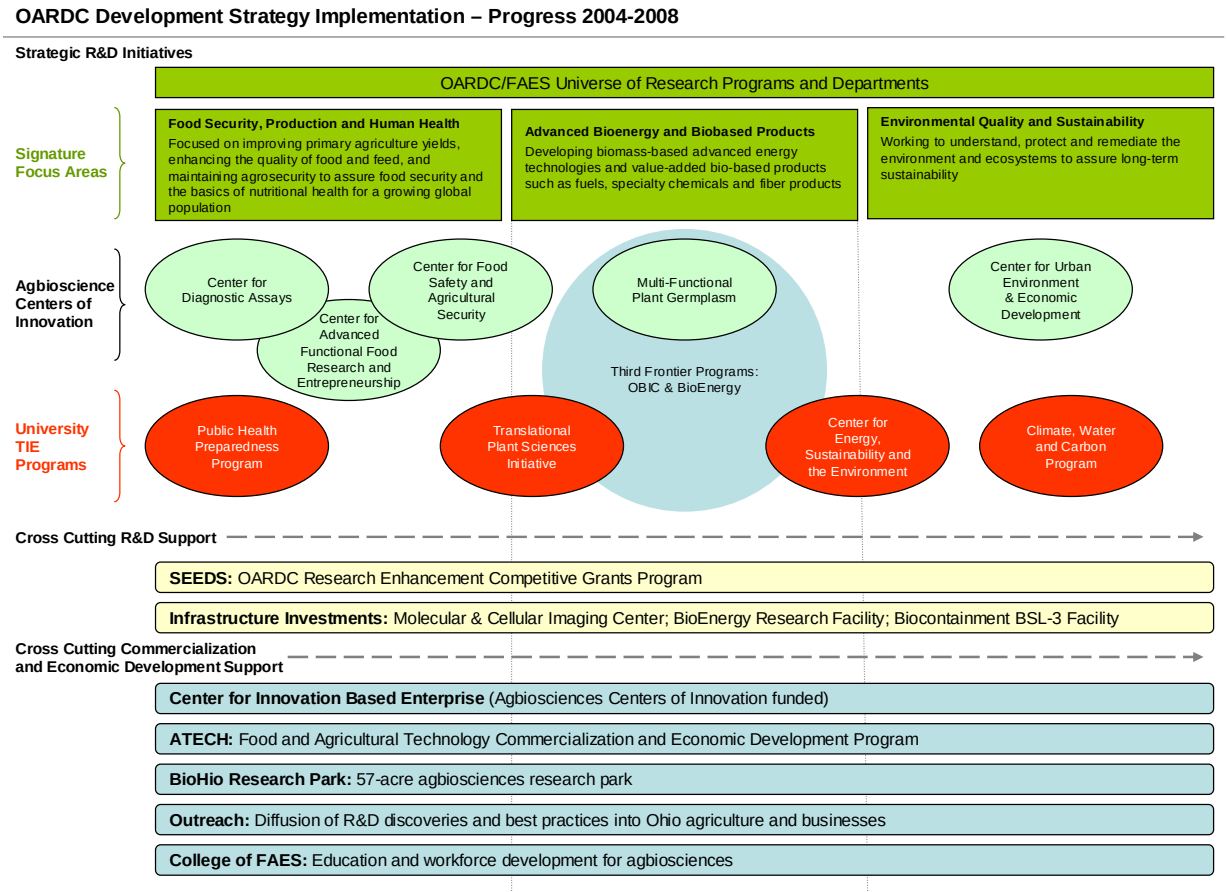
On the qualitative front, Battelle looks in detail, using case studies, at specific areas of R&D being undertaken by the OARDC and its collaborative initiatives. These functional impact case studies are designed to be illustrative of the range of programs being undertaken by the Center and the potential positive impacts for Ohio being generated by them.

II. OARDC: Organizing Along Recommended Pathways

The 2004 research undertaken by Battelle identified multiple opportunities for OARDC to build-upon its already significant economic benefits for the State of Ohio. In particular, recommendations were made for initiatives and programs that would encourage collaborative academic/industry R&D, early stage investigations of commercial viability for OARDC technologies, and proactive work in bringing new discoveries to the market through business development activities and licensing to Ohio entities. Specific opportunity areas were identified along platform-specific pathways, as shown in Figure 2.

OARDC, the College, the University and key stakeholders (such as the State of Ohio and its Third Frontier Initiative) have made significant organizational and financial commitments—forming an integrated system designed to build R&D capacity in strategically focused areas and to leverage R&D discoveries in building an enhanced agbioscience industry base in the State. As shown in Figure 3, OARDC has adopted the three platform model recommended by Battelle, plus it has funded distinctive R&D Agbioscience Centers of Innovation. OARDC has also leveraged the multi-disciplinary power of the University through major participation in multiple OSU Targeted Investments in Excellence (TIE) programs.

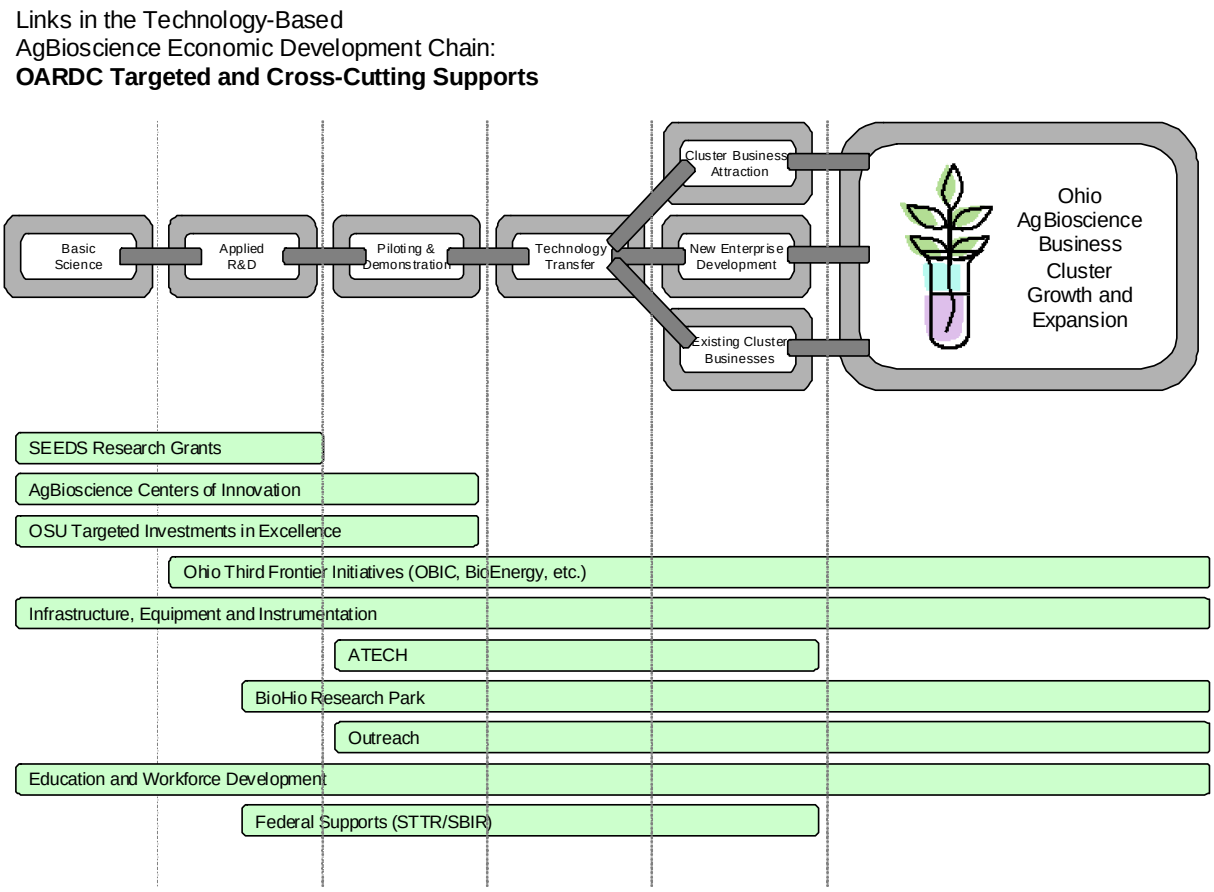
Figure 3: OARDC Development Strategy Implementation – Progress 2004 through 2008



It is evident that the investments made by OARDC and the University in collaborative R&D centers have been a direct match to the three signature focus areas identified in the 2004 work.

In addition to building a focused R&D infrastructure—an infrastructure designed to facilitate working relationships between OSU researchers and industry partners—OARDC has also invested in a series of cross-cutting supports required to translate research discoveries into commercializable innovation. As shown on Figure 4, these cross-cutting supports, in combination with the targeted research programs, provide a thorough series of supports across the technology-based economic development (TBED) spectrum, including:

Figure 4: OARDC Programs in Support of Agbioscience Economic Development Chain



Taken together, the system that OARDC has put in place provides a continuum of support including:

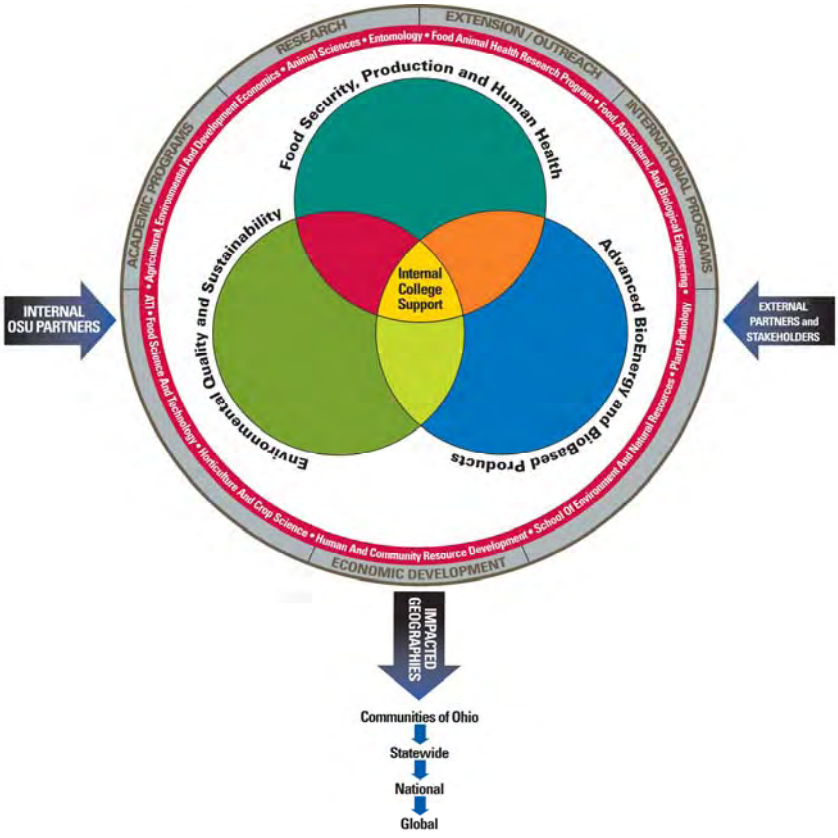
- Support for early stage basic science investigations in areas with potential signature platform linkages.
- Development of applied R&D programs focused on translating basic science discoveries into practical innovations. This is accomplished with both OARDC solo-developed discoveries, and via sponsored research with industry in jointly targeted areas.
- The testing of applied R&D discoveries for true market potential through scale-up and piloting projects, demonstration projects and market feasibility assessment.

- Transfer of proven viable technologies and intellectual property into commercial application along multiple paths including new start-up business development and licensing of technology to existing agbioscience business enterprises.

Ultimately, the development chain focuses on growing and expanding the Ohio agbioscience business cluster. It should be noted that technology-based economic development requires a long-term commitment for success. In North Carolina, for example, the development of the technology business cluster at Research Triangle Park has been a 25-year effort. OARDC has been moving at a comparatively rapid pace in terms of putting in place the supports and programs necessary to enhance agbioscience sectoral growth in Ohio. Initial results are promising (as shown in this report), but programs in support of the TBED chain must be sustained for many more years to realize full agbioscience potential in Ohio.

It should be noted that the College of Food, Agriculture and Environmental Sciences at the University has extended the three signature focus area model across the entire College. This move by FAES brings research, extension and education into alignment in support of excellence in these focus areas. The commitment of the College to this structure is illustrated in the graphics shown in Figure 5 developed by the College with assistance from Battelle TPP.

Figure 5: Three Signature Focus Area Model – College of Food, Agriculture and Environmental Sciences



FAES has developed the summary graphic for four areas: academic programs; research; extension/outreach, and international programs. With OARDC the home for research within the College, the FAES Strategic Plan graphic for research is shown in Figure 6.

Figure 6: OARDC Research Initiatives in the FAES Three Signature Focus Area Model

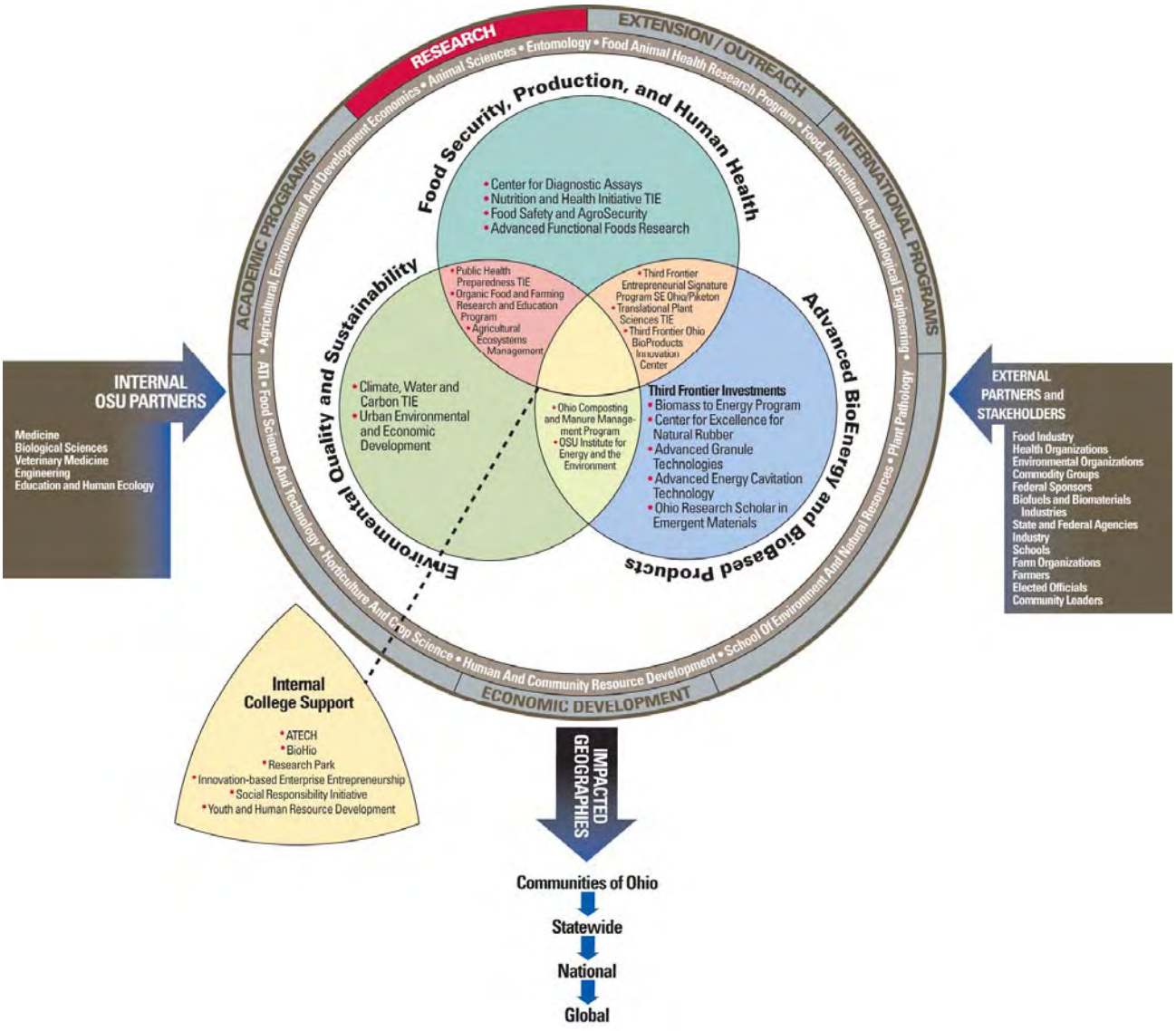
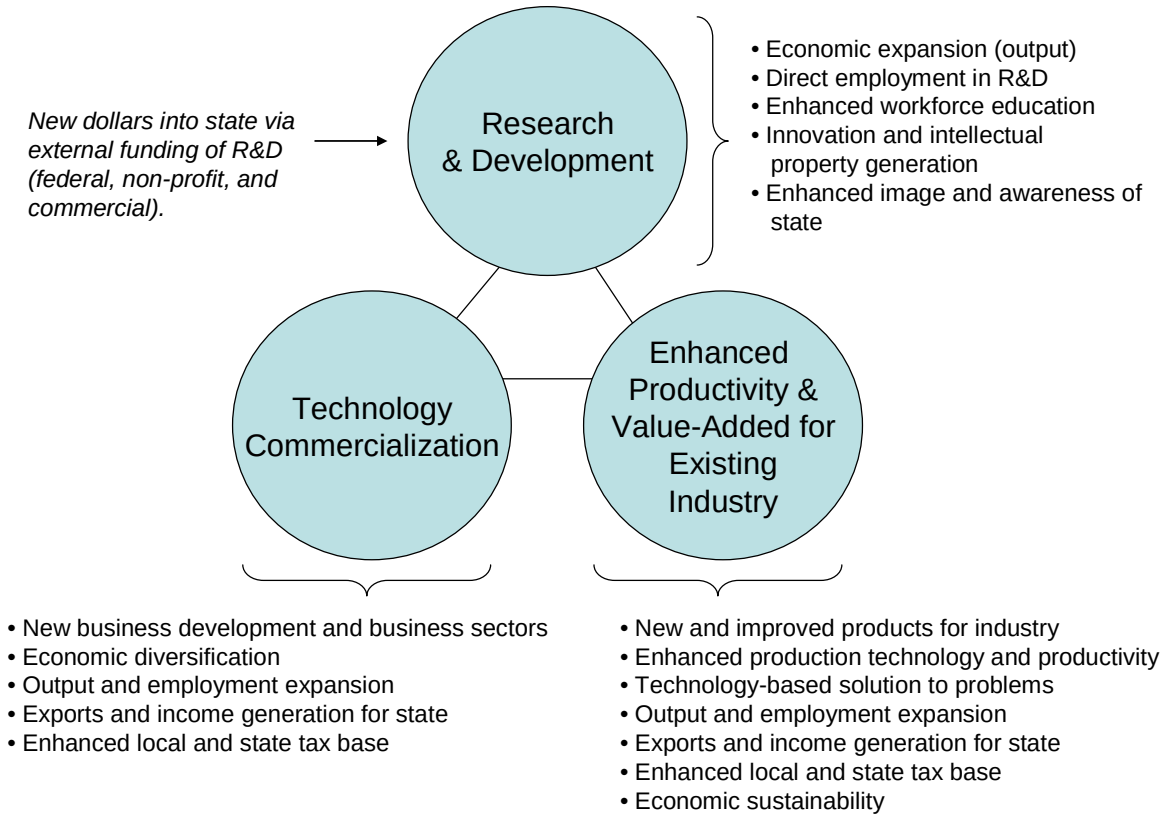


Figure 6 illustrates the three signature focus areas and highlights the many existing OARDC research programs, initiatives and centers that currently service each signature focus. A number of research programs fall within the intersection of two signature focus areas, indicative of the multidisciplinary nature of research and the broad application of agbioscience innovations to multiple issues and needs. It should also be noted, in reference to Figure 6, that OARDC is working to integrate internal OSU partners (in the colleges of Medicine, Veterinary Medicine, and Engineering for example) to bring further multidisciplinary expertise to agbioscience opportunities and applications. Because of the history of service and collaboration embodied in OARDC and Extension, agbiosciences at OSU also benefit from linkages to many external stakeholders and partners. These external relationships are likely to continue to grow in importance as OARDC focuses on applied and translational research, collaborative research with industry, and the commercialization of innovations to spur economic development across Ohio.

By specializing in signature focus areas, OARDC raises its potential impacts on technology-based economic development for Ohio. Technology-based economic development generates economic benefits for states along multiple dimensions (Figure 7). Science and technology R&D in and of itself is a major economic sector and benefits from large-scale out-of-state funding in the form of federal, non-profit and commercial funding streams. Academic and associated commercial R&D generates direct jobs and income for an economy. The functional benefits of R&D move through the economy to provide opportunities for new business development (in commercializing new innovations and technologies), and through enhancements to the existing economic base through innovations and technologies that enhance productivity or generate new business opportunities for existing industry.

Figure 7: Technology-Based Economic Development – Primary Pathways to Ohio Economic Benefits



More detailed discussion of the specific initiatives being undertaken by OARDC and examples of results achieved to-date are the principle focus of the following several chapters of this report.

III. OARDC 2004-2008: Five Years of Progress

The past five years have seen some significant changes at OARDC. The extent to which these changes have resulted in movement in some key metrics is examined in this chapter.

OARDC Sponsored Research

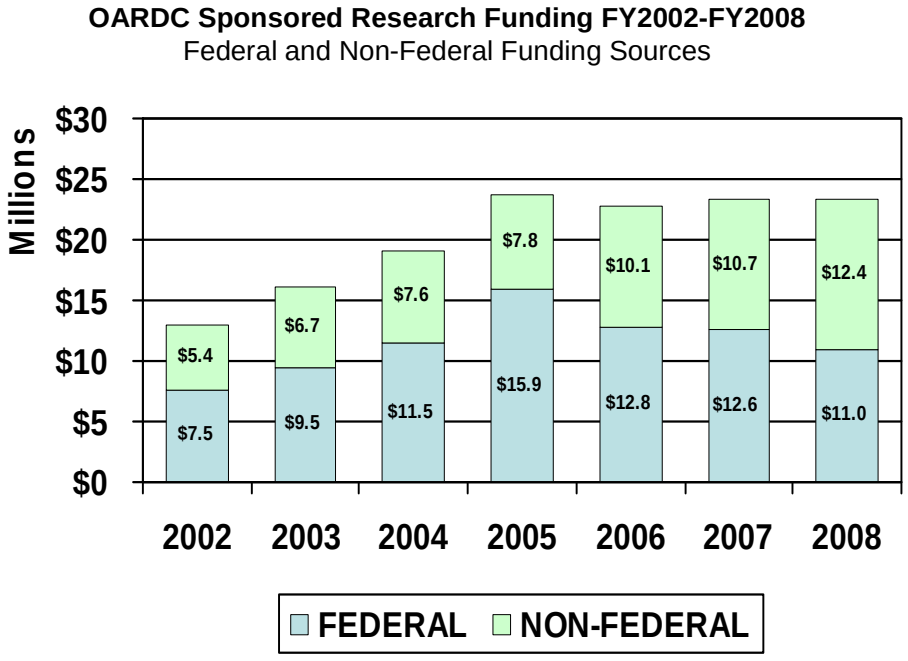
OARDC is the agbioscience research arm of The Ohio State University and, as such, is the recipient of a considerable volume of external research funds for sponsored research. Between 2002 and 2004 OARDC saw external sponsored research grow by $6.1 million from $12.9 million in 2002 to $19 million in 2004. Since the 2004 impact evaluation, the OARDC has continued to grow its external research funding, with total funding in 2007 reaching $23.3 million and 2008 $23.4 million.

It is evident that the primary gains in research funding for OARDC between 2004 and 2008 have come through non-federal sponsored research. The non-federal research funding increased from almost $7.6 million in FY2004 to $12.4 million in FY2008.

Table 1: OARDC Research Funds 2002 through 2008 – Federal and Non-Federal Sources

Year	Federal	Non-Federal	Total
2002	$ 7,513,315	$ 5,403,441	$ 12,916,757
2003	$ 9,470,116	$ 6,730,114	$ 16,200,229
2004	$ 11,489,046	$ 7,563,766	$ 19,052,812
2005	$ 15,931,013	$ 7,795,550	$ 23,726,563
2006	$ 12,793,271	$ 10,050,970	$ 22,844,241
2007	$ 12,564,801	$ 10,719,633	$ 23,284,434
2008	$ 11,015,873	$ 12,401,293	$ 23,417,166

Figure 8: OARDC Research Funds 2002 through 2008



Between FY2004 and FY2005 federal sponsored research funding at OARDC rose considerably—increasing from $11.5 million to $15.9 million. Over the FY2004 to FY2008 time period this increased level of federal funding was not sustained and for FY2008 federal funding has retuned to a pre-FY2004 level of $11 million. Between FY2005 and FY2008 USDA related funding dropped by $2.6 million, and EDA/NOAA/Fisheries funding dropped by $2 million. NIH and NIOSH funding also declined during this time period by $493,000. The main area of federal funding gain in FY2008 versus FY2005 was in environmental research funded through the EPA, which rose by almost $550,000.

The primary success story for OARDC between FY2004 and FY2008 comes on the non-federally funded sponsored research side of the equation. Non-federal research funding totaled $7.6 million in FY2004 and has risen every year since, reaching its current peak in FY2008 with $12.4 million (a 64% increase). Primary gains in this regard have come through research sponsored by non-profit associations and commodity groups (FY2005 funding = 1.5 million, FY2008 funding = 2.3 million), but most notably through state agency funding which increased from $2.1 million in FY2005 to $5.3 million in FY2008. **The state funding increase comes primarily through large scale increases in funding to OARDC by the Ohio Department of Development (ODOD)—which provided less than $0.2 million in FY2005 rising to over $3.3 million in FY2008.** It should be noted that, as with all sponsored research described in this section, OARDC has gained these resources through competitive programs and not by a formula-based process.

The major increase in ODOD funding for OARDC research programs is testimony for ODOD and the State of Ohio's recognition of agbiosciences as a major R&D core competency for the state. Specifically, the ODOD funding shows that the state recognizes agbiosciences as a key driver for future economic development in the state and has stepped forward to fund specific R&D initiatives designed to realize this potential.

With 108 research faculty, the current year $23.4 million in research funding averages to $217,000 per faculty member.

Intellectual Property, Technology Transfer and Commercialization

In a knowledge-driven economy, intellectual property is perhaps the most valuable property that can be produced. As a research and development engine for Ohio, the OARDC is a significant generator of intellectual property (IP) within the state. Data maintained by the Technology Licensing and Commercialization group within the OSU Office of Research shows the following IP activity for OARDC/FAES for 2004 through 2008:

Total Invention Reports (Disclosures)	**57**
Patent Applications	22
Patents Issued	1

Key inventions for 2004 through 2008 are listed on Table 2:

Table 2: OARDC and FAES Faculty Inventions 2004-2008

Title	Lead inventor	Department
Oasis	Beatrice Lado	Food Science and Technology
Apparatus for insertion of a coherent elastic material into soil	Edward McCoy	Environment and Natural Resources
Elimination of foodborne pathogens in ready-to-eat food by high pressure and aromatic food additives 04ID	Ahmed Yousef	Food Science and Technology
Intracellular proteinacious antimicrobial agents from lactic acid bacteria derived from fermented food samples	Ahmed Yousef	Food Science and Technology
Rapid detection system for acid and thermophilic alicyclobacillus spp. And geobacillus spp.	Hua Wang	Food Science and Technology
High yield sugar maple clones	Howard Kriebel	Environment and Natural Resources
Eradication of salmonella enteritidis in shell eggs by ozone-based synergistic treatment combinations	Ahmed Yousef	Food Science and Technology
Natural gene transfer in a mix-laboratory kit for high school science teachers	Hua Wang	Food Science and Technology
Rapid detection system for molds in the food system	Hua Wang	Food Science and Technology
Method to produce shelf stable foods	Q. Howard Zhang	Food Science and Technology
Methods for enhancing soy-containing foods and foods made thereby	Yael Vodovotz	Food, Agriculture and Biological Engineering
Process for predicting meat quality characteristics	Macdonald Wick	Animal Sciences
Modified serial analysis of ribosomal sequence tags (mSARST)	Zhongtang Yu	Animal Sciences
Buckeye sports turf, buckeye turf, turf of champions	John Street	Horticulture and Crop Science
A simple soil quality field test	Khandakar Islam	Environment and Natural Resources
Purification of anti-inflammatory, antiprofilferative, and cytotoxic compounds from Lebanese Centaurea ainentensis	Floyd Schanbacher	Animal Sciences
A bacterium that produces a potent wide-spectrum antibiotic-like substance	Ahmed Yousef	Food Science and Technology
Web garden	Tim Rhodus	Horticulture and Crop Science
A real-time RT-PCR assay for the rapid detection of very virulent bursal disease virus (vvIBDV) strains	Daral Jackwood	Food Animal Health Research Program

Title	Lead inventor	Department
Snap lock fruit bag	Joseph Kovach	Entomology
Novel bacteria seed treatments that enhance corn yield	Brian McSpadden-Gardener	Plant Pathology
Horizontal passive papillary drainage of turf soil profiles	Edward McCoy	Environment and Natural Resources
Microbiological resource management service	Brian McSpadden-Gardener	Plant Pathology
Monoclonal antibody to bovine coronavirus (BcoV)	Linda Saif	Food Animal Health Research Program
Adolescent seeds, an exercise in the classroom	John Finer	Horticulture and Crop Science
X-ray vision technology in seed cleaning and seed quality improvement	David Tay	Horticulture and Crop Science
Tomato analyzer	Esther van der Knaap	Horticulture and Crop Science
Using plant negative strand RNA viruses as transient expression vectors in eukaryotes	Saskia Hogenhout	Plant pathology
Use of byproduct ferrihydrite from water treatment facilities to sorb arsenic, lead, and phosphorus in water supplies	Jerry Bigham	Environment and Natural Resources
Agricultural fan activity sensor	Matthew Darr	Food, Agriculture and Biological Engineering
Shell-egg pasteurization using ohmic and inductive heating	Ahmed Yousef	Food Science and Technology
Enhancing gene expression through the addition of gene activity stabilizing protein (GASP)	John Finer	Horticulture and Crop Science
Cell to Sell	Stephen Myers	OBIC
Using RNA and DNA polymers as scaff9olds and possible vaccine adjuvants	John Lindbo	Plant Pathology
Animal layometer	Matthew Darr	Food, Agriculture and Biological Engineering
Multiwell multiprocessing basket	El-Desousky Ammar	Entomology
The DNA and mRNA sequence of the tomato fruit shape locus sun including the promoter and terminator regions	Esther van der Knaap	Horticulture and Crop Science
Automatic separation of overlapping seedlings by network optimization	Miller McDonald	Horticulture and Crop Science
Tomato-based food products enriched with soy and/or isoflavones	Steven Schwartz	Food Science and Technology
Natural and synthetic soybean promoters which regulate gene expression	John Finer	Horticulture and Crop Science

Title	Lead inventor	Department
Membrane proteins encoded by phytoplasma potential mobile unites (PMUs)	Saskia Hogenhout	Plant Pathology
Improving agroinfection efficiency with suppressors of RNA silencing	John Lindbo	Plant Pathology
Simultaneous detection and semi-qualification of common foodborne pathogens	Zhongtang Yu	Animal Sciences
Flexible fuel combustor	Harold Keener	Food, Agriculture and Biological Engineering
Tea Infusions	Maria Giusti	Food, Agriculture and Biological Engineering
Fruit juice and soy gummy confection	Yael Vodovotz	Food Science and Technology
College 101: Strategies for 1st year Success	Louis Raison	OSU Extension
Confidential (withheld at present time)	Maria Giusti	Food Science and Technology
Confidential (withheld at present time)	Louis Rodriguez-Saona	Food Science and Technology
Confidential (withheld at present time)	Louis Rodriguez-Saona	Food Science and Technology
Confidential (withheld at present time)	Parwinder Grewel	Entomology
Confidential (withheld at present time)	Peter Ling	Food, Agriculture and Biological Engineering
Confidential (withheld at present time)	Macdonald Wick	Animal Sciences
Confidential (withheld at present time)	Brian McSpadden-Gardener	Plant Pathology
Confidential (withheld at present time)	Brian McSpadden-Gardener	Plant Pathology
Confidential (withheld at present time)	Sally Miller	Plant Pathology

Economic Impacts of Institutional Spending

As an operating entity, irrespective of the benefits of its scientific discoveries, the OARDC generates a significant economic impact in the State of Ohio. The Center receives funds from the federal government, extramural funding sources, industry contracts and allocations from the State of Ohio—and it invests these funds in infrastructure, resources and human capital to benefit the state and the agricultural sector. In turn, the expenditures of the OARDC and its faculty and staff within Ohio, in and of themselves, become a significant generator of economic impact. Analysis by Battelle of the OARDC's direct and indirect expenditure impacts, using input/output analysis, shows that the FY2008 expenditures of OARDC in Ohio generated the following impacts:

- **$156.3 million in total Ohio economic output (sales)**, comprising $78.3 million in direct economic output and $78.0 million in indirect output.
- The operations of the OARDC also support **1,609 jobs in Ohio**, comprising 786 direct jobs and a further 823 jobs generated in the Ohio economy via the employment multiplier effect.
- OARDC direct and indirect employment generates **personal income for Ohio residents amounting to $59.2 million annually**. This is divided between direct OARDC income at $33 million and $26.3 million in indirect income.

- While state government is an important funder of OARDC operations, it also receives revenue cycled back to the State through OARDC generated taxes. The OARDC directly and indirectly generates **$5.5 million in annual tax revenues**.

The spending impact results are shown in more detail on Table 3:

Table 3: Economic Impact of Direct Center Expenditures in the Ohio Economy (FY2008)

OARDC Impact	Output	Value Added	Income	Employment
Direct	54,860,741	34,651,181	22,822,239	535
Indirect	52,802,009	27,065,364	17,445,375	551
Total OARDC	107,662,750	61,716,544	40,267,615	1,086

OSURF Impact	Output	Value Added	Income	Employment
Direct	23,417,166	15,393,221	10,138,407	251
Indirect	25,263,442	12,744,323	8,841,952	272
Total OSURF	48,680,608	28,137,544	18,980,359	523

Total Center Impact	Output	Value Added	Income	Employment
Total Center Direct Impacts	78,277,907	50,044,401	32,960,646	786
Total Center Indirect Impacts	78,065,451	39,809,687	26,287,328	823
Total Center Impacts (Direct + Indirect)	**$156,343,358**	**$89,854,088**	**$59,247,974**	**1,609**

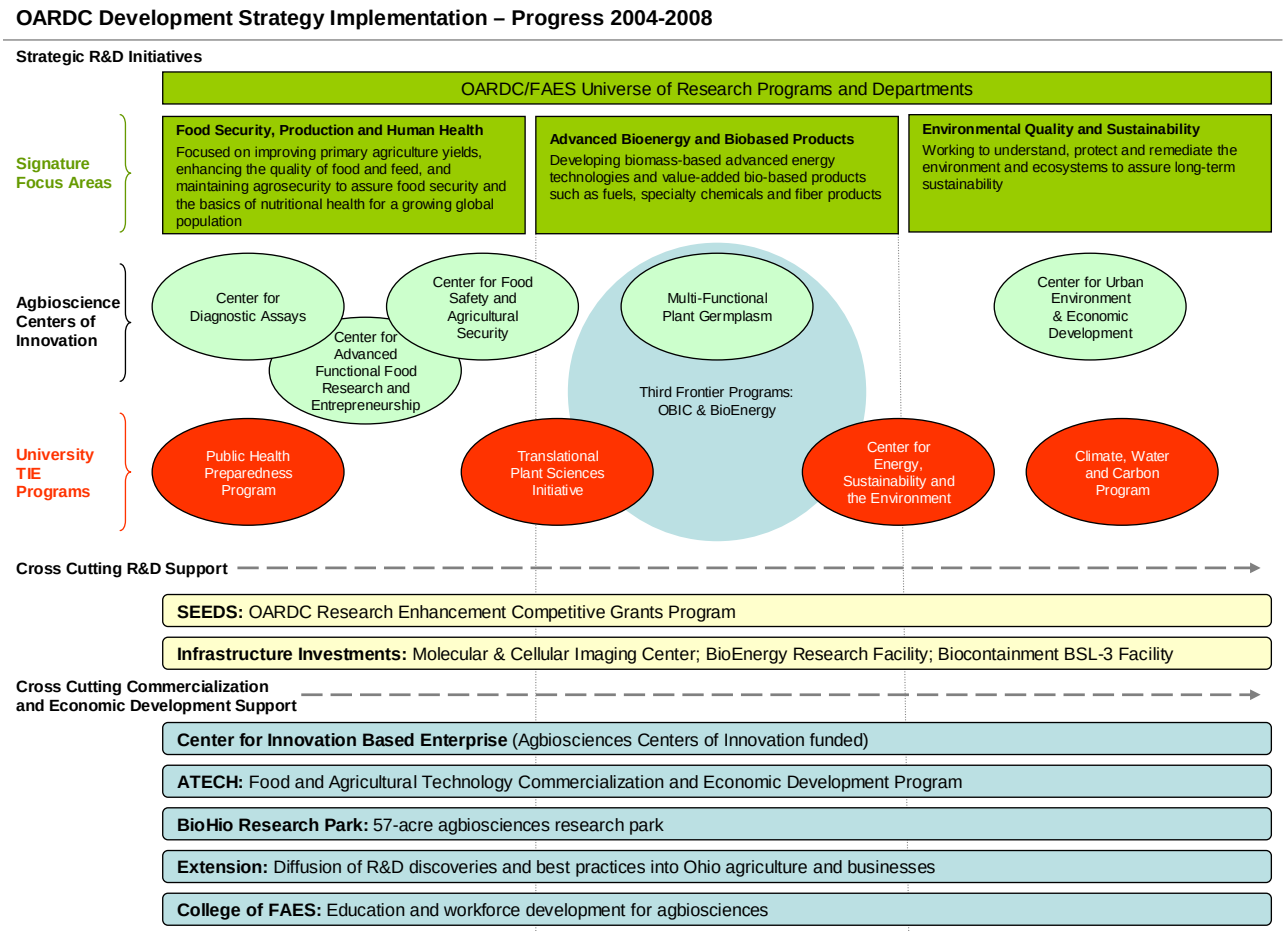
Note: Impacts presented are for a 12 month period (FY2008). Impacts repeat each year, fluctuating in relation to the OARDC's expenditures each year.

These are simply the impacts realized by the FY2008 expenditures of the OARDC and its associated faculty and staff, and the follow-on multiplier effect of these original direct expenditures. The full impact generated by the Center's scientific discoveries, production enhancements and practical solutions for farmers is, of course, far larger resulting from the functional impacts of OARDC research and development. Functional impacts are discussed in the next chapter.

IV. Functional Impacts of Signature Focus Areas

As noted in Chapter II, OARDC adopted the three platform structure recommended by Battelle and has made significant progress in providing a suite of programs and support initiatives designed to accelerate R&D and technology commercialization within the platforms. OSU refers to these platforms as "signature focus areas" (Figure 9). The use of the "signature focus area" terminology aligns with The Ohio State University's adoption of the term across the university.

Figure 9: Current OARDC R&D Structure and Supporting Initiatives for Commercialization



As Figure 9 illustrates, numerous Agbioscience Centers of Innovation have been formed under the signature focus areas, and four of the OSU Targeted Investment in Excellence (TIE) programs have a strong focus on agbiosciences research and development. Third Frontier programs likewise fall under the signature focus areas, with a special emphasis on biobased products and bioenergy in the Advanced Bioenergy and Biobased products signature focus area. Underpinning and supporting the R&D work of these Centers of Innovation, TIE and Third Frontier centers are OARDC investments in cross-cutting R&D support together with supports for innovation commercialization and proactive economic development activities.

When seen as an integrated and systematic whole in Figure 9 it is clear that OARDC has aggressively pursued the format recommended by Battelle and has built upon it to create a robust applied R&D and economic development engine for agbiosciences in Ohio.

In this chapter of the report, Battelle focuses attention on the centers and programs funded and developed by OARDC. Evaluation is performed of progress being made in these programs and observed impacts are highlighted.

OARDC Agbioscience Centers of Innovation (ABIG Centers)

Battelle's 2004 study of OARDC core research competencies identified the strengths of the Center in producing high quality science and associated innovations. One of the identified challenges, however, was in the process of translating technological innovations into commercial products. OARDC had been largely following the traditional academic pathway of *"discover → publish"* and the traditional land grant model of *"discover → diffuse into practice via extension"*.

OARDC has, since 2004, made alterations to its priorities—placing an increasing emphasis on a pathway that includes: *"discover → commercialize (ideally in Ohio)"*. This expansion of work along this pathway has been facilitated by the the AgBiosciences Innovation Grant (ABIG) Program. The program was specifically designed to accomplish the overall goal of transforming discovery and knowledge into innovations that have positive economic, social, and environmental impacts that will contribute to local and state economies and promote an entrepreneurial culture within the agbioscience university setting.

Introducing the program, OARDC noted that:

Despite the impact that university-based research has made to the U.S. and Ohio economies the rate that discoveries are commercialized is slow and the process inefficient. Programs that identify and facilitate moving research ideas to market are urgently needed. These programs must provide resources that identify the product path to market including discovery and disclosure, protection of intellectual property, conducting market assessments, developing prototypes, identifying investors, and finding the manufacturing and distribution partners to turn discoveries into commercial realities. In addition, they must bridge the cultural and procedural gaps between the university and business worlds and, in general, overcome obstacles in the path to market. These programs should accelerate the flow of discoveries that make their way to commercially available products and services and result in positive economic, environmental, and social impacts.

The OARDC's targeted response to this identified need was the ABIG program, comprising competitive grants for the establishment of interdisciplinary programs or centers that address issues in the three signature focus areas of:

- **Food Security, Production and Human Health** *(Formed out of Battelle's recommendation for a Food Collaboratory)*
- **Advanced Bioenergy and Biobased Products** *(Bioproducts Collaboratory)*
- **Environmental Quality and Sustainability** *(Environmental Collaboratory).*

The ABIG grants were specifically designed to support the formation of programs and centers that would focus on specific industry problems and issues leading to commercially available products. As such, the ideal grant award would help form centers that:

1. Build upon existing areas of research excellence at OARDC.

2. Target practical, commercializable solutions to identified market needs.
3. Collaborate with industry to identify needs and facilitate the transfer of technology to a commercial entity (either existing or newly formed).

With the ultimate goal being economic development for Ohio via technology commercialization, it was anticipated that commercial relationships would be with Ohio firms or other organizations able to realize development of technologies within the state. The long-term goal would be for each center initially funded through the grants to become self-sustaining, forming a hub for technology development serving a growing cluster of businesses in its field.

As Figure 9 shows, OARDC has initially funded six centers (five of which are specific to individual signature focus areas and one that provides cross-cutting support for innovation based enterprise). The Centers are as follows:

Table 4: Six ABIG Funded Centers

Center Name	Signature Focus Area With Which Aligned	Center Theme
Center for Diagnostic Assays http://oardc.osu.edu/cda/	Food Security, Production and Human Health	This center focuses on developing diagnostic tests for infectious pathogens impacting the health of food-producing animals and plants, and the safety and security of food supply. Center scientists have been working on development of molecular-based diagnostic assays for diseases such as infectious bursal disease virus (IBDV) of poultry, crop-damaging phytoplasma bacteria, and E. coli.
Center for Advanced Functional Food Research and Entrepreneurship http://fst.osu.edu/caffre/	Food Security, Production and Human Health	Functional foods are foods that may provide medical or health benefits beyond basic nutrition because of the presence of physiologically active compounds. This center focuses on developing functional foods with commercial potential—including berry compounds that fight cancer, heart-healthy soy bread, and a soy-tomato drink to combat cholesterol
Center for Food Safety and Agrosecurity http://fst.osu.edu/abig/	Food Security, Production and Human Health	Food safety and security are high national priorities with major local impact. This center brings advances in food safety to commercial applications, including novel processing techniques that eliminate dangerous bacteria (e.g., ozone and UV radiation for Salmonella in eggs), tamper-proof caps for food packages, and rapid tests to diagnose foodborne pathogens such as noroviruses.
***The Ohio BioProducts Innovation Center (OBIC)* – Program in Commercialization of Multi-functional Plant Germplasm** http://bioproducts.osu.edu/	Advanced Bioenergy and Biobased Products	The Third Frontier funded OBIC focuses on the development of renewable plant-based specialty chemicals, polymers, and industrial products. The ABIG funded center within OBIC is leading initiatives focused on plant breeding and transformation to create high-yield, disease-resistant varieties of soybeans, wheat, and corn, with specific value-added traits. The goal is the production of commercially viable plant varieties suitable as feedstocks for the production of industrial chemicals and products such as bio-based polymers and plastics.
Center for Urban Environment and Economic Development	Environmental Quality and Sustainability	This center builds on Ohio's active leadership in ornamental plants and the "green" sector. It is primarily focused on developing and commercializing new organic and biological products to meet the fertility, pest control, and pollution mitigation needs of rapidly expanding urbanized landscapes. Technologies being developed include pest-killing nematodes for turf grass improvement, biocontrol-amended

Center Name	Signature Focus Area With Which Aligned	Center Theme
		soils, and techniques for reclamation of urban brownfield sites.
Center for Innovation Based Enterprise http://cibe.osu.edu/	Cross-cutting support for all signature focus areas and commercial opportunities within the College and OARDC	This center was established, leveraging OSU expertise in Agricultural Economics and business development, to formally address barriers to product commercialization. The Center provides cutting-edge research into entrepreneurship, contract design, finance, marketing, and risk management for innovation-based and start-up Agbioscience enterprises.

The ABIG program was launched in 2005 with a formal request for proposals from largely multidisciplinary research teams. Selection of funded centers was made in December of 2005, with funds released starting in FY2006. With just two-years of operational activity for most of the centers (some less) there are already significant results being achieved. Some of the early results of the program and potential impacts being generated for the benefit of Ohio are profiled below:

Center for Diagnostic Assays

The Center for Diagnostic Assays has been funded with $300,000 over five years. The Center's primary focus is on diseases of food animals and zoonotic diseases (animal diseases that may also infect humans), although it also includes in its initial remit work on plant disease diagnostics.

The Center's objectives are to:

1. Facilitate the commercialization of existing technologies and intellectual property related to diagnostics by attracting new industries to Ohio.
2. Validate and improve diagnostic reagents and assays currently in development, to explore the development of new molecular based diagnostic assays and to establish new collaborations between veterinary and plant scientists.
3. Protect OARDC-developed diagnostic reagents and assays through invention disclosures and patents where appropriate.

The CDA notes that…

Diagnostic assays are essential to the health of food animals and plants, and the safety and security of our food supply. Diagnostic assays for infectious pathogens are indispensable for veterinarians, commodity groups, biologics companies, state and local diagnostic facilities, producers and federal agencies. The strengths of the Center lie in the existing diagnostic assays and the support of these assays by validation panels and libraries of strains in each investigator's laboratory. Furthermore, some of the intellectual property has been protected by invention disclosures and patents.

The Center has built upon OARDC's well-known cluster of researchers in food animal health research. Researchers at OARDC have acknowledged expertise in food animal health and immunology, enteric and respiratory diseases for food animals, and associated food safety and human health issues.

Achievements:

- Formed a unique center without peer in other academic institutions.
- Educated OARDC researchers in how to bring their innovations in reagents and diagnostics to the marketplace, including education in intellectual property protection and IP marketing.
- Molecular-based diagnostic assays have already been developed for several infectious agents including Mycobacterium, prion proteins, E. coli 0157, Bovine torovirus (BToV), infectious bursal disease virus (IBDV) (Patent #6,114,112), vvIBDV (Patent pending), as well as biological control agents Trichoderma hamatum 382, and DAPG producing Pseudomonas fluorescens.
- Diagnostic assays in development include those for Mollicutes (phytoplasma species), soybean rust pathogen, soybean root pathogens, Bacillus subtilis strains with plant disease biocontrol activity, Enterobacter sakazakii which causes meningitis in humans, and monoclonal antibody based BToV and vvIBDV assays.

High Impact Discovery: Real-Time PCR Assay for Rapid Detection of Very Virulent Infectious Bursal Disease Virus (vvIBDV)

The CDA's discovery of a RT-PCR assay for the rapid detection of nucleotide sequences unique to vvIBDV is a critical advance in the fight against a disease of significant and growing negative economic impact to the global poultry industry. The CDA discovery is the only validated tool for detection of vvIBDV and the intellectual property is patent pending.

The development of the CDA's vvIBDV real-time assay is providing a front-line tool for monitoring and controlling the spread of this immunosuppressive poultry disease.

The patent pending vvIBDV assay builds upon OARDC's existing strengths and technologies in the field. The institution already holds the patent on molecular-based diagnostic assays for infectious bursal disease virus (Patent #6,114,112).

According to recent analysis performed by Battelle, the poultry and egg production industries have a total economic impact on Ohio of over $861 million annually and generate almost 8,700 jobs in the state. Protecting this industry from one of the most economically significant diseases of the poultry industry is critically important to sustaining this important agricultural industry for the state. Because IBDV is able to rapidly produce mutated viruses that are resistant to vaccines the vvIBDV strain causes unusually high morbidity and mortality

Future Goals:

- The CDA is building an online forum which will serve as a real-time information retrieval and forum site for anyone in the U.S. and globally needing the latest information and advice in diagnostics. Key audiences for the forum will be academic researchers, government researchers and industry, in addition to assay users, readers and assay labs. There is no such comprehensive forum on the market, and it is expected that the forum will be developed as an income generating engine for the CDA, perhaps spinning out as a separate commercial company.
- Commercialization of diagnostic assays for food and animal diseases is currently hindered by a lack of a non-human diagnostic disease industry base in the state. A key focus of the center moving forward will be to: a) help existing human diagnostics companies in Ohio branch into animal and plant diagnostics, b) attract an animal/plant diagnostics company from out of state to locate an operation at the new Biohio Research Park at OARDC in Wooster, and c) build new companies in Ohio built around CDA developed technologies.

- Build upon and leverage increasingly strong research infrastructure, including the new Bio-Security Level III (BSL3) research facilities slated for completion at the Wooster campus in 2010.

Case Study: Protecting Ohio's Livestock Agriculture

Food animal health is an important economic consideration for Ohio where livestock comprises a substantial component of agriculture in the state. **Research performed in 2008 by Battelle, sponsored by the Ohio Soybean Council, shows the livestock sector having the following Ohio economic impacts:**

- **$3.6 billion in Ohio economic output.**
- **45,692 jobs in the state directly or indirectly related the livestock sector**
- **Generation of more than $396 million annually in personal income for Ohioans.**

With so much economic value on the line it is imperative that livestock producers have access to the latest in advanced animal disease diagnostics in order to prevent outbreaks and spreading of contagions.

USDA statistics show food animal disease outbreaks reducing annual livestock revenues by 1.8%. **Reducing Ohio livestock revenues by this normative amount, and extrapolating the impacts across the full livestock value chain, equates to almost $65 million in Ohio economic output at risk to livestock disease outbreaks.** Diagnostics technologies, therefore, not only have intrinsic value as direct technologies for sale, their application also brings significant benefits in terms of potential negative impacts prevented.

It is clear that the Center for Diagnostic Assays has attracted the participation of a world-class group of OARDC scientists. The experience of these researchers in infectious diseases and molecular-based diagnostics has resulted in the development of several diagnostic assays that are now being marketed.

Center for Advanced Functional Food Research and Entrepreneurship

The primary goal of the Center for Advanced Functional Food Research and Entrepreneurship (CAFFRE) is to discover and develop functional foods with special application to the treatment or prevention of major chronic diseases (such as obesity, diabetes, vascular diseases, arthritic and autoimmune conditions, and neurodegenerative diseases). OARDC defines functional foods as food products providing health benefits beyond their contribution to nutrient requirements and that demonstrate significantly contributions to the mitigation of disease. CAFFRE is pursuing the discovery and development of functional food products that assist in health promotion, disease prevention and treatment of specific diseases and disorders.

The Center has targeted the following areas to enhance the health properties of food:

- **Plant and horticultural science studies** – Investigating and developing unique food crops, assessing optimized growing conditions, improving breeding efficiency, and examining genetic mechanisms to enhance health promoting characteristics
- **Food science, product development, and processing** – Working to optimize, produce and conserve positive bioactive components of foods through the formulation, processing and packaging phases of production

- **Food chemistry and nutrient and phytochemical analysis** – Investigating the physico-chemical interactions among ingredients that enhance positive biological activity
- **Preclinical screening of novel food products and ingredients** – Evaluating bioactivity, safety, toxicology, and mechanisms of action through in vitro models, and using in vivo/preclinical models in studies to determine potential health benefits, mechanisms of action, specific biomarkers, and bioavailability.
- **Phase I and phase II human clinical trials / human translational research** – Planning and conducting studies to evaluate the safety and tolerability of functional food ingredients, pharmacokinetics and dose response, mechanisms of action and potential derived health benefits and overall efficacy. CAFFRE is able to provide the design and implementation of human Phase II clinical trials.
- **Market, regulatory, and agricultural economics studies** – Supporting product development via market research and evaluation, regulatory studies, consumer behavior studies and economic analysis.
- **Entrepreneurship, technology transfer, and intellectual property rights resources** – working with other OARDC entities, including ATECH and the Center for Innovation Based Enterprise to facilitate IP protection, commercialization and new functional foods business development.

Achievements:

It is evident that CAFFRE and its affiliated research teams have achieved considerable success in attracting grant funding for their functional foods research. Table 5 summarizes funding tracked by CAFFRE:

Table 5: Funding for CAFFRE Projects

Funding Source	Active Projects	All Projects To-Date
National Institutes of Health (NIH)	$7.9 million	$10.2 million
U.S. Department of Agriculture (USDA)	$2.2 million	$4.5 million
Other federal or non-profit source	$1.7 million	$1.9 million
University funding	$1.6 million	$2.2 million
Ohio organizations	$0.2 million	$0.3 million
Industry	$0.3 million	$1.3 million
Total	**$14.0 million**	**$20.4 million**

It is clear from these research funding figures that CAFFRE has provided a strong return on the University's original center investment of $300,000.

CAFFRE research teams are showing particular strengths in the following functional food areas:

- Tomatoes and Carotenoids[7]
- Berries, Anthocyanins[8], and Resveratrol[9]
- Soy and Isoflavones[10]
- Cruciferous Vegetables[11], Glucosinolates[12], and Isothiocyanates[13]
- Fatty Acids.

The above contain or constitute a series of phytochemicals where evidence demonstrates significant health benefits. These chemicals are being found to have benefits in cancer prevention, cholesterol reduction, the reduction of inflammation, promotion of cardiovascular health and a healthy immune system.

CAFFRE is a particularly sound investment for The Ohio State University since the University is one of the few in the country with strong programs in agbioscience, veterinary medicine and human medicine all on one campus. OSU is able to bring significant resources to bear in evaluating and developing functional foods. The center has active faculty and relationships in across six OSU colleges: Medicine, Public Health, Biological Sciences, Veterinary Medicine, Education and Human Ecology, and the College of Food, Agriculture and Environmental Sciences.

CAFFRE has been successfully accelerating several key functional food technologies along the pathway to market. Some key examples with significant economic development potential for Ohio include:

CAFFRE and Intellectual Property Development

While CAFFRE's primary stated purpose is advancing the science of functional foods through basic and applied R&D, the Center's work has also generated commercializable IP. Commercial development work has been active in:

- Tomato-based food products enriched with isoflavones
- Oral gels containing freeze-dried black raspberries
- Tea infusions
- Fruit juice and soy-based confections.

Patent pending technologies developed by CAFFRE scientists include:

- Methods for enhancing soy-containing foods
- Formula and process for making soy-based bakery products
- Anthocyanin determination in biological specimens using chromatography and spectrometry.

[7] Carotenoids are a group of more than 700 compounds that produce the red, yellow, and orange colors found in many fruits and vegetables. Antioxidant properties are associated with these compounds.
[8] Anthocyanins A group of flavonoids (a family of phytonutrients) that impart a blue or red color to some plant foods. Examples are purple cabbage, beets, blueberries, cherries, raspberries, purple grapes, black beans, wild rice, etc. Antioxidant properties are associated with these compounds.
[9] Resveratrol is a phytoalexin produced naturally by several plants when under attack by pathogens such as bacteria or fungi. In mouse and rat experiments, anti-cancer, anti-inflammatory, blood-sugar-lowering, chelating and other beneficial cardiovascular effects of resveratrol have been reported.
[10] Isoflavones are a phytochemical with a chemical structure similar to estrogen. They are particularly prevalent in soybeans, and to a lesser extent in other legumes. Isoflavones may directly inhibit bone resorption and prevent the onset of osteoporosis, and the weak estrogenic effects of isoflavones have been postulated as being protective against various forms of cancer.
[11] Cruciferous vegetables are vegetables in the cabbage family, such as broccoli, cauliflower, brussel sprouts, kale and all cabbages. Anticancer properties have been associated with these vegetables.
[12] Glucosinolates are phytochemicals found in cruciferous vegetables and are associated with antioxidant properties.
[13] Isothiocyanates are phytochemicals found in cruciferous vegetables and are associated with anti-cancer properties.

- **Soy-enhanced Bread Products.** Advancements have been made with soy enhanced bread. The soy bread "Healthyhearth" has moved from lab, to commercial prototype and into limited retailing. The soy protein in the bread gives it the ability to be marketed with the FDA's heart healthy label. With the U.S market for bread constituting an $18.5 billion market in 2007[14], heart-healthy bread presents the opportunity for significant domestic sales.
- **Soy-enhanced Tomato Juice.** Experiments have shown cardiovascular benefits through soy-enhancement in terms of oxidative resistance to LDL and VLDL cholesterol, and for improving the positive ratio between total cholesterol and HDL cholesterol. Further study has been investigating benefits in the prevention of prostate cancer also.
- **Oral Cancer Prevention via Black Raspberries.** CAFFRE researchers have shown both in vitro and in vivo cancer prevention benefits from the consumption of black raspberries. This has resulted in the development and testing of two products—a black raspberry lozenge and an oral gel containing freeze dried blackberries—both designed for topical application against oral cancers.

With the global market for functional foods estimated to reach $90.5 billion by 2013[15], there is significant potential for significant functional foods based economic development to occur in Ohio. This is not just hopeful thinking. Ohio already has a food processing sector accounting for $11.1 billion in gross state product[16] so, rather than trying to introduce a new sector for the state, functional foods represent enhanced product opportunities for an existing sector—thereby leveraging infrastructure and distribution channels that already exist in the state. Functional foods represent a distinctive opportunity for the state building upon an established and growing R&D capability in the state (from agriculture through food processing and on into human health), clinical testing and trials capability, and commercial product production, packaging and distribution.

Company Relationships

Indicative of CAFFRE's appeal to industry partners, the Center has established confidential disclosure agreements with:

- Coca-Cola
- Nestle USA
- Wyeth Pharmaceuticals
- R&S Sprouts, LLP
- WellGen, Inc.
- BioDerm Technologies.

The challenge for CAFFRE is not in generating interest from industry – rather it is assuring relationships are in R&D rather than testing services. CAFFRE seeks strong partnerships that advance science and technology. The Center is less interested in contract validation and testing services regarding the function of food constituents.

It is possible that a separate for-profit corporation could spin-out of OSU to provide more basic testing and validation services.

Center for Food Safety and Agrosecurity

The Center for Food Safety and Security predominantly focuses on leveraging OARDC expertise in

[14] www.researchandmarkets.com/reports/614538
[15] http://www.prlog.org/10139488-global-market-review-of-functional-foods-forecasts-to-2013-now-available-through-aarkstore.html
[16] Thomas L. Sporleder. "OHFOOD: An Ohio Food Industries Input-Output Model." Version 9.0, November 2007. The Ohio State University, AED Economics Department.

microbiology, pathogen detection, and packaging technologies in developing technological solutions to the threat of food-borne pathogens.

The food sector in Ohio is a major driver of the Ohio economy, as noted in a recent report to the state:

> *Ohio is home to a varied and substantial agricultural and food sector. Ohio ranks among the top ten states in many agricultural commodities, including corn, soybeans, winter wheat, eggs, chickens, and hogs, as well as a number of crops in the fruit and vegetable industry, such as sweet corn, fresh tomatoes, cucumbers, apples, and strawberries. The diverse nature of Ohio's agricultural production reflects its varied growing regions and natural resources. When the agricultural sector is aggregated with the food sector, the economic contribution to the state is staggering. The food and related agricultural cluster accounted for $98.2 billion of economic output in 2006. Ohio's agricultural processing sector is one of the fastest growing subsectors in Ohio's economy.*[17]

As natural products for human consumption, food products have to be protected from contamination by illness causing pathogens. In addition to naturally occurring pathogens, ongoing vigilance against bioterrorism also places a new burden on producers, processors and distributors to prevent the deliberate introduction of pathogens or toxins to the food supply. The recent introduction of melamine into baby formula supplies in China vividly illustrates the impact of tainted food—with CNN reporting on September 19th 2008 that circa 13,000 Chinese infants had been sickened by tainted milk[18].

Case Study: Safeguarding Egg Production in Ohio

Producing 7.5 billion eggs per year, Ohio ranks second in the nation in egg production. Production was valued at $279 million in 2006, with a total impact on the Ohio economy of $527 million, and supported over 5,300 jobs in the state. Industry efforts to reduce *Salmonella* in eggs have already resulted in a halving of cases in Ohio since 1997. Now, the work of the OARDC research teams is targeting a further significant reduction.

The potential economic benefits from *Salmonella* elimination technologies in eggs would be highly significant. The USDA ERS estimates from extrapolation of monitoring system data that 1.4 million cases of *Salmonellosis* occurred in the United States in 1997.[1] On a normative level, this would equate to 56,000 cases in Ohio. A halving of this rate through the food safety initiatives targeting *Salmonella* in Ohio would equate to more than 28,000 *Salmonellosis* illnesses avoided per year. ERS data place the average cost of a *Salmonellosis* case at between $331 and $1,664 (two different methodologies were used to derive the two separate estimates). **On this basis, the estimated cost savings to Ohio through the *Salmonella* reduction initiatives adopted by the vertically integrated livestock industry would equal between $9.3 million and $46.6 million.**

The development of advanced food safety and security technologies thus has both economic and human health ramifications. Consumption of food contaminated with microbial pathogens (bacteria, fungi, parasites, viruses, and their toxins) causes an estimated 76 million illnesses, 325,000 hospitalizations, and 5,000 deaths each year in the United States[19].

The new technology need is pressing in the U.S. where the FDA reportedly only has the resources to inspect 1% of imported food coming into the country[20]. The FDA simply cannot provide enough

[17] Ohio Agriculture to Chemicals, polymers and Advanced Materials Taskforce. "Report and Recommendations to the General Assembly and the Governor." July 14, 2008.
[18] http://www.cnn.com/2008/WORLD/asiapcf/09/21/china.tainted.milk/
[19] Jean C. Buzby. "Children and Microbial Foodborne Illnesses." Food Review. Volume 24, Issue 2. Available online at http://www.ers.usda.gov/publications/FoodReview/May2001/FRV24I2f.pdf
[20] Julie Schmidt. "U.S. Food Imports Outrun FDA Resources". USA Today, March 18, 2008. Online at http://www.usatoday.com/money/industries/food/2007-03-18-food-safety-usat_N.htm

manpower for inspections covering all US food imports and it is clear that automated diagnostics and sensor technologies will need to be developed and brought to market cost effectively in order for the risk to be abated. Likewise, enhanced food decontamination, sterilization and packaging technologies are required to assure that pathogens are eliminated at the food processing and packaging source.

The Center for Food Safety and Agrosecurity at OARDC is focused on developing and bringing innovative advances in food safety into commercial application. One of the major focus areas for the Center is on the U.S. Egg Safety Action Plan which calls for complete eradication of Salmonella from eggs by the year 2010. As noted above, Ohio is a national leader in egg production (ranked second among U.S. states) and the Center for Food Safety and Agrosecurity is working to make Ohio the national leader in egg safety by developing industrial processes that will eradicate Salmonella from commercial eggs. In addition, this group is looking at the development of tamper proof caps for food packages and rapid test diagnostics of food borne pathogens.

The Center has advanced several promising technologies along the pathway towards market. A notable examples includes:

- Safe Eggs – Using ozone pasteurization technology, scientists within the Center are well on the way to meeting the goal of pathogen free eggs. Eggtech, with three major egg production companies as investors, is working with OARDC in bringing advanced ozone technology to market.

Further upstream, in the earlier stage of commercialization investigation, are two promising technologies in:

- Tamper evident packaging development
- Rapid diagnostic test kit development for norovirus.

It should be noted that the Center will be a major contributor to the University TIE in Public Health Preparedness.

Commercialization of Multi-functional Plant Germplasm The Ohio BioProducts Innovation Center

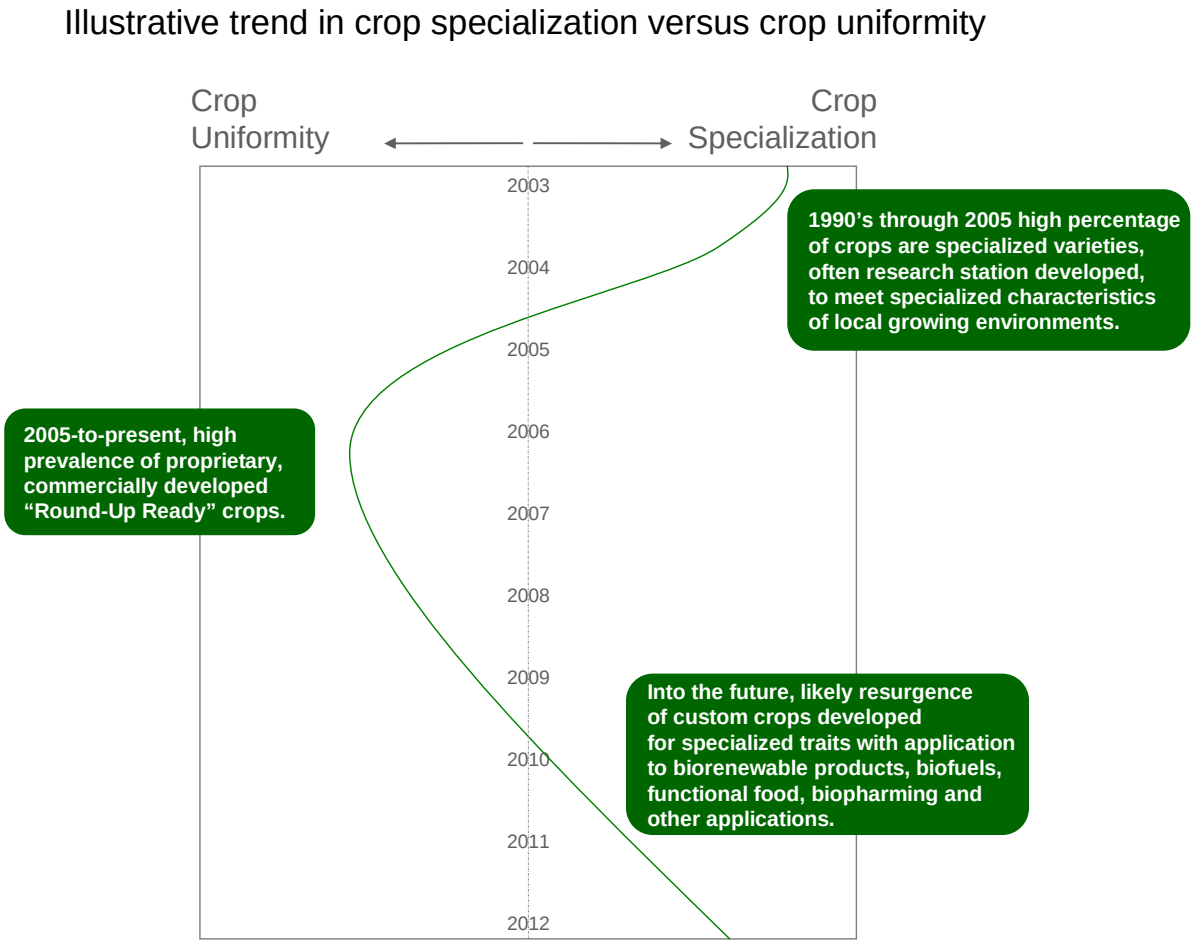
This ABIG project (also known as the Program for Advanced Plant Genetics and Specialty Traits) is designed to enhance OARDC's already significant R&D leadership position within the Ohio Third Frontier Funded "Ohio BioProducts Innovation Center" (OBIC). Specific engagement of OARDC in Third Frontier initiatives, and OBIC in particular, is discussed later in this report.

The Multi-functional Plant Germplasm ABIG program is focused on the development and production of quality plant biomass which has desired characteristics for downstream processing and specialized bioproducts manufacturing. The program leverages the expertise of OARDC's plant breeders in developing adapted crops (such as soybeans, wheat and maize) with genes for resistance to diseases and having value-added traits involving proteins, sugars, fatty acids, starch gluten, hilum color, pigmentation and processing properties. Multi-functional germplasms possess more than one valuable trait and are, therefore, suitable for several uses.

Historically, the work of OARDC scientists in plant breeding and crop variety development has had strong economic impact benefits for Ohio. In 2004 Battelle's analysis indicated that OARDC's work in developing high-yield, disease-resistant soybeans, optimized for Ohio growing environments, generated a $191 million impact on Ohio economic output and were responsible for the generation of 4,030 jobs in the state. Clearly, OARDC research in plant breeding and trait development can have a significant farm-level impact, and generate specialized varieties of crops with value-added traits.

Since the 2004 study was released there have been quite dramatic changes in agricultural markets. As the 2004 study predicted, bio-based products (including biofuels) have emerged as a major market for commodity crops (especially corn and soybeans)—thereby increasing demand and commodity prices for these crops. During this time, however, the market for crop varieties shifted away from specialized university varieties in favor of standardized varieties with stacked traits led by Monsanto's "Round-Up Ready" brand. As the illustrative figure below depicts, there has been a significant swing away from crop specialization (which university R&D specialized in) towards crop standardization (favored by big industry). It is likely however, that a new trend will emerge—driven by the previously mentioned bio-based products and emerging functional foods markets. These markets require specialized crop traits—an area of research and development in which OSU and OARDC excels. Therefore, into the future, Battelle anticipates that OARDC will once again play a critically important role in developing crops with specialized value-added traits for Ohio producers that are suited to production in Ohio growing environments.

Figure 10: Crop Specialization versus Crop Uniformity



Working in collaboration with the Ohio BioProducts Innovation Center, the Program for Advanced Plant Genetics and Specialty Traits is working to accelerate commercialization of multifunctional germplasm with value-added product traits. The Program is using the OBIC model in bringing OSU researchers

together with industry partners in generating projects that have significant market pull (i.e. they meet an identified industry need or opportunity).

Currently biobased products such as ethanol and biodiesel are being produced using commodity crops (primarily corn for ethanol and soy beans for biodiesel). The crops and varieties being used have not been specifically developed for biobased product applications, rather their characteristics have been honed by plant breeders and geneticists for food and feed applications. As the biobased products economy moves forward, plant biomass will need to be optimized for more specific biobased product applications. The usual issues of yield, disease and pest resistance, etc. will continue to be important, but additional traits will be important such as downstream processability, ease of enzymatic break-down, usability of by-products, compatibility with rotation requirements, etc. Plant scientists will also need to develop expertise in species which have not been traditionally grown in Ohio—crops such as canola, camelina, dandelions and sunflowers, to name just a few. OARDC plant scientists will be at the forefront of this work for Ohio's emerging biobased products industry.

ABIG funds are accelerating the development of ten soybean lines which demonstrate significant industrial potential due to their specific fatty acid composition.

Intellectual Property Generation

Soybean variety disclosures:

- Dennison
- HC99-2763
- OHS 202
- Prohio
- Wyandot
- Wooster

Soybean germplasm lines:

- OHS 202
- HS1-3661
- HS1-3886
- HS3-2829
- HS3-2840
- HS4-3203

Maize inbred lines:

- Oh605

In addition to supporting the development of optimized feedstocks for biofuels and industrial bio-based products (such as lubricants, polymers, rubber, etc.), OARDC research in plant traits and multi-function germplasm also has relevance to emerging functional food, specialty foods, biopharming and other specialized applications. In soybeans, for example, the OHS 201 "Wyandot" line is optimized for food applications such as tofu, while HC01-289 "Prohio" combines high yield with very high protein content. In maize, OARDC breeders are accelerating development of lines high in carotenoid pigments and Anthocyanin content—valuable functional food traits.

Case Study: A "New" Natural Rubber for Ohio's Tire Industry

Natural rubber is a strategically important global commodity—a commodity in high demand because of growth in vehicle use across the globe. Access to natural rubber is especially important in Ohio, home to a large base of tire and industrial rubber user industries in the Akron area. Asia is by far the largest producer of natural rubber (produced from the sap of the *Hevea brasiliensis* Para rubber tree) accounting for 94% of global output. The three largest producer countries (Indonesia, Malaysia and Thailand) together account for 72% of all natural rubber production and operate a price controlling cartel, the International Tripartite Rubber Organization (ITRO), to manage sales and withhold stocks. As with OPEC controlled oil, it is strategically important for the United States to have alternative domestic sources of natural rubber.

OARDC is playing a central role in the cultivation, development and domestication of a promising latex rubber producing alternative crop. The Russian dandelion, *Taraxacum kok-saghyz* (TKS), produces high-quality natural rubber in its fleshy taproot—a rubber that compares well in performance characteristics with rubber from the Para rubber tree. OARDC researchers have used seed from Uzbekistan and conducted extensive tests of latex levels across more than 1,000 roots, determining the plants with the optimal characteristics for propagation. Using greenhouse, hydroponic and field growing tests, OARDC scientists are working to improve the yield of this potential crop, determine best practice for growing the

crop and testing methods for harvesting the roots.

A Program of Excellence in Natural Rubber Alternatives (PENRA) has been created to coordinate work between OARDC and partnering organizations in the project. The PENRA is housed at OARDC and includes the participation of Ohio State, the University of Akron, Oregon State University, Cooper Tire, Bridgestone Americas, and Veyance Technologies (formerly Goodyear Engineered Products). Each of the corporate partners produces tires and industrial rubber products in Ohio and has its corporate R&D center in the state. The research collaborators have now been supported with a $3 million Third Frontier Wright Projects Program grant to accelerate the development of a new crop and processing industry for Ohio.

Projections indicate that the new industry will generate over $130 million in revenues and produce 165 jobs in Ohio—but, more importantly the availability of secure domestic natural rubber supplies will help reinforce Ohio's major tire and industrial rubber products sector with its multi-billion dollar economic impact on the state. Polymer Ohio notes that 247 Ohio companies depend on natural rubber as a component of their manufactured products.

Third Frontier funds are being used to support the construction of the pilot-scale processing facility on OARDC's Wooster campus. This facility will produce 20 metric tons of rubber a year—providing the necessary volume of raw materials needed for university and industry testing. The work being performed by OARDC and its partners is steadily moving the dandelion rubber product towards a marketable product—a product with the potential to reinforce Ohio's polymer industry strengths and capture part of the fast growing $10 billion global natural rubber market. OARDC testing performed to-date proves that the TKS-derived rubber has the properties required to be a suitable alternative to Para tree rubber, the next stages in the commercialization will engage the pilot plant and industry in industrial testing of larger samples while ongoing work takes place in plant and processing technology improvement. Additional work is examining the use of co-products (such as inulin) from the rubber processing as further value-added commodities for Ohio.

Case Study: New Soybean Variety for Ohio Farmers

OARDC developed soybean varieties are increasing in importance as specialized soybean demand begins a resurgence from the very large market penetration of the Monsanto Round-Up ready standardized varieties.

The new OARDC Dennison soybean variety is expected to replace Kottman which was planted on an estimated 30,000 acres of Ohio cropland. The yield advantage of Dennison over Kottman in tests has been 6.1 bushels per acre which with soybeans selling between $7 and $11 per bushel during 2008 **equates to an additional $1.3 to $2.0 million in revenue for Ohio farmers. Including indirect impacts, the total output benefits to the Ohio economy would be between $3.4 and $5.3 million. An estimated $1.2 to $1.9 would be generated in personal income for Ohioans through this impact.**

The Ohio State University is the primary player in plant sciences, new variety development and testing in the State of Ohio. As the bio-based economy greatly expands into the future much of the growth is going to depend on high yield, specialized plant biomass as feedstocks. It is clear that in this critically important component of the Ohio economy, OARDC is the most important R&D asset in the state's economic development arsenal. OARDC's work in plant development, process

Anne Dorrance and the National Soybean Rust Team were awarded the 2006 USDA *Secretary's Honor Award* – the highest honor awarded by the USDA for outstanding contributions to agriculture.

development and collaborative R&D with Ohio's industries, agricultural producers and processors will be an increasingly significant driver of economic development for Ohio's future. **As such, the OARDC and its operations should be considered a high priority strategic investment for the State of Ohio and The Ohio State University.**

Center for Urban Environment and Economic Development

This center operates in support of Ohio's green industry, also known as the environmental horticulture industry. Comprising the production, marketing and maintenance of flowers, foliage, potted plants, bedding plants, turfgrass and other nursery crops, the green industry in Ohio has been a fast growth economic sector.

The U.S. green industry experienced strong growth during the 1990's that has continued into the 21st century. Greenhouse and nursery crops were the fourth largest crop group based on farm cash receipts in 2003 with cash receipts for greenhouse and nursery crops estimated at $14.3 billion. This significant market share continues to grow: of the estimated $50 billion in U.S. horticulture sales in 2005, greenhouse and nursery crops contributed a third, or $16 billion, only slightly less than vegetables' as well as fruits and nuts sales receipts of $17 billion each.[21]

Definition of the Green Industry

The green industry, also known as the environmental horticulture industry, is comprised of a variety of industry sectors involved in production, distribution, and services associated with ornamental plants, landscape, and garden supplies and equipment. Segments of the industry include wholesale nursery, greenhouse and sod growers, landscape architects, contractors and maintenance firms, retail garden centers, and marketing intermediaries such as brokers, horticultural distribution centers, and re-wholesalers.

The green industry in Ohio is a sizeable sector that has seen significant growth over the past 15 years. Battelle's analysis shows that in 2005 the sector in Ohio included 6,682 establishments employing 66,647 personnel. Moreover, the sector has experienced rapid growth in the state, with revenues growing by over 30% between 1990 and 2005 and employment expanding by 28% during the same time period. This green industry growth significantly outpaced Ohio's average private sector employment growth rate which was 11.2% over the same fifteen year period.

In a study led by the University of Tennessee[22], the economic impact for the U.S. green industry in 2002 (values expressed in 2004 dollars) was estimated at:

- $147.8 billion in output
- $95.1 billion in value added
- Almost 2 billion jobs
- $64.3 billion in labor income.

CUEED notes that…
"Ohio is the birthplace of the landscape industry as many of the world's most powerful landscape companies, including Scotts, TrueGreen Chemlwan, Davey Tree, LESCO, the Andersons and MTD were founded here and is also a leader in the urban soils industry (Hyponex, now a subsidiary of Scotts, Paygro, now a subsidiary of Garick, Garick and Kurtz Bros are all headquartered in Ohio."

The study then calculated the estimated economic impact of the green industry in each state. **For Ohio, the report calculates that the green industry**

[21] http://www.ers.usda.gov/Briefing/floriculture/
[22] Hall, Charles R., Alan W. Hodges, and John J. Haydu. *Economic Impacts of the Green Industry in the United States.* www.utextension.utk.edu/hbin/greenimpact.html

represents $5.9 billion in output and accounts for almost 80,000 jobs, ranking the state fifth and fourth in the nation respectively. As these impact numbers clearly indicate, the green industry is a significant economic driver of Ohio's economy, and this growth is fostered and sustained in large part due to the research activities found within OARDC.

The ABIG funded Center for Urban Environment and Economic Development (CUEED) focuses on the development and commercialization of a series of new organic and biological products designed to meet the fertility, pest control, and pollution mitigation needs of urbanized landscapes and the green industry. The use of chemical lawn fertilizers, pest control agents, herbicides and other chemicals in the urban landscape can be a significant source of pollution. CUEED is working on solutions to this problem—solutions that could have significant market potential with increasingly "green" focused, environmentally conscious consumers. Control of pollutant chemicals may also become more stringent in the urban environment as states and communities seek to preserve the quality of ground water and surface waters. Indeed, some communities and states have moved to limit chemical use in the urban landscape.

The Need for Organic Alternatives

American residential communities apply nearly 54 million pounds of pesticides and fertilizers to treat lawns each year. The American Cancer Society and the Environmental Protection Agency have reported that 95% of pesticides used on residential lawns are considered possible or probable carcinogens. The use of neurotoxin diazinon on golf courses is illegal because of the risk it poses to wildlife. However homeowners who are not restricted by this law apply more than 8 million pounds of diazinon to their own residential lawns per year.

The pesticides and fertilizers used to treat lawns not only pose risk to human and animal health; they also cause hazards for the environment. According to a 1997 study by the United States Geological Survey 95% of stream samples collected contained the presence of at least one commonly used lawn pesticide.

Case Western Reserve University: Center for Business as an Agent for World Benefit. Profile of Innovation Case Study 450.

CUEED is actively working in several areas of R&D to find natural alternatives to polluting chemicals. At the heart of the Center's work is fundamental progress made using pelletized or granulated natural products. Examples product categories under development include:

- Novel organic fertilization product for top-dressing application in lawns and landscapes
- Organic fertilization products for lawns and landscapes with added microbial inoculants
- Organic combined fertilization/biocontrol products for top dressing applications in lawns and landscapes, with biocontrol achieved via nematodes contained within the pelletized product.

Environmental concerns, consumer preference for organic products, plus a growing organic agriculture market, each suggest strong market potential for organic fertilization and pest control products. The National Gardening Association reports that 8.1 million households in the U.S. say they definitely plan to use all-natural/organic gardening methods in the future—and the total market for homeowner fertilizers, insect controls and weed controls stands at circa $8.5 billion (including both non-organic, which currently dominate, and organic products)[23].

The research taking place within CUEED is targeting new product development that will help sustain and grow Ohio's position as a leader in landscape products (see sidebar). Furthermore, the research builds upon OARDC's historic track record in work with composts and manures, well known through the work of individual OARDC researchers and the Ohio Composting and Manure Management Program

[23] National Gardening Association. 2004 Environmental Lawn and Garden Survey Summary.

(OCAMM). The Center has noted that it seeks to be a leader in the "greening of the green industry"—riding the trend towards organic, environmentally sustainable solutions to the needs of the urban landscape and green industry.

Case Study: Biological Control of Turf Grass Insect Pests

White grubs are one of the most serious and damaging insect pests invading turf grass. The grubs feed on lawn grass roots, causing a characteristic browning of the grass. Traditional approaches to white grub control have focused on the application of aggressive chemical insecticides (such as diazinon, imidacloprid, trichlorfon, bendiocarb and halofenozide)—but there are increasing human health and environmental health problems being identified and associated with the widespread application of these chemical agents. OARDC researchers are playing a leading role in finding alternative solutions for turf grass insect control.

One area in which OARDC researchers have made great strides is in the use of biological (rather than chemical) insect control. One of the key OARDC achievements has been the identification of a new strain of nematode with highly positive insect control traits. The OARDC strain of nematode is more virulent and effective against a range of white grub species and also has better storage stability than all other products on the market. In addition to identification of the strain, OARDC researchers performed each of the key steps required for the biological control agent to be able to be brought to market—this included research on its application, such as via standard irrigation equipment, and its compatibility with other pesticides, fungicides and fertilizers used on turf grass. Ultimately, the OARDC team produced a complete "technology package" for licensing to commercial partners for production and distribution.

As is often the case in agbiosciences research, fundamental discoveries in one application are often found to have substantial utility for other applications. This has proved to be the case with the OARDC nematode technology for biological insect control. For example, the white grub control nematode has been found to also be effective in the control of the grape root borer—an insect pest affecting Ohio grape production.

In addition to avoiding the introduction of potentially toxic, carcinogenic and mutagenic chemicals into the environment, nematode-based biocontrol agents have the advantage of inherent reproduction. The nematode feed on bacterium within insect hosts and then reproduce, providing carry over control effects—thereby requiring less frequent application than competing chemical products. Nematodes are also a "smart system" rather than a passive control system, in that the nematodes actively seek insect hosts in the soil—traveling directly to their targets.

Other insect biocontrol projects at OARDC are focusing on fungi-endophytic grass interactions in producing alkaloids that are toxic to insects. OARDC R&D is establishing cultivation practices that encourage increased production of the protective plant alkaloids.

With increasing concerns being expressed over chemicals in the environment, OARDC is assuring that Ohio is well-placed to take advantage of a trend towards alternative eco-friendly pest-control technologies. Canada, and some individual US states such as New York and Minnesota, have made significant moves in restricting the use of chemicals in urban settings and some agricultural settings, and this trend is expected to expand considerably. It should also be noted that the initial work in biocontrol systems at OARDC has resulted in a broader OSU program in urban landscape ecology—a program that brings together a diverse groups of OSU scientists to work on the urban environment and the reduction of negative chemicals within the environment.

OARDC work in bio-insecticides has multiple economic and environmental benefits for Ohio. Firstly, it is helping to develop new technologies that can be used as the basis for new commercial products and business development. Secondly, it is finding new cost-effective, non-toxic bio-treatments to enhance the productivity of Ohio's $5.9 billion green industry. Thirdly, it is resulting in the introduction of technologies that prevent environmental and ecological damage through reduction in the build up of toxic chemical pesticide residues[24].

Related to the work of the Center for Urban Environment and Economic Development is OARDC's long sustained record of work in growing media development for horticulture, floriculture and other applications suited to the urban and suburban environment. In particular, OARDC's reputation in composting is well-regarded on the international stage. OARDC has played a central role in developing systems that optimize composting processes and produce value-added compost products. OARDC led projects have been instrumental in the development of advanced potting soil using disease suppressive compost technology—and these products have proven to be of fundamental importance in establishing and growing the "green industry" in Ohio. In addition, considerable attention has been paid by OARDC scientists to advanced composting systems for the processing of organic materials from multiple sources, including urban sources (such as yard waste and municipal sewage sludge) and rural sources (poultry, dairy cattle and swine manure).

Advanced Compost-Based Potting Mixes

The work of OARDC scientists has been internationally recognized for its fundamental importance to the nursery and horticulture industry. Researchers interviewed by Battelle at OARDC noted that the nursery industry would only be a minor player in Ohio agriculture if it were not for the development of disease-resistant potting soils at OARDC. Prior to the release of OARDC's disease resistant compost technology, up to 75% of potted plants could be lost to disease in production (whereas today advanced potting mix technology has reduced these losses to the 10-15% range). The very large resulting advance in nursery productivity has resulted in nursery production moving into a whole new scale of operations and profitability in Ohio. As of 2001, when OSU undertook a formal analysis of the nursery industry in the State, the industry employed over 96,000 persons, had sales of over $2.79 billion, and over $275 million in payroll. Without OARDC composting technology and potting mix development there is little doubt that this sector would be far less impactful on the Ohio economy than it is today.

The production and sales of potting mixes has grown into a significant industry. In Ohio, OSU data show that wholesale production, distribution and retail sales of nursery and garden center plants totaled circa $1.37 billion in 2001. Of these, OSU estimates that 75% are produced in containers, thereby requiring the use of potting mix (this would equate to $1.03 billion in sales). Potting mix typically represents between 3% and 5% of the retail value of the plant, so using a midpoint estimate

[24] American residential communities apply nearly 54 million pounds of pesticides and fertilizers to treat lawns each year. The American Cancer Society and the Environmental Protection Agency have reported that 95% of pesticides used on residential lawns are considered possible or probable carcinogens. The use of neurotoxin diazinon on golf courses is illegal because of the risk it poses to wildlife. However homeowners who are not restricted by this law apply more than 8 million pounds of diazinon to their own residential lawns per year. The pesticides and fertilizers used to treat lawns not only pose risk to human and animal health; they also cause hazards for the environment. According to a 1997 study by the United States Geological Survey 95% of stream samples collected contained the presence of at least one commonly used lawn pesticide. Case Western Reserve University: Center for Business as an Agent for World Benefit.
http://worldbenefit.case.edu/innovation/bankInnovationView.cfm?idArchive=450

of 4% results in an estimate of over $41 million in potting mix used at the commercial level in Ohio.

Bio-Control of Disease in Plant Growth Media

Another fundamental contribution of OARDC research to the economics of the horticulture industry has come through advanced R&D in biological control of disease causing organisms (as opposed to chemical control). Agriculture and horticulture have a long history of applying considerable volumes of expensive, and environmentally questionable, chemical agents to plants and soil/growing media in efforts to control disease. In the horticulture industry, chemical fungicides are a major cost, accounting for up to $400 million in direct expense for greenhouse and nursery operators.

Work at OARDC is now providing a superior performing, lower cost, and environmentally friendly option for plant disease control. The approach uses "biological control", rather than chemicals, whereby specific organisms are identified that either attack disease agents or stimulate plants to activate natural disease and pest resistance mechanisms. In the latter area of stimulating plant innate resistance, OARDC is at the forefront of work in the field and is in the process of generating substantive patentable technologies. The impact of these new approaches on the Ohio nursery and greenhouse plant industry will be substantial. The traditional application of chemical fungicide, for example, costs between $4-$7 to treat each cubic yard of potting mix and the treatment has to be repeated four times per year. The new biocontrol inoculant technology produced at OARDC only needs to be applied once per year, at a total cost of $6 per cubic yard.

Given the previously cited estimate of $41 million in potting an estimate of the total cubic yards consumed in Ohio may be derived. A survey of various Web sites indicates a typical average wholesale price for potting mix and custom blended growing media being circa $30 per cubic yard. Based on this pricing, $41 million in potting mix would equate to 1.37 million cubic yards of mix consumed. If it costs an average of $5.50 per cubic yard to treat with chemical fungicide and four applications are required per year this equates to $30.1 million in chemical fungicide application costs. **If OARDC developed biocontrol technology is used instead, at a one time per year application cost of $6 per cubic yard, the cost would be just $8.2 million, providing a potential cost savings to the Ohio nursery industry of almost $22 million.**

As Table 6 shows, the benefits for the environment and the economy in Ohio from advanced growing media development are significant:

Table 6: Positive Impact Benefits of Compost to the Environment and Agriculture[25]

Environmental Benefits	Agriculture Benefits
• Water and soil conservation • Protects groundwater quality • Minimizes odors from agricultural areas • Avoids methane production and leachate formation in landfills by diverting organics from landfills into compost • Prevents erosion and turf loss on roadsides, hillsides, playing fields and golf courses • Drastically reduces the need for pesticides and fertilizers • Binds heavy metals and prevents them from migrating to water resources or being absorbed by plants or being bioavailable to humans • Facilitates reforestation, wetlands restoration, and wildlife habitat revitalization efforts by amending contaminated, compacted and marginal soils • Long-term stable organic matter source • Buffers soil pH levels • Off-farm materials can be brought in and added to manure to make compost • Composted manure weighs about one-fourth as much as raw manure per ton	• Adds organic matter, humus and cation exchange capacity to regenerate poor soils • Suppresses certain plant diseases and parasites and kills weed seeds • Increases yield and size in some crops • Increases soil nutrient content and water holding capacity of sandy soils and water infiltration in clay soils • Reduces fertilizer requirements • Restores soil structure after soil microorganisms have been reduced by the use of chemical fertilizers. Compost is a soil inoculant • Increases earthworm populations in the soil • Provides slow, gradual release of nutrients, reducing loss from contaminated soils • Reduces water requirements and irrigation • Provides opportunity for extra income. High quality compost can be sold at a premium price in established markets • Moves manure to non-traditional markets that do not exist for raw manure • Brings higher prices for organically grown crops • Minimizes odors in agricultural areas

Moving into the future, it is clear that OARDC research teams are poised to make further significant strides in compost and advanced plant growth media. The latest OARDC development uses the *Trichoderma hamatum* (T382) fungi organism to activate plant innate defense mechanisms against disease. A patent is currently applied for on this technology, and the T382 product, produced using processes developed and refined at OARDC, shows broad applicability for a range of food and ornamental plants (including, for example: tomatoes, potatoes, rhododendrons, poinsettias, begonias and geraniums). The highly advanced work of OARDC in plant immunity and microorganism impacts on plant defense mechanisms at OARDC is direct result of having advanced DNA micro-array infrastructure and gene sequencing investments made at OSU in 2004.

The above examples only cover some of the multi-faceted work taking place at OARDC in waste management and adaptive re-use of waste products (see later discussion of the *Biomass-to-Energy* program).

Center for Innovation Based Enterprise (CIBE)

With this Center, OARDC took the important step of funding cross-cutting support for agbioscience innovation commercialization. The Center for Innovation Based Enterprise, led by the Department of Agricultural, Environmental and Development Economics (DAEDE) within FAES was established to

[25] "Food Waste Composting: Institutional and Industrial Applications" Cooperative Extension Service, The University of Georgia College of Agricultural and Environmental Sciences

address barriers to product commercialization by providing research into entrepreneurship, contract design, financing, marketing, and risk management for innovation-based and start-up agbioscience enterprises.

Each of the science based Centers of Innovation has a goal of moving innovation into commercialization and economic development for Ohio. However, the R&D personnel in these Centers are predominantly research bioscientists with little prior experience in technology acceleration, market assessment or commercialization. The DAEDE came forward with a proposal to fund an additional center dedicated to supporting the other centers, and other groups within OARDC and the university, with market analysis, economic modeling and forecasting, and commercialization assistance. The CIBE plays the critical role of keeping the other centers rooted in reality—helping them to assess technology in terms of market potential and potential for business development success. The analytical expertise within CIBE provides the ability to assess the commercial scalability of R&D based agbioscience innovations and to identify the best pathways to market for those technologies demonstrating process and business scalability.

CIBE operates under agreement with each of the other ABIG funded centers and ATECH to support their commercialization work across any potential product category. The Center leverages its expertise to provide the following services:

- Identification and evaluation of target markets
- Determination of the size, growth rates, trends, and competitiveness of markets
- Defining entrance criteria into target markets
- Conducting economic feasibility studies
- Conducting industry and consumer studies
- Developing appropriate business concepts.

Through provision of these services CIBE makes important contributions to improving the chance of commercialization success for OARDC innovations. The key economic impact of the Center's work will come though enhanced probability of commercial success for OARDC-based innovations.

Demand for CIBE services from the other ABIG-funded centers has been significant. Examples of projects in support of innovation commercialization at the other centers include:

Table 7: CIBE Support Projects with Other Centers

Center	CIBE Supporting Projects
Center for Food Safety and Agrosecurity (CFSA):	o Evaluation of the role for tamper evident packaging (including focus group and survey research) o Working with EggTech in completion of an industry survey and journal article assessing the impact of the U.S. Egg Safety Action Plan on R&D and adoption of innovative technologies such as ozone treatment. o Support of food recall research, assessing industry and government response.
Center for Advanced Functional Food Research and Entrepreneurship	o Evaluating consumer reaction to health information (labels and promotional material) on functional foods. o Tracking of the use of dietary guidelines, nutrient content claims,

(CAFFRE	and (qualified) health claims on functional food labels and promotional material.
The Ohio BioProducts Innovation Center (OBIC)	o Market analysis of soybean and corn varieties that may be well suited for industrial applications. o Work with a private company in the development and market assessment of a bio-based plant growth medium.

CIBE has also been active in providing work in support of ABIG Center funding submissions seeking to provide longer-term funding to sustain the operations of the other centers.

The quality of services and research supports provides by CIBE under its remit is evident in CIBE personnel having significant scholarly success through their CIBE projects. Research findings have been published in several scholarly journals, particularly in food science fields, and CIBE personnel have been active presenters at leading seminars and events.

OARDC Leadership and Participation in Third Frontier Programs

The Ohio Department of Development (ODOD) has a targeted industry approach to economic development, and is focused on nine primary industry sectors—many of which are directly or indirectly impacted by agbioscience. The nine ODOD target sectors and potential agbioscience linkages are illustrated on Table 8 below:

Table 8: ODOD Target Sectors and their Agbioscience Linkages

Ohio's Statewide Targeted Industry Sectors	Potential Agbioscience/OARDC Linkages
Agriculture and Food Processing	**Direct** – Development of comprehensive approaches to improving and diversifying agricultural production, commodity processing, and value-added product development. Connects to all OARDC signature focus areas.
Bioscience and Bioproducts	**Direct** – Development of biobased industrial products and work in human health and safety aspects pertaining to agriculture and natural products. Connects to all OARDC signature focus areas.
Advanced Energy and Environmental Technologies	**Direct** – Development of bioenergy and environmental technologies. Connects to OARDC Advanced Bioenergy and Biobased Products signature focus area.
Polymers and Advanced Materials	**Direct** – Major focus of work linking OARDC, OBIC and the polymer cluster in Akron. Biocomposite materials for application within other Ohio target industry clusters. Connects to OARDC Advanced Bioenergy and Biobased Products signature focus area.
Distribution and Logistics	**Indirect** – Relevance in emerging issues pertaining to biomass transportation and the location of biomass conversion and value-added manufacturing facilities. Biologistics is an emerging field as are local food networks.
Instruments, Controls and Electronics	**Indirect** – May be relevant work in instruments and controls relating to precision agriculture and improvement of value-added processes. Direct work in technologies with application to food safety and packaging.
Motor Vehicle and Parts Manufacturing	**Indirect** – Application of Biocomposite materials in automotive applications. Direct potential application of alternative rubber sources in tire and rubber component manufacturing.

Aerospace and Aviation	**Indirect** – Relationships in biobased aviation fuels and lubricants, and advanced biobased materials. Work in food product development, nutritional enhancement and packaging for space and long-term environment applications.
Corporate and Professional Services	**Indirect** – May be relevant in terms of services for agribusiness and bio-based corporate enterprises. Specific support through development of the BioHio Research Park.

As Table 8 shows agbiosciences has a role to play in each of the target industries and **a major leadership role in four of them:**

- **Agriculture and Food Processing**
- **Bioscience and Bioproducts**
- **Advanced Energy and Environmental Technologies**
- **Polymers and Advanced Materials**.

OARDC obviously plays an important role in the ODOD *Agriculture and Food Processing* target industry sector. OARDC and OSU extension are dedicated to improving agricultural productivity, diversity and sustainability in the state. OARDC is also highly active in R&D and support for downstream agricultural processing and food processing functions. Three of the ABIG funded Centers of Innovation specifically focus on the *Agriculture and Food Processing* sector, namely:

Center for Diagnostic Assays	Food Security, Production and Human Health	This center focuses on developing diagnostic tests for infectious pathogens impacting the health of food-producing animals and plants, and the safety and security of food supply.
Center for Advanced Functional Food Research and Entrepreneurship	Food Security, Production and Human Health	This center focuses on the development and testing of functional foods with commercial potential, and basic research leading to innovations in functional foods.
Center for Food Safety and Agrosecurity	Food Security, Production and Human Health	This center brings advances in food safety to commercial applications, including novel processing techniques that eliminate dangerous bacteria, specialized food packaging, and rapid tests to diagnose food borne pathogens.

In addition other Centers of Innovation contain work germane to the *Agriculture and Food Processing* ODOD industry target sector, including the Program for Advanced Plant Genetics and Specialty Traits (working to develop specialized crops such as wheat and soybeans with enhanced qualities) and the Center for Urban Environment and Economic Development whose work in pelletized and granulated fertilization and organic pesticide products is relevant to on-farm crop agriculture as well as lawn and garden applications.

Three of the ODOD target industry sectors are directly linked to non-food biomass resources and will depend heavily on agricultural inputs and agbiosciences for their future progress and success—these include:

- **Bioscience and Bioproducts**

- **Advanced Energy and Environmental Technologies**
- **Polymers and Advanced Materials**.

At the heart of agbioscience work related to these ODOD target industry sectors is the work of OARDC and its leadership and participation within the Ohio BioProducts Innovation Center.

The Ohio BioProducts Innovation Center (OBIC) and OARDC: Driving the Biobased Economy

The Ohio BioProducts Innovation Center (OBIC) is a statewide Wright Center, funded through an $11.5 million Third Frontier award from the State of Ohio. OBIC is focused on industrial applications of biomass and biotechnology—which will include applications in a range of biobased products, bioenergy products and biobased advanced materials.

OBIC is a collaborative research center bringing key partners and stakeholders together to work on areas of industry need that have technology-based economic development and commercialization potential. According to the Director of OBIC, OARDC is one of the most important supporters/stakeholders and one of the most active participants in sustaining OBIC's momentum.

Based on a market pull model, OBIC works to align research with identified industry needs and opportunities. The R&D momentum generated by OBIC has led to a need to expand faculty resources at key participating academic partners (primarily OSU/OARDC and the University of Akron). OARDC has been able to hire several additional faculty members with a focus on bioproducts, as has the University of Akron.

Headquartered at OARDC, OBIC draws on its partners' research capabilities in agbiosciences, biological sciences, engineering, advanced materials and many others. Through its board of advisors, which has representatives from across the bio-products supply chain, OBIC links these research capabilities with the needs of the industry. Board members represent production agriculture, the bio-processing industry, and leaders in the polymer, chemicals, and materials industries.

OBIC is a unique endeavor because it builds on the strength of Ohio's two largest industries—agriculture and the chemicals, plastics, and rubber materials sector—as well as the significant portfolio of research capabilities at The Ohio State University, Battelle Memorial Institute, the University of Akron, the U.S. Department of Energy's national laboratories, and the U.S. Department of Agriculture.

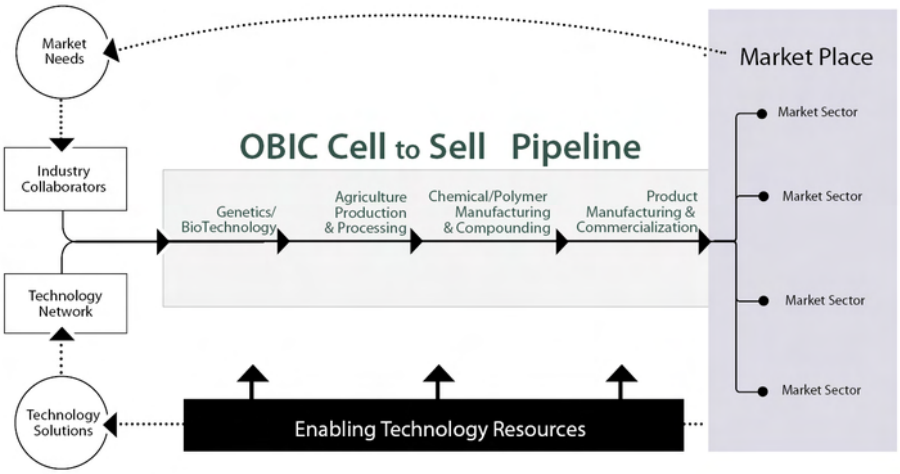
OARDC and OSU scientists are key to the future success of OBIC and are playing a lead R&D role in significant OBIC projects, including for example:

- **Development of Advanced Granule Technologies** – OARDC and Extension specialists are working with the Ohio-based company The Andersons, Inc. on a $5 million, three-year Third Frontier grant to produce advanced granule technologies that address the economic, health and environmental concerns of the turfgrass, horticulture and agricultural industries. The Andersons and OARDC are leading a development which also includes Syngenta Crop Protection, Inc.; Ohio-based PSB Company, a division of White Castle System; Ohio-based National Lime and Stone Company; and the U.S. Department of Agriculture's Agricultural Research Service. The broad range of targeted applications of the granule technology includes turf, nursery, floriculture, fruits, vegetables and field crops.

- **Advanced Crop Development** – OBIC has been collaborating with the world-renowned soybean breeding team at OARDC to develop specialized soybeans with traits suitable to multiple industrial and food/feed uses. OARDC's state-of-the-art technological resources in molecular marker identification and molecular imaging in combination with a multi-decade track record in soybean improvement provides a strong resource for Ohio's bioproducts economy development. OARDC researchers are also engaged in significant wheat improvement research.
- **Alternative Natural Rubber Development** – As noted previously in this report, OBIC and OARDC, in addition to other supporting partners are the recipient of a $3 million Third Frontier grant to develop a renewable, domestic source of natural rubber using the Russian Dandelion as the feedstock.
- **Bio-based Polymer Development** – OARDC, OSU, OBIC and PolymerOhio are working closely together, in collaboration with industry, to develop resins, plastics and other polymer materials using bio-based feedstocks. This work builds on OARDC's expertise in soybean, corn and other crops and the genetics and molecular analysis capabilities of OARDC. Additional work is taking place across a range of value-added bio-based chemical product opportunities.

OBIC is not only actively engaged in support of research but is also proactively working on the commercialization of technological innovations. Using what OBIC terms the "Cell to Sell" model, shown in Figure 11, OBIC is using Third frontier funding to specifically target bioproducts-based economic development and job creation for Ohio.

Figure 11: OBIC Cell to Sell Model



OARDC and The Ohio Plant Biotechnology Consortium: A Model for Statewide Collaboration

The Ohio Plant Biotechnology Consortium operates a competitive grants program statewide, with OSU/OARDC representation on the consortium. Eleven universities participate in the consortium and it has been an effective tool for bringing Ohio's plant bioscientists together for joint projects.

Key areas of focus for consortium collaborations include:

- Novel plant products
- Nutraceuticals
- Plant nutrition
- New uses for traditional crops
- Plant bioremediation
- Pest resistance\
- Recombinant DNA technology.

The competitive grants awarded through the consortium have achieved a 5:1 leverage on funding to-date ($1.5 million in total funding provided has seen $8.3 million in additional external funds brought in). Funding has mostly comprised seed grants in the range of $10,000 a year, but there is also a large grant category of $50,000. Approximately $220,000 in competitive awards has been granted per year.

OARDC scientists receive approximately 40-50% of OPBC funding, and at least 60% of all funded grants under the program have at least one OSU faculty member engaged in the project.

While OARDC is the big player in Ohio agbiosciences, other universities in the state have specialists who are able to make significant contributions. The OPBC lets OARDC scientists access and leverage expertise in the state that is not replicated at OARDC (for example, chemical ecologists at Wright State University or molecular taxonomy expertise at Miami University of Ohio).

Biomass to Energy Program

The OARDC's Third Frontier-funded *Biomass-to-Energy* project is focused on producing a high value product (energy) from low (or negative) value waste materials. The Biomass-to-Energy project is leveraging OARDC's long-held expertise in biomass waste management and adaptive re-use to focus on using animal manure (an environmental concern) and food-processing leftovers (an expensive waste-disposal issue) for generating clean, renewable energy.

The potential for using biomass resources for energy generation in the state is significant. Rather than being a marginal energy product, biomass has the potential to meet an estimated 65% of Ohio's residential electricity demand[26]. Work at OARDC is focusing on multiple technologies for biomass-to-energy conversion, especially biodigesters (which turn waste into biogas) and fuel cells (which can use that biogas and other feedstocks such as vegetable oils to generate energy).

Converting organic waste from agricultural and livestock operations into a renewable source of energy is a key strategic and economic need for the U.S. and its individual states. Currently, however, most Ohio biomass represents only energy potential, rather than useable energy, and much basic and applied R&D is required to develop economically and technologically viable systems for waste-to-energy and biomass-to-energy projects.

OARDC is taking a leading role in bioenergy projects for the state—a role formally recognized through the $1.5 million Third Frontier Project award and $1.74 million in federal funding. The focus of the state and federal awards is R&D leading to optimization of multiple technologies (such as fuel cells and anaerobic digesters) that will use biological conversion to convert biomass into scalable energy systems. Building upon other biomass conversion projects at OARDC, the Third Frontier funded project has facilitated the development of advanced infrastructure at the Wooster campus able to support R&D in multiple technology areas, including anaerobic digestion, biogas and fuel cell technology. These technologies show great promise not only for the conversion of livestock waste, such as manure, but also for the conversion of energy-rich industrial food processing wastes from Ohio's substantial food processing sector. It is expected that technologies developed may be applied to on-site power generation at waste-producing industry and livestock operations—helping to generate significant power and economic value from waste that currently has low value or a negative value (having significant disposal costs). **The economic promise here is for Ohio is fourfold:**

- **For Ohio to develop a new industry sector in advanced biomass conversion and energy production technology**
- **For Ohio to generate valuable electrical energy and renewable fuels from renewable in-state biomass resources**
- **For Ohio industry and agriculture to achieve significant cost efficiencies through the use of their own waste streams for on-site power generation (i.e. "distributed generation")**
- **For Ohio to achieve enhanced energy security thereby reducing economic exposure to high cost, off-shore supplied diminishing fossil fuels.**

[26] http://www.ag.ohio-state.edu/~news/story.php?id=4182

Within OARDC multiple R&D initiatives are being pursued in relation to bioenergy and waste-to-energy conversion. Examples include:

Treatment of Bioenergy Byproducts

Ohio has a significant base of dairies, and these operations can reclaim energy from animal waste via the use of methane digester technology. The economics of the conversion process are helped significantly if the post-conversion waste can be sold as organic fertilizer or used as livestock bedding material. A key problem associated with this by-product re-use, however, has been the substantial pathogen load contained within the material. OARDC scientists have analyzed by-product and characterized the microflora in the waste. This has enabled the team to develop approaches to the treatment of this waste to neutralize negative microbial content.

Microbial Fuel Cell Technology

Microbial fuel cells show potential as a scalable renewable energy source using both agricultural and industrial biomass waste as the input for conversion. OARDC researchers are investigating the generation of electricity from cellulose in a microbial fuel cell using mixed rumen bacteria as a biocatalyst. The R&D has achieved success conversion at a laboratory scale, and shows promise for progression into pilot scale tests.

Biomass to Energy, Increasing Biogas Yield

OARDC researchers have been working to significantly increase biogas yield, and resultant energy yield, through improvement of anaerobic digestion processes. A key approach in the OARDC work has been the introduction of enhanced levels of trace elements into waste feedstock and it has been found that this “seeding” with trace elements results in an increase of between 60% and 200% in biogas yield. The commercial potential of this discovery is significant—making a substantial difference to the economics and return on investment of biomass waste-to-energy conversion equipment.

Converting Cellulose Materials into Energy

A key to the future success and viability of much more widespread bioenergy use is the conversion of lignocellulosic material into useable forms—such as fermentable sugars, biogases and ethanol. An OARDC research team has undertaken in-depth study of microbial communities and their function in plant cell wall degradation. Using genomic analysis, OARDC scientists are facilitating deeper understanding of the fundamental mechanisms involved in plant cell wall degradation leading to specific recommendations and potential technology for improving anaerobic digester operational efficiency and economic viability.

Enhancing Waste-to-Energy Conversion for Sand-Bedded Dairies

Sand is commonly used as a bedding material in Ohio dairies, but the presence of significant quantities of sand in manure generates equipment maintenance problems when the manure is processed in anaerobic digesters. OARDC has been working with industry on approaches to manage and recover the sand within digesters before it causes equipment damage. The new approaches provide for the economic use of dairy cattle waste for bioenergy production.

Engineering Combustion Systems for Bioenergy

OARDC agricultural engineers are focusing on the development of biomass combustion systems—particularly those using crop and crop residue as the primary fuel. A key goal of the OARDC team’s

work is the development of high-efficiency and automated combustion systems. A particular emphasis is being placed on fluidized bed combustion processes. Prior work by members of the team resulted in development and commercialization of an 8 million BTU/hr. flex-fuel combustion system, using the fluidized bed technology, which was installed at an Ohio greenhouse. Greenhouse operators found the system to be effective and cost-efficient, reducing overall energy expenditures by a substantial $200,000 annually. Currently the team has developed a fluidized bed combustion unit using shelled corn as fuel with a 65% combustion efficiency. The engineers are now working on refining the system with a more advanced third-generation model with goals of reaching 85-90% combustion efficiency.

It should be noted that, while OARDC is making significant progress in bioenergy R&D, there are certain key investments required to boost capabilities in certain key technologies. To advance work in lignocellulosic digestion, for example, capital expenditures for HPLC (high-performance liquid chromatography) equipment will be required as well as investment in a pretreatment lab. OSU has the breadth of expertise required for making significant progress in lignocellulosic digestion, identification and development of required enzymes, and for pretreatment technology development—but more depth may be required to reinforce these areas.

Given OARDC's ties to the agricultural production industry it is not surprising that significant research is being directed towards realizing value from primary agricultural waste streams. A particular focus is on manure, litter and wastewater generated by concentrated animal feeding operations. In the past, animal waste could be used as a fertilizer for cropland; however, recent national trends in the growth and consolidation of the livestock industry have created a geographic separation between crop/rangeland and animal operations, and caused an oversupply of manure in many regions of the country. This trend has, in turn, caused pollution issues as the excess of manure-based nutrients and chemicals find their way into groundwater and surface waters. The problem is of considerable size—according to the U.S. Environmental Protection Agency nearly 40% of the nation's waters are too polluted for swimming or fishing and approximately 60% of the pollution in rivers and streams, and 45% in lakes, comes from agricultural sources[27].

While the direct use of animal waste as agricultural fertilizer is still viable, valuable and continues to occur, considerable scientific and economic interest is also being directed towards the use of manure as a source of renewable bioenergy.

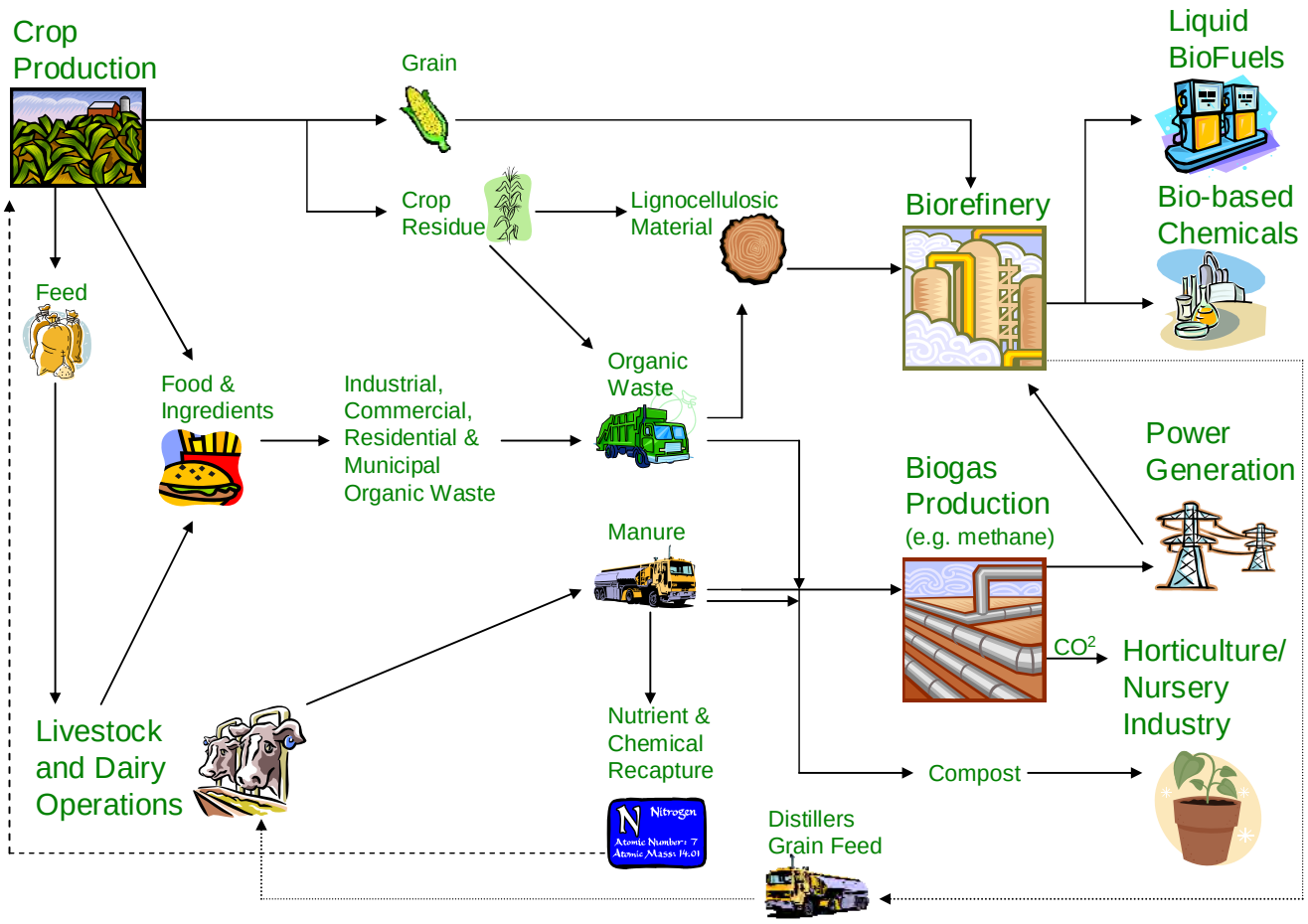
Key to the application of manure to both fertilization and bioenergy is the efficient and safe handling of the material at source and through the transportation system to ultimate end-use. OARDC research teams have been active in R&D for both poultry (egg layer) operations and hog operations in management, treatment, odor control and value-added byproduct production from waste streams. One of Ohio's largest egg producers has received assistance from OARDC in developing a waste management system that transports manure via conveyor to a separate building for processing. A water curtain system is used to capture ammonia and a liquid fertilizer product is produced as a process byproduct. Similar work has been conducted in development of a high-rise hog facility in Ohio, again using water curtain and bio-filter technologies.

One of the advantages contained in the breadth of skills and technology capabilities in a system the size of the OSU/OARDC research complex is having the ability to work on multi-disciplinary integrated systems

[27] "Alternative Technologies/Uses for Manure: Draft" US EPA Office of Wastewater Management

projects. The opportunity exists, going into the future, for OARDC to develop highly integrated, high-efficiency holistic production systems using raw and waste agricultural and other organic waste materials to generate multiple high-value products. A simplified illustration of such a system is shown in Figure 12, with OARDC having capabilities to work in each of the areas illustrated:

Figure 12: Simplified Illustration of an Integrated Agriculture, Waste and BioEnergy/Bioproducts Production System



The Climate, Water and Carbon TIE

The Climate, Water, and Carbon Program is a collaborative project of faculty in FAES together with the Colleges of Mathematical and Physical Sciences; Social and Behavioral Sciences; the Byrd Polar Research Center; and the John Glenn School of Public Affairs. Work will focus on scientific and policy responses to questions of global importance—including subjects such as fresh water availability, causes of climate change, and the impacts of energy consumption on water and climate.
Cash: $11,350,000; continuing funds: $510,000
Lead Dean: Matthew Platz, College of Mathematical and Physical Sciences

The Public Health Preparedness TIE

The Public Health Preparedness Program comprises faculty and researchers within FAES and the Colleges of Public Health; Medicine; and Veterinary Medicine; Biological Sciences, and Pharmacy. Work will focus on food pathogens, avian flu, anthrax, and other infectious diseases with the pragmatic goal of developing improved detection solutions, enhanced monitoring, safer food, new diagnostic tools, therapies, and vaccines for human and animal diseases, including those resulting from bioterrorism and natural hazards.
Cash: $3,331,112; continuing funds: $1,457,835
Lead Dean: Wiley (Chip) Souba, Jr., College of Medicine

Center for Energy, Sustainability and the Environment

This Center is very much focused on the College of Engineering, but FAES will have an important contributory role to play in relation to biomass-to-energy, environmental resources and sustainability. The Center for Energy, Sustainability and the Environment will address both the national and the global energy needs and issues, engaging in research on clean coal and nuclear power, fuel cells, and new technologies to integrate renewable energy into the energy mix. Center affiliated faculty will also study of the impact of energy solutions on society, the environment, and the economy will the goal of informing energy policy and the development of codes and standards to regulate new energy technologies.
Cash: $1,273,000; continuing funds: $704,500
Lead Dean: Gregory Washington, College of Engineering

Translational Plant Sciences Initiative

FAES and the College of Biological Sciences are collaborating to bring the considerable expertise of OSU faculty and researchers to bear on molecular plant sciences and to accelerate the movement of basic research discoveries to application. This TIE is expected to further collaborate with external partners including Department of Energy National Laboratories, Battelle, and the Ohio Bioproducts Innovation Center to leverage basic and translational plant sciences as drivers of technology-based economic development. Applications will be focused across a range of fields, including agricultural products, industrial products and human health and medicinal products.
Cash: $3,225,000; continuing funds: $156,500
Lead Dean: Matt Platz, College of Biological Sciences

OARDC Investment in Emerging Research Opportunities: Priming the Pump for Future Innovations

OARDC has been proactive in developing programs that encourage both established and junior faculty members to pursue new lines of applied and translational research. One of the key supporting programs

for this is “SEEDS: The OARDC Research Enhancement Competitive Grants Program”. SEEDS was established in 1996 by the Ohio Agricultural Research and Development Center (OARDC) with funding from the Ohio General Assembly and provides grants for work focused on:

- Addressing problems of importance to agriculture, the food industry and the environment aspects of these problems.
- Stimulating new collaborations among scientists from different disciplines and between OARDC and private-sector partners.
- Enhancing and encouraging creative and innovative research
- Employing SEEDS funds to leverage external resources.

OARDC data show that the funding provided through this program has been successful in achieving considerable leverage. OARDC funds have leveraged an additional $40 million in competitive grants—a $5 return for every $1 invested by OARDC. SEEDS funded research programs have engaged over 150 companies in partnering on research with OARDC researchers (see Table 9) and more than 570 publications have resulted from SEEDS funded research projects.

The SEEDS Program has generated eight applications for U.S. patents through its funded research projects. Two patents have been awarded and three technology licenses generated.

The program has helped support human capital development for Ohio, with work having supported 24 doctoral dissertations and 57 master’s theses.

Table 9: Current and Past Corporate Partners in SEEDS Research Programs

3-I
6062 Holdings LLC
AccuDX Inc.
Ag-Spectrum
Alltech
Alpaca Jack's Suri Farm
American Aggregates Corp.
American Coal Ashland Association
American Hosta Society
Ampac Seed Company
Antorchas Foundation
Archer-Daniels-Midland Company
Argus Control Systems Ltd.
Asgrow Seed Company
Athersys, Inc.
Aviagen
BASF Plant Science GmbH Agrarzentrum Limburgerhof
Bass Endowment
Bayer Advanced LLC
Bayer Corporation
Bayer CropScience LP Environmental Sciences
Bedding Plants Foundation, Inc.
Berlin Natural Baker, Inc.
Biotechnology Research and Development Corporation
Boehringer Ingelheim-NOBL
British Columbia Greenhouse Growers' Association
British United Turkeys of America
California Avacado Commission
Camelid Health Foundation
Loveland Industries, Inc.
Magical Farms, Inc.
Maple Leaf Farms, Inc.
Martek Biosciences Corporation
Merial Limited
MicroBio Limited
Mid-America Food Processors
Middlefield Cheese
Midtech
Midwest Regional Hosta Society
Ministry of Culture, Education, & Scientific Exchanges, Spain
National Fish and Wildlife Foundation
National Sea Grant Program
National Wildlife Federation
Natural Fiber Composites Corporation
North American Strawberry Growers Research Foundation, Inc.
Nourse Farms, Inc.
Novartis Crop Protection, Inc.
Nursery Growers of Lake County Ohio, Inc.
N-Viron International, Inc.
Ohio Bioprocessing Research Consortium
Ohio BioProducts Innovation Center
Ohio Corn Marketing Program
Ohio Dairy Farmers Federation, Inc.
Ohio Dairy Producers
Ohio Floriculture Foundation
Ohio Fruit Growers Society
Ohio Lawn Care Association
Ohio Nursery and Landscape Association, Inc.

Campbell R & D
Cargill Animal Nutrition Center
Cattlemen's Carcass Data Service
Center for Asceptic Proccessing and Packaging Studies
Central Ohio Hosta Society
Certified Angus Beef
Ciba Crop Protection
Cinergy
City of Columbus
Cognis Deutschland GmBH & Co.
Consortium for Plant Biotechnology Research
Cooper Farms, Inc.
Cultiva
Dairy Management, Inc.
Danone
DeVenture
Donlar Corporation
Dow Agrosciences
DuPont
Dynal Biotech
E.I. DuPont de Nemours and Co.
Eagle-Picher Minerals, Inc.
Earthgro
Edstrom Industries, Inc.
Elanco Animal Health
Eli Lilly and Company
Farmland Industries
First Energy
Floriculture Industry Research and Scholarship Trust
Food Science Austrailia
Fremont Pickle Growers Association
Fruit Growers Marketing Association
Garick
General Chemical
George F. Ackerman Company
Great Lakes Hosta Society
Gregson Technologies, Inc.
Gustafson, Inc.
Harris Moran Seed Company
Hillshire Farm and Kahn's
Hirzel Canning Co.
Holmes Cheese Company
Holmes Cheese Table
Horticultural Research Institute
Iams Corporation
Infectech, Inc.
Ingredient Innovations International
Integrated Research Technology, LLV
J. Frank Schmidt Family Charitable Foundation
Jarrow Incorporated
Jatco, Inc.
Kamiasahi Feed Lot, Ltd.
Kanter Associates
Kohlpyr
Kraft Foods Global, Inc.Kurtz Brothers, Inc.
Lilly Research Laboratories
Lipha Tech, Inc.
Lipton Tomato Research Center
Ohio Pork Producers Council
Ohio Poultry Association
Ohio Seed Improvement Research
Ohio Sheep and Wool Program
Ohio Soybean Council
Ohio Space Grant Consortium
Ohio Vegetable and Small Fruit Research and Development
Ontario Greenhouse Vegetable Growers
Optimum Quality Grains, L.L.C.
Otterbein College
Outback
Park Foundation
Pennington Seed, Inc. Oregon Division
Petroseed
Pfizer
Pharmacia, Wyeth Ayterst Research
Philip Morris, Inc., Shared Solutions in Agriculture
Phycotransgenics
PIC USA
Pig Improvement Company
Pioneer Hibred International, Inc.
Polter Berry Farm
Protein Technologies International
Purity Foods, Inc.
Quality Liquid Feeds
Rainbow Treecare Scientific Advancements
Rainforest Phytoceuticals
Raven
Rhodia, Inc.
Roche Vitamins Inc.
Satloc
Select Sires
Seminis Vegetable Seeds, Inc.
Small Farm Institute
Syngenta
The Chef's Garden, Inc.
The Garland Company, Inc.
The HANOR Company, Inc.
The Scotts Company & Subsidiaries
Theis Technology Inc.
Thomas Cook
Toh Products, L.LC
Top Soil Precision Ag
Tree Research & Education Endowment Fund
TruGreen-Chemlawn
Turkish Republic Harran University
Valent USA Corp.
Warner Endowment Grant
Welch's

Cross Cutting Supports for Agbioscience-Based Economic Development

The growth of university research parks around the nation shows the value companies place on proximity to academic institutions that are major R&D and innovation engines. Such research parks host university spin-off companies and the operations of existing companies that recognize the benefits of academic-industry R&D partnerships and enjoy the access to skilled human capital graduating from universities.

The Battelle TPP has performed independent evaluation work for the Association of University Research Parks and has concluded that these research parks are emerging as strong sources of entrepreneurship, talent and economic competitiveness[28]. Battelle's survey of 134 university research parks in the U.S. and Canada revealed that:

- More than 300,000 workers in North America work in a university research park.
- Every job in a research park generates an average of 2.57 jobs in the economy resulting in a total employment impact of more than 750,000 jobs.

OARDC has become an active stakeholder in the university research park concept and, with the support of the State of Ohio and Wayne County, is developing the BioHio Research Park. Rather than simply setting aside some land and hoping a research park will develop, OARDC has taken a proactive stance in planning the development of an integrated university-industry-government innovation sustaining environment. While development of the park is still ongoing, the strategy is for integration of the following key components:

Component	Description
Innovation Village	A collaborative environment offering individual offices, labs and other working areas along with common areas and meeting rooms
Research Park	Up to 90 acres of land is available for the development of facilities to house growing and established companies that can capitalize from the research capabilities of the OARDC and BioHio components.
Plant & Animal Agrosecurity Research Facility	An advanced and secure research facility for organisms that cause disease in animals or plants. This BL3 facility will enable scientists to undertake critically important research in new and emerging areas in the study of infectious diseases of animals and plants. Very few facilities exist of this type and scale and demand for their use is increasing because of new government policies.
Bioproducts/Bioenergy Research Complex	Accelerated research into the development of bioproducts and biofuels (including cellulosic ethanol) seeks to make renewable feedstocks viable and cost effective alternatives to fossil fuels. The Center has already proven effective in its research into bio-based products and biofuels utilizing renewable feed stocks and waste by-products, including anaerobic fermentation.
The Molecular and Cellular Imaging Center	Facilities include advanced capabilities to perform DNA sequencing, genomics, bioinformatics, and state-of-the-art microscopy.

[28] Battelle Technology Partnership Practice. "Characteristics and Trends in North American Research Parks: 21st Century Directions". Association of University Research Parks. October 2007. http://www.aurp.net/more/FinalBattelle.pdf

Arden Shisler Center for Education & Economic Development/Fisher Auditorium	A modern conference and distance-learning center that includes a 1,000-seat auditorium.

While the BioHio research park, being driven by ATECH, is still in its early stages, work is progressing well, significant milestones included:

- Current renovation work for Pounden Hall which is to serve as business incubation space with flex labs and co-lab facilities. The building will provide 30,000 sq.ft. of space once renovations are completed. The Pounden Hall renovations have been supported with a $744,000 federal EDA grant.
- Generation of a $3.5 million Jobs Ready Sites grant to renovate Secrest Road leading to the 90 acres that will house the research park.
- Recruitment of companies, such as Schmack BioEnergy, to locate operations at the Wooster campus.

Between 2005 and 2007 ATECH has worked with more than 100 business enterprises and has developed commercial partnerships that provide significant sponsored research opportunities for OARDC researchers. ATECH is leading the recruitment of industry operations to the BioHio Research Park.

Support for research commercialization and collaborative research and development with industry is being provided through the OARDC/OSUE ATECH operation. ATECH serves to coordinate industrial engagement for OARDC and spearheads work to accelerate OARDC-developed technologies towards market commercialization.

V. OARDC 2008 Core Competency Evaluation

Introduction to Core Competency Development and Evolution

The Competitive Positioning Strategy of 2003 assessed the status of OARDC's agbioscience R&D activities and highlighted those areas where the Center has signature research strengths, competitive advantages, and unique assets that could be leveraged for growing the state's agbioscience research base, achieving technology commercialization and ultimately driving economic growth. The research strengths that were identified ranged across a broad spectrum of the agbiosciences, which is logical for a state with a diverse agricultural base and for OARDC which constitutes the largest university agricultural R&D center in the nation. These research strengths, or core competencies, were:

- **Breeding, Genetics & Protection of Crop Plants**, focusing on soybeans, corn, wheat, fruits, and vegetables; development of new varieties and cultivars; plant genetics and transgenics; plant protection from pests, disease, and stress; and functional food crops.
- **Breeding & Genetics of Food Animals**, focusing on beef cattle, dairy cattle, pigs, and poultry; breeding and genetics for desired traits; and trait marker identification.
- **Food Animal Infectious Diseases**, focusing on enteric and respiratory diseases; livestock and poultry diseases; and basic and applied research in bacteria, viruses, and vaccines.
- **Food Safety, Food Processing, and Preservation Technology**, focusing on detection and decontamination; food sterilization and pasteurization; and advanced food processing, preservation, and packaging technologies.
- **Breeding & Genetics of Ornamental Plants**, focusing on ornamental plant breeding and horticulture; germplasm preservation of Ohio-specific varieties; and growing media.
- **Environmental Protection & Sustainability**, focusing on environmental monitoring, protection, remediation, and decontamination; waste management; soil and water preservation; land use; and composting.

While the 2003 Strategy provided a snapshot of OARDC's position in core research focus areas, the global agbiosciences landscape has evolved, and continued investments have been made in the Center's agbiosciences capacities including the economics of agbiosciences. Together, these changes call for a fresh assessment of OARDC's areas of greatest strength and most promising opportunities for agbioscience-driven economic development. Battelle, herein, identifies established sources of competitive advantage, emerging areas of expertise, and promising market opportunities that may guide OARDC's programmatic activities and collaborative efforts moving forward and aid in the direction of strategic and financial investments that will generate economic growth for the future.

In the following sections Battelle presents an updated assessment of:

- OARDC's agbioscience research core competencies determined through quantitative and qualitative analyses of research grants, publications, and extensive interviews; and
- Targets of opportunity in the agbiosciences that build upon the Center's growing base of R&D and leverage this R&D for commercial development and economic growth.

Summary of Key Findings

The analysis presented in this report finds:

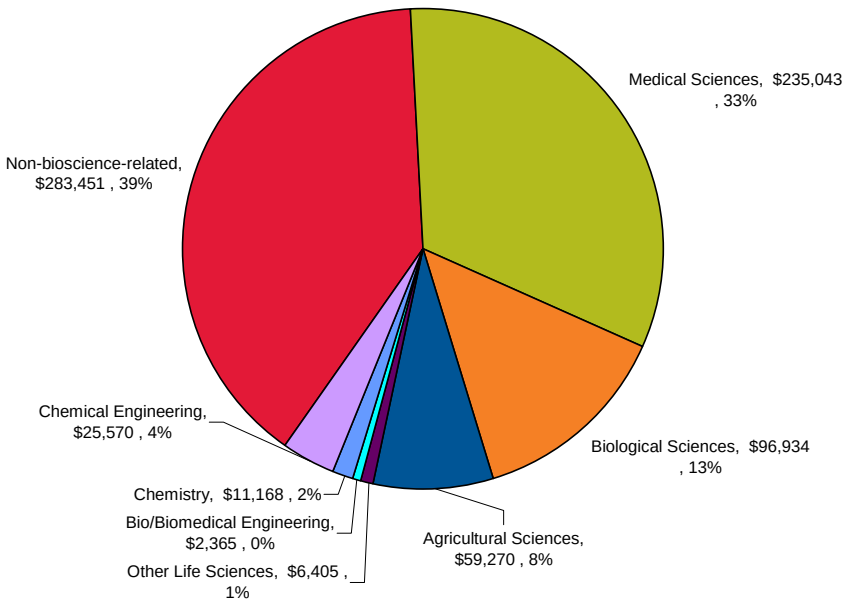
Identification of eleven core competencies. Nine of these core competencies are direct descendants of the 2003 core competencies, but two, agricultural economics and biobased products research, are new.

Identification of five technology platforms linking OARDC's research core competencies with industry strengths and market opportunities. These technology platforms represent areas of convergence of OARDC's research core competencies with strong development potential and competitive advantages in which the Center can build a stronger position in the global agbiosciences economy.

R&D Base

One of the most important indicators of an organization's research strength is the size of its academic research base. Because OARDC is the agbioscience R&D center of OSU, it is instructive to review OSU's performance in academic research expenditures. In 2007, OSU reported $720 million in total academic R&D, of which 61% ($323 million) was in disciplines directly or indirectly related to the life sciences, including medical sciences, biological sciences, agricultural sciences, "other" life sciences,[29] bio/biomedical engineering, chemistry, and chemical engineering (Figure 13). Agricultural R&D accounted for $59.3 million, or 8.2%, of OSU's total academic research expenditures. Comparatively, the percentage of academic R&D that is agriculture-based nationwide was 5.9% (data not shown). As in 2001, when OSU's agricultural R&D was 10.1% of its total academic base, versus 7.1% nationally, OSU continues to have a greater concentration of research in the agricultural sciences than the nation.

Figure 13: Composition of Academic Life Science-related R&D at OSU, 2007 ($ Thousands)



Source: NSF, Survey of R&D Expenditures at Universities and Colleges, FY 2007.

[29] The NSF definition of "other life sciences" includes gerontology, health and medical laboratory technologies, physical therapy, communication disorders sciences and services, nursing technologies, rehab/therapeutic services, health and medical administrative services, occupational therapy, and other health professions and related services.

In 2007, OSU ranked 9th among all U.S. academic institutions in total academic R&D expenditures (Table 10). This ranking is a substantial increase from 19th place in 2001. OSU's ranking also increased in total life sciences, agricultural sciences, biological sciences, medical sciences, and chemical engineering but decreased in other life sciences and chemistry. Of particular note, OSU led the nation in chemical engineering R&D expenditures, accounting for 4.2% of all chemical engineering research performed nationwide. Chemical engineering is especially pertinent to the agbiosciences in terms of developing bioconversion processes and energy and advanced materials from agricultural resources, areas in which OSU, primarily through OBIC, is gaining an exceptionally strong reputation.

Across all U.S. academic institutions, OSU ranked 18th in agricultural R&D, an increase from 27th place in 2001. Among schools in the Great Lakes region, OSU ranked 4th, behind Purdue, Cornell, and Penn State. OSU is the clear leader within the state of Ohio for agricultural R&D, performing 94.8% of all agriculture-focused research (the University of Toledo accounts for the remainder). OSU's $59.3 million in agricultural R&D reflects an impressive 59% increase since 2002, compared to a 19% increase in agriculture-related R&D nationwide.

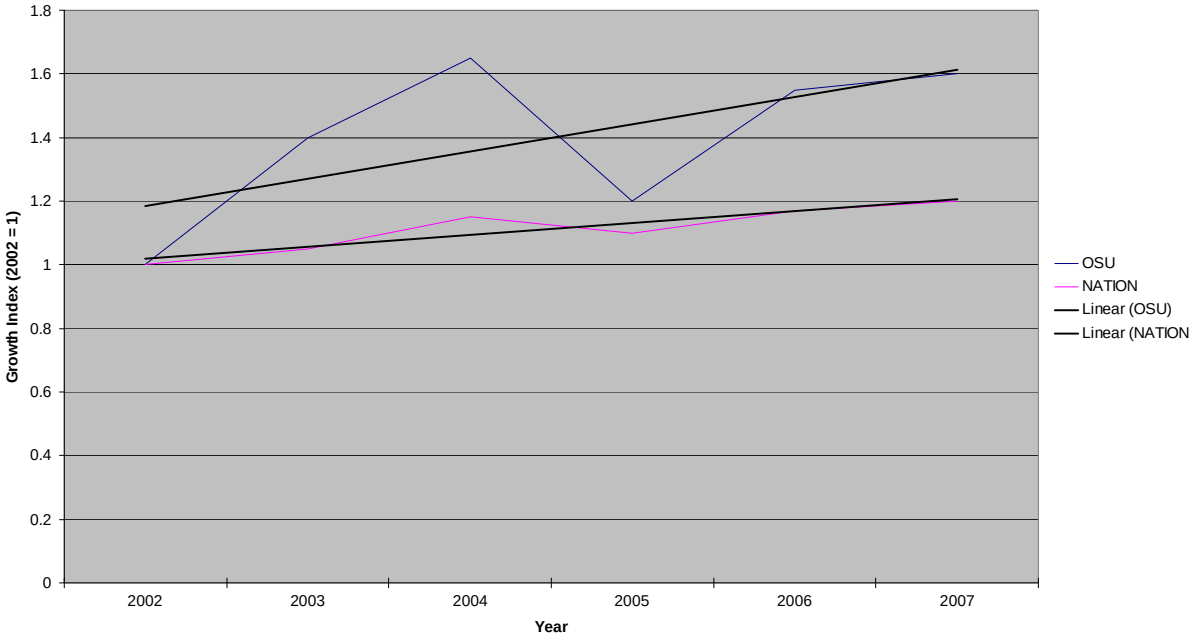
Table 10: R&D Expenditures at OSU Compared to All Ohio and All U.S. Academic Institutions, FY 2007.

Total R&D Expenditures at OSU, FY 2007 (Rank of OSU vs. Other Ohio Schools and vs. All Other Surveyed U.S. Academic Institutions) Nominal (2007) dollars (000s)					
	OSU R&D, FY 2007	% OH	OH Rank '07 (OH Rank '01)	% U.S.	U.S. Rank '07 (U.S. Rank '01)
Total Of All Academic Disciplines	**$720,206**	**39.9%**	**1 (1)**	**1.5%**	**9 (19)**
Life Sciences Total	$397,652	35.2%	1 (1)	1.3%	19 (29)
Agricultural Sciences	$59,270	94.8%	1 (1)	2.0%	18 (27)
Biological Sciences	$96,934	31.5%	1 (1)	1.1%	27 (32)
Medical Sciences	$235,043	32.3%	1 (3)	1.4%	21 (49)
Other Life Sciences	$6,405	21.1%	3 (1)	0.6%	49 (12)
Other Critical Sciences					
Chemical Engineering	$25,570	50.8%	1 (1)	4.2%	1 (17)
Chemistry	$11,168	22.5%	2 (1)	0.8%	44 (19)

Source: NSF, Survey of R&D Expenditures at Universities and Colleges, and Battelle calculations, FY 2007.

Figure 14 displays growth indices for OSU and the U.S. using the 2002 agricultural R&D levels as reference points. From 2002 to 2007, growth of OSU's agriculture R&D expenditures consistently outpaced that of the nation, even during the 2004-2005 period during which growth was negative. It is important to note that OSU's growth appears amplified in this figure due to the comparatively low size of its R&D base relative to that of the entire U.S. However, nothing should be taken away from the fact that OSU has made significant advances in its ability to receive federal R&D funding, despite declining resources and increased competition.

Figure 14: Growth of University Agricultural R&D Expenditures for OSU and the U.S., 2002–2007



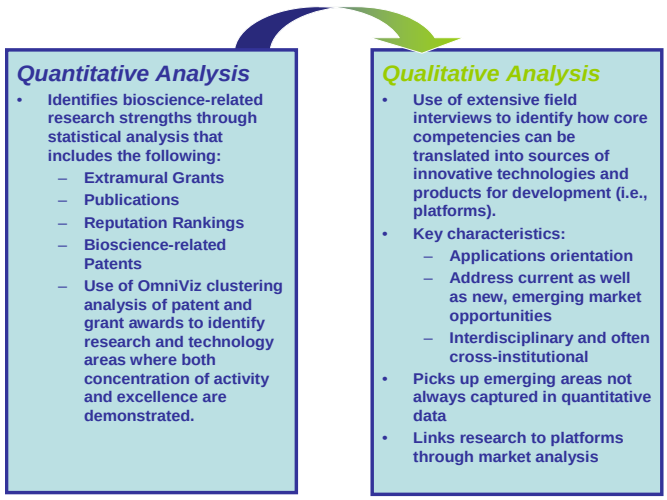
Source: NSF Survey of R&D Expenditures at Universities and Colleges, FY 2002-2007.

Approach to Assessing Research Core Competencies

To understand the potential for continued agbioscience development, it is necessary to undertake a rigorous analysis of the existing agbioscience research core competencies found across OARDC. Research core competencies are those fields with a critical mass of ongoing activity along with some measure of excellence. No single source of information is sufficient to identify research core competencies. Rather, a variety of integrated and complementary analyses are required to help identify an institution's current position and areas of focus that may contribute or lead to future agbioscience-related growth.

Using both quantitative and qualitative methods, Battelle has developed a rigorous approach for assessing the core competencies of research institutions (Figure 15).

Figure 15: Battelle's Quantitative and Qualitative Analysis



Battelle's **quantitative assessment** involves a unique cluster analysis of abstracts from grant awards and publications, analysis of publication and citation activities, and a review of major competitively funded research grants.

Tools used include:

- ***A unique cluster analysis of abstracts of OARDC's grant awards and publications to identify key themes in agbioscience research activity.*** Battelle used the visual intelligence software tool OmniViz™ to provide unique insight into focused areas of research activity across OARDC. Abstracts of 610 competitive research grants and publications from FY 2004 to July 2008 were entered into OmniViz™, which analyzes text by allowing for free association based on the use of words and phrases rather than forcing clustering based on preselected key words. Thus, no "a priori" bias to the clusters is identified. The OmniViz™ cluster analysis involves the following steps (Figure 16):

  Step 1: **Content Development:** A data set is developed with sufficient descriptive content, such as grant, publication, or patent abstracts.

  Step 2: **Pattern Recognition:** The analysis generates clusters where grant, publication, or patent activity has apparent relationships and produces a series of words to describe and link these cluster areas.

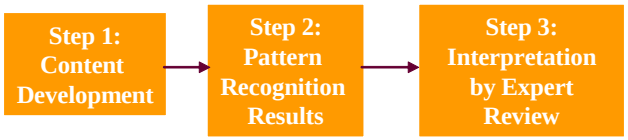


Figure 16: Method for Using OmniViz™ Cluster Analysis

  Step 3: **Interpretation and Grouping into "Meta-clusters" by Expert Review:** The identification of key themes and groupings that result from an OmniViz™ cluster analysis requires an experienced research analyst to read through the cluster items to interpret and explain the types of technologies and specific activities that are represented. The results of the OmniViz™ analysis are presented in Appendix A.

- ***Publications performance.*** This analysis examines the level and quality of OSU publications and citations from 2003 through 2007 in peer-reviewed bioscience publications. The analysis uses 40 fields directly and indirectly related to agbiosciences that are tracked by Thomson Reuters' University Science Indicators (USI), ranging from basic sciences such as genetics, microbiology, and plant sciences, to applied fields such as chemical engineering and biomaterials. In assessing OSU's performance, Battelle considers both the level of publications, measured as OSU's share of total U.S. publications in a field, as well as OSU's relative impact on the field, measured by how its citations per publication for a field compare with the national average in that field. The results of the publications and citations analysis are presented in Appendix B.

- ***Presence of major research grants.*** The presence of major research awards—$250,000 and higher—funded by organizations such as EPA, USDA, state, and private entities indicates areas of research concentration and excellence. Battelle examined awards granted between January 2004 and May 2008. Multiple awards suggest areas where OARDC has a critical mass of research activity, a substantial pipeline of agbioscience-related R&D and where potential commercial opportunities lie.

Battelle developed criteria rankings for each of these quantitative measurements to help illustrate the degree of strength of each identified research core competency. Table 11 explains these criteria and how they are used to assess each core competency.

Table 11: Key to 2008 Quantitative Assessment of OARDC's Agbioscience Research Core Competencies

Presence in Cluster Analysis of Grant Awards and Publications: An internal measure of activity within OARDC.
• Tier 1: Related meta-clusters contain 20 percent or more of all 610 records
• Tier 2: Related meta-clusters contain 10 to 19.9 percent of all 610 records
• Tier 3: Related meta-clusters contain less than 9.9 percent of all 610 records
• No Presence (n/p): No related meta-clusters
Position in USI Publications and Citations Analysis: Analyzes OSU's share of all U.S. publications per field and degree of citations per publication.
• Tier 1: Relevant fields of research with relative impact at least 20 percent higher than the national average for the field
• Tier 2: Relevant fields of research with relative impact between 10 and 20 percent higher than the national average for the field; or relative impact between 1 and 10 percent higher than the national average with above-average share of U.S. publications
• Tier 3: Relevant fields of research with relative impact between 1 and 10 percent higher than the national average for the field; or relative impact below the national average with above-average share of U.S. publications
• Tier 4: Relevant fields of research with relative impact below the national average
Presence of Major Research Grants: Lists major grant awards of $250,000 or more funded since 2004.
• Tier 1: Ten or more major research grants
• Tier 2: Five to nine major research grants
• Tier 3: One to four major research grants
• No Presence (n/p): No competitively funded research grants

The **qualitative assessment** is based on insights gained from interviews with OARDC's research leaders, internal, and external stakeholders on the particular strengths of OARDC's research activities, what differentiates them from others, and where they are headed. Key affiliated departments, programs, and centers were noted and illustrate how each core competency is supported by more than one entity—often a critical mass of investigators working collaboratively across multiple disciplines.

While the quantitative assessment of core competencies reveals where the research enterprise at OARDC is, the qualitative assessment reveals *where it is going*. More than 30 interviews were conducted with OARDC research faculty, staff, and external partners across the state. Altogether, these quantitative and qualitative analyses indicate focused areas of agbioscience research core competencies where OARDC stands out.

VI. Summary of OARDC's Research Core Competencies

Based on the results of the Omniviz™ analysis, reviews of publications, citations, and presence of major research grants, and insights gained from over 30 interviews with key internal and external OARDC stakeholders, the 2008 agbioscience research core competencies are:

Core Competency	Presence in Cluster Analysis	Position in Publications Analysis	Level of Major Research Grants	Interview Highlights	Key Departments and Centers
Economics of Agbiosciences	3	2	1	Basic and applied research on commercialization of agbioscience technologies	• CIBE • Ag, Env & Dev Econ
Biobased Products Research	n/p	2	3	Soy and other feedstock-based development of bioproducts such as bioenergy, rubber, inks, and adhesives.	• OBIC • Chem Eng • OPBC
Environmental Sustainability & Ecosystem Management	2	1	1	Sustainable use of resources, composting, pollution control, carbon sequestration, optimal land use, urban environment and urban landscaping.	• CUEED • Env & Nat Res • Inst E&E
Food Animal Genetics & Breeding	1	2	3	Genetics and breeding to improve growth, yield, and nutrition of food animals including poultry, cattle, and other livestock.	• Animal Sci
Food Animal Virology & Infectious Diseases	2	2	1	Focus on enteric and respiratory diseases, food animal immunology, zoonotic disease diagnostics, and food safety.	• CDA • Animal Sci • FAHRP
Food Processing & Post-harvest Technology	n/p	4	2	Advanced and emerging technologies in food processing and packaging.	• FABE • FST • CAPPS • CIFT
Food Safety	1	3	3	Focus on food sensors and food sterilization with noted expertise in egg safety. Development of food-borne illness preventive vaccines.	• CFSA • FST • FAHRP • CIFT
Functional Foods Research	n/p	2	3	The development of nutritionally enhanced ingredients, foods, and crops to improve health or prevent disease. Particular focus on soy.	• CAFFRE • FABE • FST • OPBC
Plant Genetics & Breeding	1	2	2	Breeding of crops and ornamental plants for improved growth, yield, pest resistance, bio- products, and germplasm development.	• Hort & Crop Sci • OPBC
Plant Pathology & Crop Protection	1	1	1	Focus on soybeans, wheat and corn. Strengths in pathogen detection, breeding	• Plant Path • Entomology • Hort & Crop

Core Competency	Presence in Cluster Analysis	Position in Publications Analysis	Level of Major Research Grants	Interview Highlights	Key Departments and Centers
				for pest resistance, and understanding pathogen-host interface.	Sci • OPBC
Soil Systems	3	1	3	Broad range of focus including soil ecology, soil chemistry, ecosystem modeling, carbon cycling, and composting.	• Env & Nat Res • Soil Eco Lab

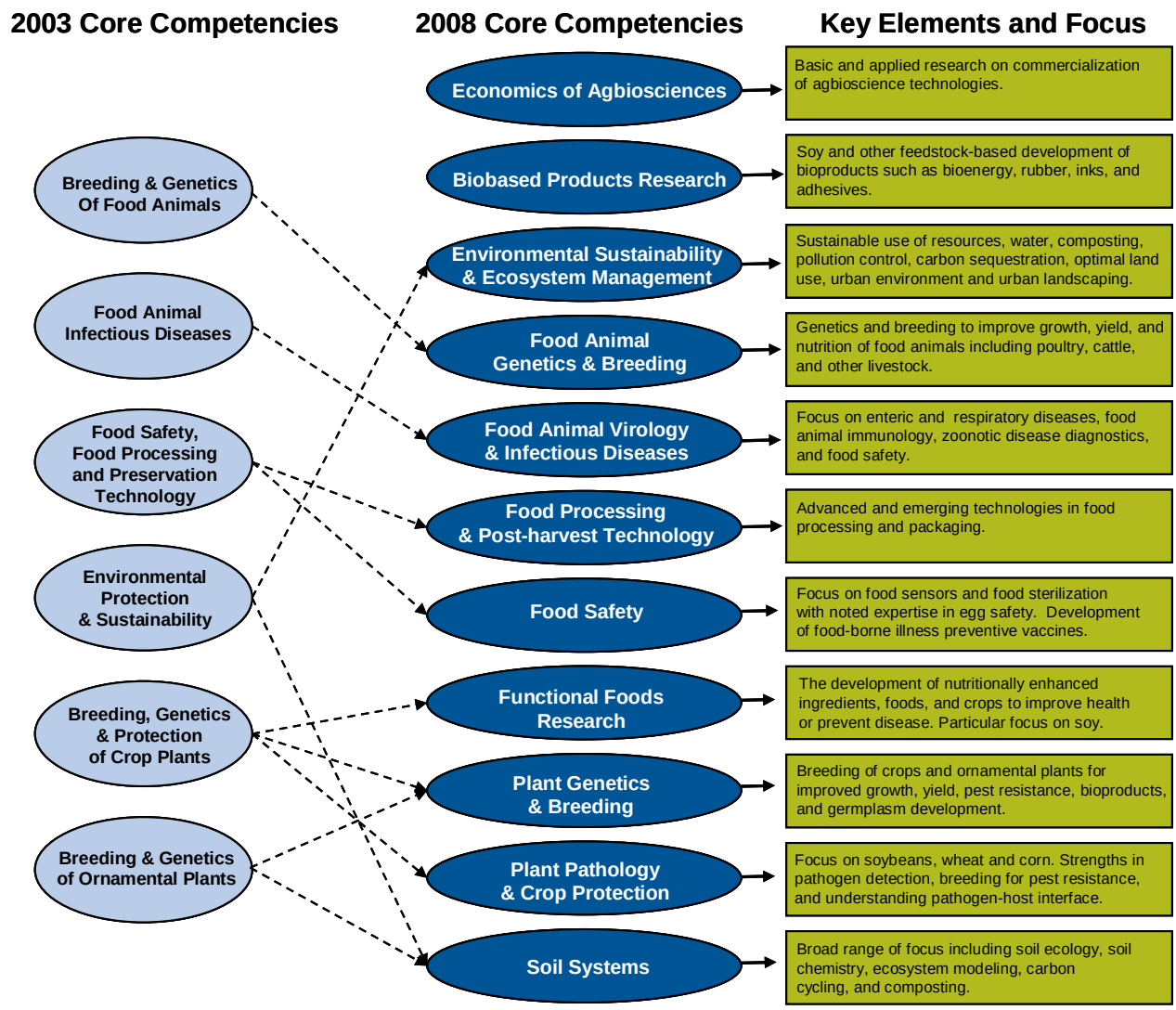
*Rankings defined previously

Key findings of the core competency assessment include:

- **Nine core competencies identical or related to those identified in the previous study and two newly identified core competencies (Economics of Agbiosciences; Biobased Products Research)**
- **Eight broad or cross-cutting core competencies, with multiple well-funded researchers and extensive product applications.**
  - Economics of Agbiosciences (cuts across all other core competency areas)
  - Environmental Sustainability & Ecosystem Management
  - Food Animal Genetics & Breeding
  - Food Animal Virology & Infectious Diseases
  - Food Processing & Post-harvest Technology
  - Food Safety
  - Plant Genetics & Breeding
  - Plant Pathology & Crop Protection
- **Three niche core competencies, with smaller but still significant research base and/or a more targeted focus of activity into specific application areas.**
  - Biobased Products Research
  - Functional Foods Research
  - Soil Systems

Figure 17 illustrates the evolution of these core competencies from those identified in 2003. The tables on the subsequent pages offer more insights into the nature of OARDC's agbioscience research landscape, including statistics on grants and publications, and interview highlights.

Figure 17: OARDC Core Competencies



OARDC's core competencies are explained in greater detail in the following tables.

Economics of Agbiosciences	
Field Definition	**The study of the production, distribution, and consumption of agricultural resources, emphasizing the development and application of economic theories and quantitative methods.**
Supporting Statistics	**Presence in Cluster Analysis: Tier 3** • **One related meta-cluster, "Ag Economics," comprised of one cluster with 14 records equaling 2.3% of all records.** **Position in Publications Analysis: Tier 2** • **40 OSU publications in the USI field "Agr Economics & Policy" with a relative impact 8% higher than the national average. OSU's share of all U.S. publications in this field was 3.4%.** **Presence of Major Related Research Grants: Tier 1** • **Strengthening the Capacity of East African Faculties of Agriculture to Improve Smallholder Productivity (American Council on Education)** • **Understanding the Competitiveness of Online Farm Machinery and Equipment Markets (Cooperative State Research, Education & Extension Service)** • **An Extended-season Berry Production and Marketing System to Enhance Viability of Small Appalachian Farms and Rural Communities (National Research Initiative Competitive Grants Program)** • **Agricultural Adaptation at the Rural-Urban Interface: Can Communities Make a Difference? (National Research Initiative Competitive Grants Program)** • **Organic Food Marketing: Panacea or Problem? (National Research Initiative Competitive Grants Program)** • **Ohio Center for Farmland Policy Innovation (Cooperative State Research, Education & Extension Service)** • **Study to Determine whether Performance-based Cost-share Payments to Provide Incentives for Load Reductions Result in the Reduction of Nutrient and Sediment Impairment in the Stillwater River Watershed (Miami Conservancy District)** • **University Partnership to Build Rural and Microfinance Capacity in Mexico (American Council on Education)** • **Agricultural Exports and Rural Income: Egypt (University of Illinois)** • **Rural Cooperative Development Grant Program (USDA Rural Development)**
Insights from Interviews	• **The program is among the top five agricultural economics departments worldwide; within OSU, it is in the top 3rd of its peers in faculty productivity.** • **The program is particularly well-known for its research on economic development, microfinance, environmental economics, understanding farm-income enhancement, and numerous other areas.** • **Plays a major role in the Agroecosystems Management Program,**

	a key OARDC initiative, multiple OSU Targeted Investments in Excellence (TIE) programs, and all of the Agbioscience Initiative (ABIG) Centers. • **Specific economic development-related areas of expertise include prediction and quantification of market impact by ag-related products, experimental economics, product development, development of commercialization strategies, and grower surveys to assess likelihood of adoption of new agricultural technologies.** • **Novel research in collaboration with the medical school uses fMRI to examine brain signaling during risky decision making.**
Key Departments and Centers	• **Center for Innovation-based Enterprise** • **Department of Agricultural, Environmental & Development Economics**

Biobased Product Research	
Field Definition	**The development and application of novel chemical and biological processes to convert renewable biological, agricultural, or forestry materials into industrial and consumer products. Examples of products include biofuels, supplements, soy-based adhesives and lubricants for industrial uses, biodegradable mulches, biodegradable plastics, corn starch-based packaging, and many others.**
Supporting Statistics	**Presence in Cluster Analysis: Not Present** • **Not present in discrete clusters.** **Position in Publications Analysis: Tier 2** • **149 OSU publications in the USI field "Agronomy" with a relative impact 22% lower than the national average. OSU's share of all U.S. publications in this field was 1.9%.** • **65 OSU publications in the USI field "Agr Engineering" with a relative impact 36% lower than the national average. OSU's share of all U.S. publications in this field was 2.9%.** • **85 OSU publications in the USI field "Polymer Sci" with a relative impact 34% lower than the national average. OSU's share of all U.S. publications in this field was 0.8%.** • **43 OSU publications in the USI field "Mat Sci Biomaterials" with a relative impact 68% lower than the national average. OSU's share of all U.S. publications in this field was 1.4%.** • **274 OSU publications in the USI field "Chem Organic" with a relative impact 26% lower than the national average. OSU's share of all U.S. publications in this field was 1.4%.** • **155 OSU publications in the USI field "Eng Chem" with a relative impact 24% higher than the national average. OSU's share of all U.S. publications in this field was 1.3%.** **Presence of Major Related Research Grants: Tier 3** • **Ohio BioProducts Innovation Center (Ohio Department of Development)** • **Research on Anaerobic Digestion: Optimization and Scalability of Anaerobic Digestion of Mixed High Strength Food Processing Wastes for Renewable Biogas Energy (US Department of Energy)** • **Development and Commercialization of an Integrated Biomass to Electricity System (Ohio Department of Development)** • **Acquisition and Installation of a Pilot-Scale Anaerobic Digester for High-strength Biomass Wastes (Animal & Plant Health Inspection Services)**
Insights from Interviews	• **Due to the strength of the state's agricultural and polymer industries, Ohio is the national leader in R&D of soy-based bioproducts. There is increasing political recognition of the importance of bioproducts, which should be hailed as a signature focus area for the state.** • **Relevant OSU research strengths include plant genetics and breeding (particularly soybean) and chemical engineering, although OARDC needs to increase its interface with the**

	chemical engineering and chemistry departments to better address this and other important opportunities within the agbiosciences. • OBIC is extremely well-known and well-respected for organizing and accelerating activities critical to advancing the R&D of bioproducts. The College of Food, Agriculture and Environmental Sciences and OARDC are crucial supporters of OBIC. • The Ohio Department of Development's $18M Research Scholars Program will provide top researchers at OSU, the University of Dayton, and the University of Akron for work on emergent materials and bioproducts. The University of Akron in particular is ramping up focus on bioproducts and biopolymers, hiring faculty and increasing interactions with OARDC. • Bioenergy, while not an exceptional strength for Ohio, is still a notable area of research activity that includes efforts on algae-based biodiesel, grain and cellulosic ethanol production, and methane production. OARDC is adding a $5 million feedstock processing research facility, including a pilot scale biorefinery. The Wooster campus houses a methane production system utilizing plant and animal waste; industry interest in this is strong. Schmack Bioenergy expects to build an operational biogas production plant in the BioOhio Research Park.
Key Departments and Centers	• Ohio BioProducts Innovation center (OBIC) • Chemical Engineering • Ohio Plant Biotechnology Consortium (OPBC)

Environmental Sustainability & Ecosystem Management	
Field Definition	**Ecological sustainability and ecosystem management refer to the practice of environmental protection to maintain or improve ecosystems and to ensure conservation of resources for future generations.**
Supporting Statistics	**Presence in Cluster Analysis: Tier 2** • **Three related meta-clusters, "Ecosystem Management," "Compost & Nutrient Cycling," and "Crop & Soil Sciences," comprised of three, two, and three clusters respectively with 120 records equaling 19.7% of all records.** **Position in Publications Analysis: Tier 1** • **78 OSU publications in the USI field "Eng Environmental" with a relative impact 31% higher than the national average. OSU's share of all U.S. publications in this field was 0.9%.** • **304 OSU publications in the USI field "Environmental Scis" with a relative impact 3% higher than the national average. OSU's share of all U.S. publications in this field was 1.0%.** • **92 OSU publications in the USI field "Environmental Studies" with a relative impact 20% higher than the national average. OSU's share of all U.S. publications in this field was 1.7%.** • **161 OSU publications in the USI field "Agr Soil Sciences" with a relative impact 52% higher than the national average. OSU's share of all U.S. publications in this field was 3.9%.** • **149 OSU publications in the USI field "Agronomy" with a relative impact 22% lower than the national average. OSU's share of all U.S. publications in this field was 1.9%.** • **257 OSU publications in the USI field "Ecology" with a relative impact 27% lower than the national average. OSU's share of all U.S. publications in this field was 1.1%.** **Presence of Major Related Research Grants: Tier 1** • **Terrestrial Wildlife Ecology Lab (Ohio Division of Wildlife)** • **Landscape Scale Disturbances in an Agroecosystem: Impacts on Aquatic and Riparian Environments in the Sugar Creek Watershed, Ohio (Cooperative State Research, Education & Extension Service)** • **Midwest Regional Carbon Sequestration Partnership—Phase II (Battelle Memorial Institute)** • **Transition Strategies that Control Perennial Weeds and Build Soil (Cooperative State Research, Education & Extension Service)** • **Responding to Emerald Ash Borer Impacts on Forest Structure and Invasive Plant Colonization (Cooperative State Research, Education & Extension Service)** • **Management Intensive Grazing to Improve Profitability of Appalachian Hill-Farms in Southeast Ohio – Research and Extension (Cooperative State Research, Education & Extension Service)** • **Wilma H. Schiermeier Olentangy River Wetland Research Park:**

	Teaching, Research and Outreach Initiative (Environmental Protection Agency) • **Establishment of Plant- and Microbial-mediated Functions in Created Wetlands (Cooperative State Research, Education & Extension Service)** • **Interactions among Human, Biological, and Physical Processes within Large Lake Ecosystems (Cooperative State Research, Education & Extension Service)** • **Understanding Ecological Processes in Channelized Headwater Systems Is a Key to Ecosystem Protection while Maintaining Crop Production (Environmental Protection Agency)** • **Second Ohio Breeding Bird Atlas (Ohio Division of Wildlife)** • **Investigation of Interspecific Variation in Physiological Responses of Ash to Emerald Ash Borer Disease (USDA Forest Service)** • **An Integrated Intertemporal Analysis of Land Use Change in Forestry and Agriculture: An Assessment of the Influence of Technological Change on Carbon Sequestration in Land Use (U.S. Department of Energy)** • **Above ground-Below ground Interactions: Relating Plant Community Composition and Diversity to Methane Cycling in Wetland Ecosystems (NSF)** • **Restoration-based Fuel Reduction Recommendations for Mixed-pine Forests of Upper Michigan (US Fish and Wildlife Service)** • **Regional Water Quality Leadership for North Central States in USEPA Region 5 (University of Wisconsin)** • **Towards a Mechanistic Understanding of Landscape-scale Responses of Animal Communities to Urbanization (NSF Environmental Biology)** • **Meigs 2 Coarse Refuse Reclamation with Reduced Soil Cover (CONSOL Energy Inc.)**
Insights from Interviews	• **OARDC core research strengths in this field include climate change, sustainable use of resources, carbon sequestration, optimal land use, and ecosystem health.** • **The Center for the Urban Environment and Economic Development has made significant advancements in R&D pertaining to pelletized compost for urban lawns, desiccated nematodes as compost additives, microbial degradation, weed control, and pollution control (e.g., "rain gardens" that filter groundwater runoff and recharge the ground), and has multiple partnerships with industry in product development and commercialization.** • **Ohio State is the only university with a concentration on urban lawn and urban landscape ecology that is not golf course-focused. The Urban Landscape Ecology Program performs fundamental research on issues such as storm water run-off, chemical pesticide use, and landscaping practices that have an effect on the health of urbanized environments.** • **Composting is another significant strength related to environmental sustainability; Wooster has a strong composting lab that processes dairy manure and other organic materials. A**

	goal of the Center for the Urban Environment and Economic Development is to develop technology to pelletize compost on-site for local sales and use.
Key Departments and Centers	• **Center for the Urban Environment and Economic Development (CUEED)** • **School of Environment and Natural Resources** • **Urban Landscape Ecology Program** • **OSU Institute for Energy and the Environment**

Food Animal Genetics & Breeding	
Field Definition	**Research on the selection of food animals for desirable traits such as growth, meat, milk, egg, or wool production, leanness, or disease resistance. Involves the application of quantitative and molecular genetics to farm production systems.**
Supporting Statistics	**Presence in Cluster Analysis: Tier 1** • **Three related meta-clusters, "Dairy Sciences," "Poultry Science," and "Genetics & Molecular Biology," comprised of four, four, and two clusters respectively with 168 records equaling 27.5% of all records.** **Position in Publications Analysis: Tier 2** • **207 OSU publications in the USI field "Ag Dairy & Animal Sciences" with a relative impact 5% higher than the national average. OSU's share of all U.S. publications in this field was 3.6%.** • **548 OSU publications in the USI field "Veterinary" with a relative impact 16% lower than the national average. OSU's share of all U.S. publications in this field was 3.3%.** • **359 OSU publications in the USI field "Genetics & Heredity" with a relative impact 4% higher than the national average. OSU's share of all U.S. publications in this field was 1.1%.** **Presence of Major Related Research Grants: Tier 3** • **Major Histocompatibility Molecules in Luteal Function (NIH)** • **Impact of Reproductive Steroid Hormone Concentrations on Uterine Mechanisms Regulating Embryonic Survival in Cattle (National Research Initiative Competitive Grants Program)**
Insights from Interviews	• **OARDC is home to award-winning research in poultry science (i.e., the determination that breast meat is maternally inherited)** • **OSU has a national and international reputation in food animal genetics, physiology, and reproduction** • **OARDC's Molecular and Cellular Imaging Center (MCIC) is critical for handling the large increase in genotyping for food animal breeding**
Key Departments and Centers	• **Department of Animal Sciences**

Food Animal Virology/Infectious Diseases	
Field Definition	**Research related to the detection, diagnosis, treatment, and control of livestock infectious diseases as well as surveillance and reporting systems. Involves veterinary medicine, veterinary pathology, microbiology, immunology, food science, and agricultural economists to evaluate the impact of outbreaks.**
Supporting Statistics	**Presence in Cluster Analysis: Tier 2** • **Two related meta-clusters, "Animal & Human Virology," and "Pathology & Microbiology," comprised of five and two clusters respectively with 119 records equaling 19.5% of all records.** **Position in Publications Analysis: Tier 2** • **316 OSU publications in the USI field "Microbiology" with a relative impact 2% higher than the national average. OSU's share of all U.S. publications in this field was 1.4%.** • **39 OSU publications in the USI field "Parasitology" with a relative impact 25% lower than the national average. OSU's share of all U.S. publications in this field was 1.4%.** • **548 OSU publications in the USI field "Veterinary" with a relative impact 16% lower than the national average. OSU's share of all U.S. publications in this field was 3.3%.** • **207 OSU publications in the USI field "Ag Dairy & Animal Sciences" with a relative impact 5% higher than the national average. OSU's share of all U.S. publications in this field was 3.6%.** • **124 OSU publications in the USI field "Infectious Diseases" with a relative impact equal to the national average. OSU's share of all U.S. publications in this field was 0.8%.** • **144 OSU publications in the USI field "Virology" with a relative impact 26% lower than the national average. OSU's share of all U.S. publications in this field was 1.3%.** **Presence of Major Related Research Grants: Tier 1** • **Design Costs for New Construction of a Facility to Support Emergency Detection and Response Research Program on Emerging Animal and Plant Diseases (US Department of Health & Human Services)** • **Porcine Respiratory Coronavirus as a SARS Model (National Institute of Allergy & Infectious Diseases)** • **The Role of European Starlings in the Epidemiology of E. coli 0157 of Dairy Cattle (Cooperative State Research, Education & Extension Service)** • **Enhancing the Immunogenicity of Human Rotavirus Vaccines (National Institute of Allergy & Infectious Diseases)** • **Developing Recombinant Coronavirus Vaccines for SARS (University of Arkansas)** • **Emergency Detection and Response Research Program on Emerging Animal and Plant Diseases at OARDC (Cooperative State Research, Education & Extension Service)** • **Animal Coronavirus Pools (Fisher BioServices, Inc.)**

	• Antigenic Relationships of SARS and Animal Coronaviruses (National Institute of Allergy & Infectious Diseases) • Attachment, Uptake, Dissemination and Inactivation of Foodborne Enteric Caliciviruses in Vegetables (National Research Initiative Competitive Grants Program) • Paracrine Factors Regulating Immune Cell Function in the Bovine Corpus Luteum (University of Maryland) • Vaccination with Attenuated Influenza Viruses and Biological Characterization of Avian Influenza Viruses (USDA Agricultural Research Service) • Effects of Probiotic Lactobacilli on Rotavirus Immunity (NIH)
Insights from Interviews	• Food animal health research, focusing on enteric diseases, respiratory diseases, food safety, and food animal immunology, is a core strength at OSU. Wooster has valuable food animal health research capabilities and animal facilities, with a BSL3 ag facility planned for 2010. • The Center for Diagnostic Assays is the only center of its kind in academia focusing on bringing zoonotic disease diagnostics to the marketplace. • Ohio has a good human diagnostics industry, but not food animal diagnostics; a goal of the Center for Diagnostic Assays is to develop an infectious disease diagnostics forum for food animals and food plants that would connect growers, researchers, assay labs, and industry and would be instructive for R&D and market analyses. • The BioOhio Research Park will help bring focus to an Ohio-based food animal diagnostics industry.
Key Departments and Centers	• Center for Diagnostic Assays • Department of Animal Sciences • Food Animal Health Research Program

Food Processing & Post-harvest Technology	
Field Definition	**Research related to the development of methods and technologies for the transformation of raw ingredients into high-quality, safe, and marketable food products; to the reduction of food losses; and to higher profits for growers and marketers.**
Supporting Statistics	**Presence in Cluster Analysis: Not Present** • **Not present in discrete clusters.** **Position in Publications Analysis: Tier 4** • **378 OSU publications in the USI field "Food Science & Technology" with a relative impact 20% lower than the national average. OSU's share of all U.S. publications in this field was 3.2%.** **Presence of Major Related Research Grants: Tier 2** • **Center for Innovative Food Technology (Cooperative State Research, Education & Extension Service)** • **Pork Quality Benchmark Project (National Pork Board)** • **Reheating & Sterilization Technology for Food, Waste and Water (Johnson Space Center)** • **Characterizing the Effect of Plant Genotype and Processing Techniques on Carotenoid Stability in Tomato Products by Direct Infrared Spectroscopy (Cooperative State Research, Education & Extension Service)** • **Pressure-assisted Thermal Processing: Key Engineering Properties and Process Improvement (Cooperative State Research, Education & Extension Service)** • **Punjab Agricultural University and Food Processing: New Linkages with the Private Sector (American Council on Education)**
Insights from Interviews	• **Food processing—particularly emerging food processing methods for preservation and production such as cold sterilization, pasteurization, and pressurization—are among the strongest agbioscience opportunities for the state.** • **The Center for Advanced Processing and Packaging Studies (CAPPS), an NSF funded center of excellence connecting OSU, University of California-Davis, North Carolina State University, and industry, is the only NSF center of its kind in food science. The Columbus site is the only in the world with three pilot plants dedicated to emerging food** • **The OSU site is the only campus in the world with three pilot facilities devoted to emerging food processing technologies.** • **Ohio has a sizable base of food processing/equipment companies who will be logical consumers for CAPPS and OARDC food processing technologies.**
Key Departments and Centers	• **Department of Food, Agricultural, and Biological Engineering** • **Department of Food Science and Technology** • **Center for Advanced Processing and Packaging Studies (CAPPS) and the Center for Innovative Food Technology**

Food Safety	
Field Definition	**Research concerning the tracking foodborne illness, investigation of outbreaks of foodborne disease, and the development of food handling, processing, and storage techniques to prevent foodborne illnesses.**
Supporting Statistics	**Presence in Cluster Analysis: Tier 1** • **Three related meta-clusters, "Food Safety," "Animal & Human Virology," and "Pathology/Microbiology," comprised of two, five, and two clusters respectively with 159 records equaling 26.1% of all records.** **Position in Publications Analysis: Tier 3** • **378 OSU publications in the USI field "Food Science & Technology" with a relative impact 20% lower than the national average. OSU's share of all U.S. publications in this field was 3.2%.** • **316 OSU publications in the USI field "Microbiology" with a relative impact 2% higher than the national average. OSU's share of all U.S. publications in this field was 1.4%.** • **124 OSU publications in the USI field "Infectious Diseases" with a relative impact equal to the national average. OSU's share of all U.S. publications in this field was 0.8%.** • **144 OSU publications in the USI field "Virology" with a relative impact 26% lower than the national average. OSU's share of all U.S. publications in this field was 1.3%.** **Presence of Major Related Research Grants: Tier 3** • **Integrating Social and Biological Sciences to Enhance Adoption of Vegetable Safety Behaviors from Farm to Table (Cooperative State Research, Education & Extension Service)** • **Safety of Foods Processed by Four Alternative Processing Technologies (Cooperative State Research, Education & Extension Service)** • **Implementation: Ultrasonic Sealing of Preformed Pouches in Production (Defense Logistics Agency)** • **Incidence, Significance, and Control of Listeria monocytogenes in the Home Environment (USDA Agricultural Research Service)**
Insights from Interviews	• **Food safety (along with food security) is a major agbioscience opportunity for Ohio, building off OSU's expertise in food-borne illness and public health research, and the state's considerable food manufacturing industry.** • **OSU researchers in food-borne illness range from environmental epidemiologists and public-health oriented veterinarians to food microbiologists and experts in infectious disease.** • **Unique, well-funded (USDA and NIH) niches in food safety include E. coli, Salmonella, Norwalk Virus, and Campylobacter.** • **The Center for Food Safety and AgroSecurity (CFSA), an ABIG center, is a partnership with the Center for Innovative Food Technology (based at the University of Toledo) and the food industry focused on bringing food safety applications to the**

	marketplace. • **A major CFSA initiative is in egg safety, working with ozone technology and Ohio-based EggTech Ltd. to eradicate Salmonella from eggs.** • **Another CFSA effort surrounds development of a rapid test for Norwalk Virus. This effort links with the Ohio Center for Public Health Preparedness, a $4.7 million Targeted Investment in Excellence. OSU is hiring faculty in this area and planning investments for the development of a human preventive vaccine through multidisciplinary research with the Schools of Public Health, Medicine, and Veterinary Science.** • **Food safety and food sensors are very likely to be either OSU- or Ohio Department of Development-funded centers of excellence.**
Key Departments and Centers	• **Center for Food Safety and AgroSecurity (CFSA)** • **Department of Food Science & Technology** • **Food Animal Health Research Program** • **Center for Innovative Food Technology**

Functional Foods Research	
Field Definition	**Functional foods are any fresh or processed ingredient or food claimed to have a health-promoting and/or disease-preventing property. Such claims may be supported by in vitro, in vivo, and clinical trials data. Related disciplines span plant breeding, plant sciences, food science and technology, and clinical studies.**
Supporting Statistics	**Presence in Cluster Analysis: Not Present** • **Not present in discrete clusters.** **Position in Publications Analysis: Tier 2** • **378 OSU publications in the USI field "Food Science & Technology" with a relative impact 20% lower than the national average. OSU's share of all U.S. publications in this field was 3.2%.** • **395 OSU publications in the USI field "Plant Sciences" with a relative impact 6% higher than the national average. OSU's share of all U.S. publications in this field was 2.2%.** • **143 OSU publications in the USI field "Nutrition & Dietetics" with a relative impact 10% lower than the national average. OSU's share of all U.S. publications in this field was 1.4%.** • **757 OSU publications in the USI field "Oncology" with a relative impact 4% higher than the national average. OSU's share of all U.S. publications in this field was 1.7%.** • **287 OSU publications in the USI field "Cardiology & Cardiovascular Systems" with a relative impact 7% higher than the national average. OSU's share of all U.S. publications in this field was 1.1%.** **Presence of Major Related Research Grants: Tier 3** • **Characterizing the Effect of Plant Genotype and Processing Techniques on Carotenoid Stability in Tomato Products by Direct Infrared Spectroscopy (Cooperative State Research, Education & Extension Service)** • **Federal Administration Grant for the Dietary Intervention: Chemoprevention of GI Tract Cancers with Berries** • **Special Research Grant for Dietary Intervention (Cooperative State Research, Education & Extension Service)** • **Tomato-Soy Juice for Prostate Cancer (National Cancer Institute)**
Insights from Interviews	• **Functional foods research is considered one of the stronger agbioscience opportunities in Ohio due in large part to the location of all key disciplines (plant breeding, horticulture, food science and technology, cancer, cardiology, clinical trials, public health, education, and human ecology) on a single campus.** • **The Center for Advanced Functional Foods Research and Entrepreneurship (CAFFRE) has made significant advances in the development of products linking food nutrition and cancer prevention; soy-enhanced tomato juice is one noted success story. Soy-enhanced bread is another.** • **OARDC is well-known for development of high-protein soybeans.**

Key Departments and Centers	• Center for Advanced Functional Foods Research and Entrepreneurship (CAFFRE) • Department of Food, Agricultural, and Biological Engineering • Department of Food Science and Technology • Ohio Plant Biotechnology Consortium (OPBC)

Plant Genetics & Breeding	
Field Definition	**Addresses the principles and methodologies related to the improvement of agricultural or ornamental plant yield, quality, and resistance to diseases and pests. The development of improved cultivars and germplasm are key objectives. Research areas include biochemical and molecular genetics, quantitative genetics, cytogenetics and cytology, horticulture, and agronomy.**
Supporting Statistics	**Presence in Cluster Analysis: Tier 1** • **Three related meta-clusters, "Genetics & Molecular Biology," "Plant Breeding for Resistance," and "Seed Genetics," comprised of two, two, and three clusters respectively with 167 records equaling 27.4% of all records.** **Position in Publications Analysis: Tier 2** • **395 OSU publications in the USI field "Plant Sciences" with a relative impact 6% higher than the national average. OSU's share of all U.S. publications in this field was 2.2%.** • **104 OSU publications in the USI field "Horticulture" with a relative impact 33% lower than the national average. OSU's share of all U.S. publications in this field was 2.9%.** • **359 OSU publications in the USI field "Genetics & Heredity" with a relative impact 4% higher than the national average. OSU's share of all U.S. publications in this field was 1.1%.** **Presence of Major Related Research Grants: Tier 2** • **Ornamental Plant Germplasm Center (USDA Agricultural Research Service)** • **Grafting to Improve Organic Vegetable Production in Field and High Tunnel Systems (Cooperative State Research, Education & Extension Service)** • **Genetic, Molecular and Developmental Analysis of Variation in Tomato Fruit Morphology (National Science Foundation)** • **Low Temperature Regulatory Circuits and Gene Regulons in Higher Plants (Michigan State University)** • **Deep Transcriptional Profiling of Rice Using Signature Sequencing (University of Delaware)** • **Toward Cloning Rps3 and Rps8, Effective Resistance Genes for Phytophthora sojae for the New Millenium (Iowa Soybean Association)** • **Uniform Nursery for Soft Red Winter Wheat and Breeding Scab Resistant Varieties for Ohio (USDA Agricultural Research Service)**
Insights from Interviews	• **Strengths in plant breeding and genetics range across soybeans, tomatoes, wheat, other crops, and ornamental plants.** • **Another key strength is in the development of seed traits with improved germplasm for a higher crop yield. Germplasm development and trait licensing may in fact be more valuable than developing new varieties.** • **Soybean-specific breeding and genetic efforts include breeding for improved growth/yield, development of improved food-grade**

	varieties, breeding for pest/disease/stress resistance, and breeding for bioproduct applications. • **The Molecular and Cellular Imaging Center plays a critical role in accelerating the process on genotyping and breeding for new traits.**
Key Departments and Centers	• **Department of Horticulture and Crop Science** • **Ornamental Plant Germplasm Center** • **Ohio Plant Biotechnology Consortium**

Plant Pathology & Crop Protection	
Field Definition	**Refers to the study of plant diseases caused by pathogens, including fungi, bacteria, viruses, nematodes, and parasites. Also involves the study of pathogen detection, diagnosis, disease cycle, disease management, epidemiology, effect on growth and yield, effect on consumers, and economic impact.**
Supporting Statistics	**Presence in Cluster Analysis: Tier 1** • **Four related meta-clusters, "Plant Virology," "Pathology/Microbiology," "Plant Breeding for Resistance," and "Entomology/EPNs," comprised of one, two, two, and two clusters respectively with 162 records equaling 26.6 % of all records.** **Position in Publications Analysis: Tier 1** • **395 OSU publications in the USI field "Plant Sciences" with a relative impact 6% higher than the national average. OSU's share of all U.S. publications in this field was 2.2%.** • **161 OSU publications in the USI field "Entomology" with a relative impact 20% higher than the national average. OSU's share of all U.S. publications in this field was 1.7%.** **Presence of Major Related Research Grants: Tier 1** • **Design Costs for New Construction of a Facility to Support Emergency Detection and Response Research Program on Emerging Animal and Plant Diseases (US Department of Health & Human Services)** • **Functional Genomics of Phytophthora-plant Interactions (National Science Foundation)** • **Use of Oligo Arrays to Dissect Rice Defense Response Pathways (Cooperative State Research, Education & Extension Service)** • **Limiting Losses to Phytophthora sojae in the North Central Region (North Central Soybean Research Program)** • **Biophysical and Ecological Processes Impacting the Growth and Survival of E. coli 0157 on and in Vegetables (Cooperative State Research, Education & Extension Service)** • **Emergency Detection and Response Research Program on Emerging Animal and Plant Diseases at OARDC (Cooperative State Research, Education & Extension Service)** • **Toward Cloning Rps3 and Rps8, Effective Resistance Genes for Phytophthora sojae for the New Millennium (Iowa Soybean Association)** • **Upper Sugar Creek Watershed, Ohio: A Model Watershed for Study of Pathogen Origin, Fate and Transport (National Research Initiative Competitive Grants Program)** • **Elucidating the Function of a U-box E3 Ligase-mediated Ubiquitination Pathway in Programmed Cell Death and Disease Resistance in Rice (National Research Initiative Competitive Grants Program)** • **Plant Responses to Bacterial Quorum Sensing Signals (Cooperative State Research, Education & Extension Service)**

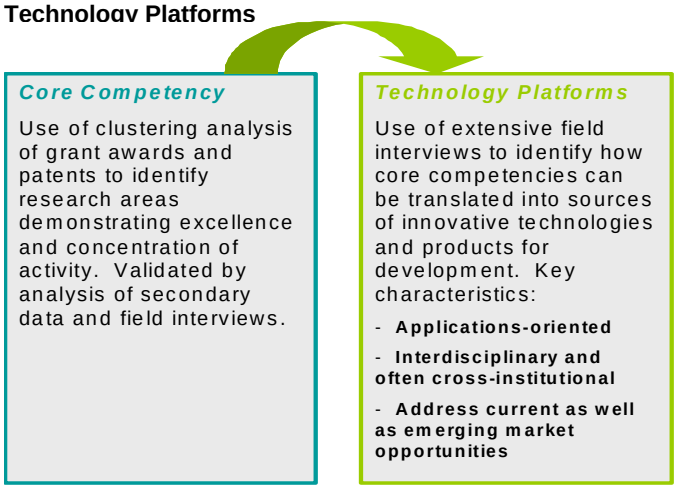
	• Chemical Ecology of Host-mediated Systemic Interactions between Pathogens and Insects in Austrian Pine over a Fertility Gradient (Cooperative State Research, Education & Extension Service) • A High-throughput Protoplast System for Rice Functional Genomics and Proteomics: Protein-protein Interactions at the Host-pathogen Interface (North Carolina State University) • International Regional Plant Diagnostic Network (Virginia Polytechnic Institute) • Role of Phytophthora infestans Protease Inhibitors and Their Target Tomato Proteases in Disease (Cooperative State Research, Education & Extension Service) • Genome Sequencing of Phytoplasmas, Pathogens of Insects and Plants (Cooperative State Research, Education & Extension Service) • Hand-held Assays for Field-friendly Diagnosis of Soybean Rust (Iowa Soybean Association) • Dissecting Soybean Resistance to Phytophthora by QTL Analysis of Host and Pathogen Expression Profiles (Virginia Polytechnic Institute) • The Role of WtsE and Other hrp-Dependent Effector Proteins in the Pathogenicity of Pantoea stewartii to Zea mays (Cooperative State Research, Education & Extension Service) • Manipulation of Plant Signaling by Bacterial Effector Proteins (NSF Molecular & Cellular Biosciences)
Insights from Interviews	• Established OARDC strengths in plant pathology include pathogen detection, soybean breeding for pest and disease resistance, characterization of vector-borne pathogens, emerging insect-borne pathogens, plant-pathogen communication mechanisms, and corn and soybean virus research. • Other chief strengths include wheat and soy applied genomic research, basic research on a broad range of plant pathogens (e.g., aphids, soybean rust, emerald ash borer), and studies of new sources of disease resistance (e.g., in peppers and wheat). • Entomology, virology, and molecular virology are key related disciplines in which OSU is planning strategic hires. • One of the biggest success stories is an OARDC research group's identification of the soybean Phytophthora resistance RPS8 gene. Industry is now developing a new soybean variety containing this gene although it could be a year or longer until it is in the field. • Promising work is being conducted on the use of statistical and computer forecasting models to predict plant disease dynamics and to inform disease management decisions. • Novel research in integrated pest management focuses on host plant resistance, conservation tillage practices, and other responses to invasive pests in order to prevent crop losses.
Key Departments and Centers	• Department of Plant Pathology • Department of Entomology • Department of Horticulture & Crop Science • Ohio Plant Biotechnology Consortium

Soil Systems	
Field Definition	**The study of soil as a natural resource, including, soil formation, classification, chemical and biological properties, and the use of soil for economic and environmentally sound land use.**
Supporting Statistics	**Presence in Cluster Analysis: Tier 3** • **One related meta-cluster, "Crop & Soil Sciences," comprised of four clusters, with 46 records equaling 7.5% of all records.** **Position in Publications Analysis: Tier 1** • **161 OSU publications in the USI field "Agr Soil Sciences" with a relative impact 52% higher than the national average. OSU's share of all U.S. publications in this field was 3.9%.** • **149 OSU publications in the USI field "Agronomy" with a relative impact 22% lower than the national average. OSU's share of all U.S. publications in this field was 1.9%.** **Presence of Major Related Research Grants: Tier 3** • **Role of the Eeotic Earthworm, Lumbricus terrestris, in the Colonizing Behavior of the Native Weed, Ambrosia trifida (Cooperative State Research, Education & Extension Service)** • **Assessing Fossil and Recent Carbon Pools in Reclaimed Mined Soils (National Energy Technology Laboratory)** • **Consortium for Agricultural Soils Mitigation of Greenhouse Gases (Kansas State University)** • **Carbon Sequestration in Reclaimed Mined Soils of Ohio (National Energy Technology Laboratory)**
Insights from Interviews	• **Notable research strengths related to soil science include soil chemistry, soil ecology, carbon cycling, and ecosystem modeling. Research interests of department faculty span an extremely wide range of focus areas.** • **Composting is a significant strength related to soil science; Wooster has a strong composting lab that processes dairy manure and other organic materials.**
Key Departments and Centers	• **School of Environmental and Natural Resources** • **Soil Ecology Laboratory**

VII. Current Platform Recommendations

OARDC's core competencies reflect the wide range and scope of the Center's R&D expertise across the agbiosciences. These core competencies are the foundations on which OARDC maintains its strong reputation in global agbiosciences research. But the translation of these core competencies into broader technology platforms (Figure 18) will enable OARDC to exploit existing and emerging market opportunities and to maintain significant agbioscience-based economic impact within Ohio.

Figure 18: Translation of Core Competencies into Technology Platforms



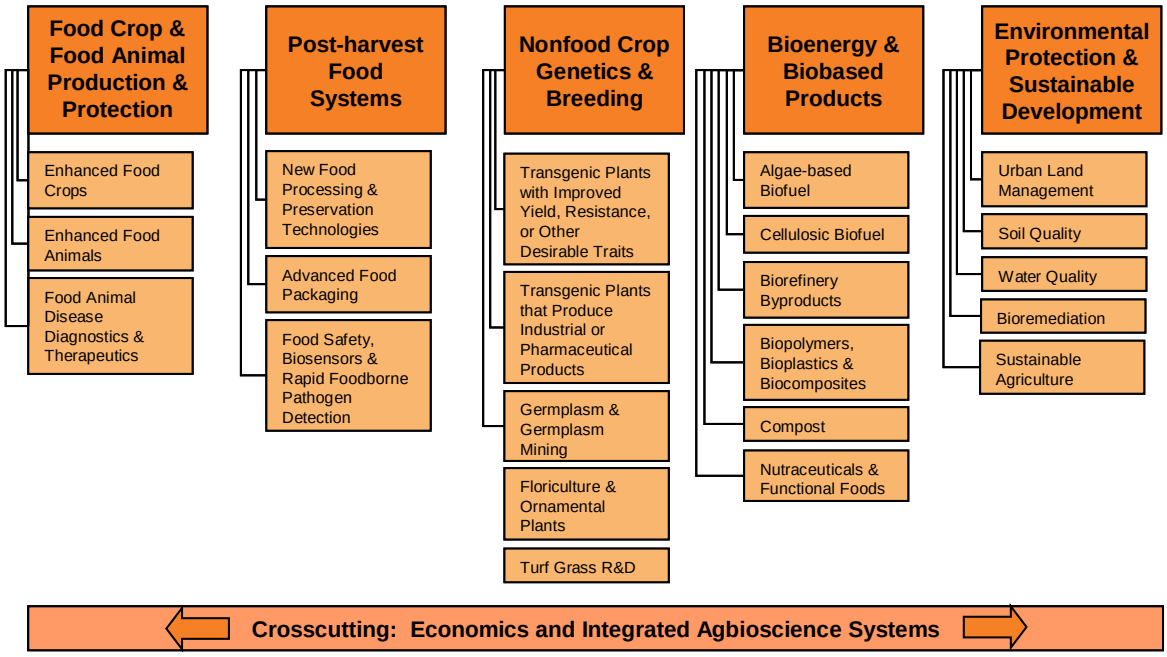
Technology platforms are broad, applications-oriented, strategically chosen areas that offer the potential to realize significant gains in economic development. They should correspond to the development of technologies in a favorable timeframe and in multiple substantial, growing markets, and possibly evolve into or generate new technology platforms. Focusing on them can accelerate technology development, foster effective collaboration and partnerships, raise public awareness of the global issues they address, and stimulate investment in R&D. And in the long term, implementation of a technology platform can produce sustainable competitiveness by stimulating innovation, overcoming the barriers to the deployment of new technologies, and generating economic growth and expansion.

Identification of technology platforms requires the consideration of several criteria:

- **Opportunities drawing upon multiple research strengths.** The technology platform should address market opportunities that transcend multiple core competencies and organizations, ensuring that OARDC's agbioscience research base is a fertile, multidisciplinary, cross-cutting, and collaborative research environment rather than a collection of stand-alone research strengths.
- **Presence of existing or emerging commercial activity.** The technology platform should align institutional research strengths with local industries, creating new linkages and strengthening existing connections.
- **Opportunity for external funding.** The technology platform should relate to pressing issues or needs and thus be likely to attract major external R&D funding and investment.
- **Limited competition from other states or regions.** A successful technology platform builds on specific competitive advantages such as geography, market base, tacit knowledge base, exclusive resources, or policies.

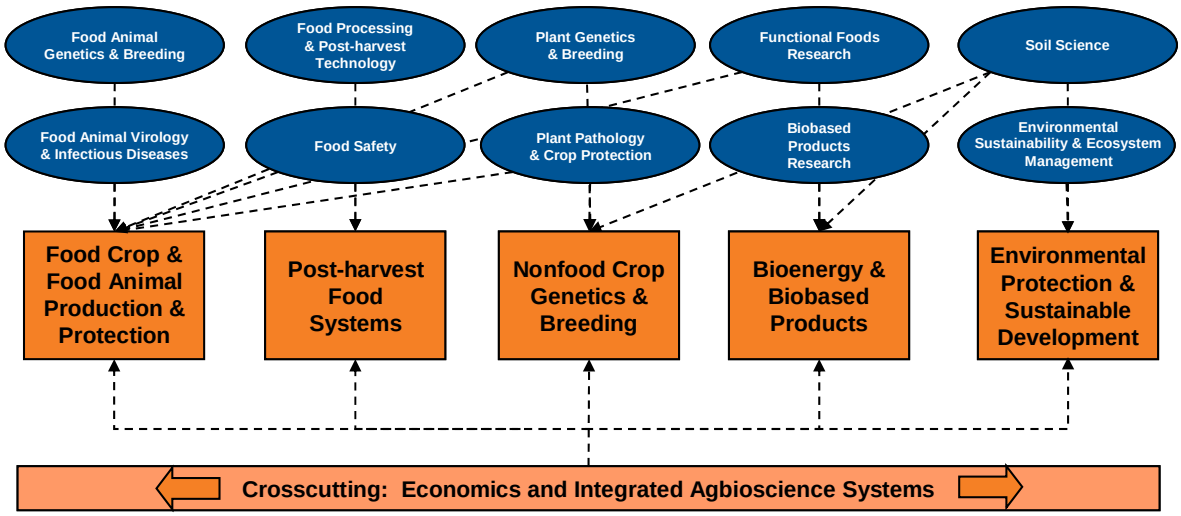
Based on these criteria, five technology platforms in the agbiosciences were identified, together with one cross-cutting support platform. These platforms are broad areas in which OARDC has significant opportunity to capitalize upon R&D excellence for economic gain. These platforms do not correspond to each and every promising opportunity in the agbiosciences, but represent the areas in which OARDC has the greatest likelihood of achieving a leadership position based on research strengths, industry activity, development potential, and competitive advantages. The technology platforms and examples of promising applications are presented in Figure 19 below:

Figure 19: 2008 OARDC Technology Platforms



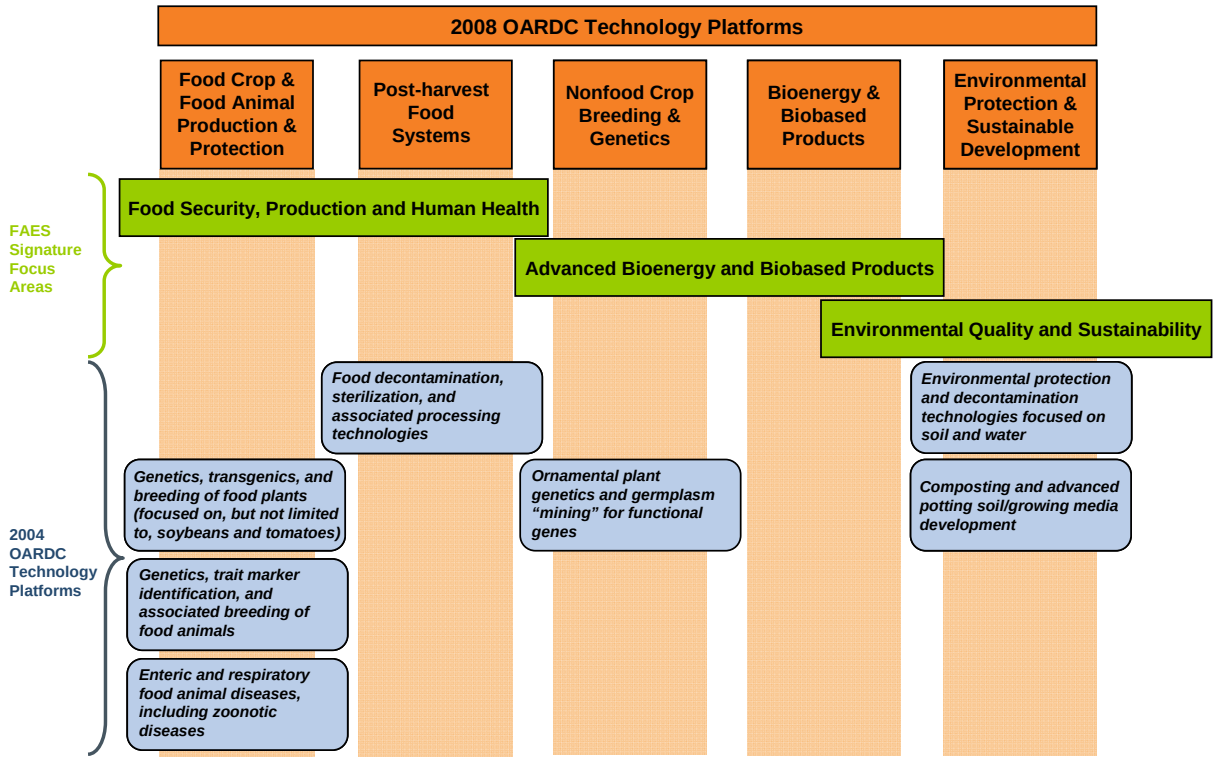
Each platform is supported by multiple research core competencies as shown in Figure 20. Such multidisciplinary support bolsters OARDC's position in each platform and increases the chances that novel discoveries will be made and that innovative technologies will be developed. Of note, the Economics of Agbiosciences core competency offers cross-cutting support to all of the platforms by rooting product development with real-world application, pragmatism and market analysis.

Figure 20: Multiple Core Competencies Support Each Platform



It should be clear that these technology platforms correspond closely to the seven identified in the 2004 Battelle report. This is suggestive of one or more of the following: the 2004 platforms were sufficiently broad that they encompass any new platforms; the 2004 platforms were accurate and very little—either within OARDC or the broader agbioscience landscape—has changed that would warrant identification of new platforms; and/or OARDC strategically positioned around the 2004 platforms, resulting in a structure and focus that clearly influenced the calculations undertaken by Battelle in determination of the 2008 platforms. Also, not only are the 2008 platforms directly evolved from the 2004 platforms, they are closely related to the three overarching R&D areas put forth in the 2008 strategic plan of the College of Food, Agriculture, and Environmental Science (FAES) (Figure 21). Altogether, these overlaps validate and support the recommendations presented by Battelle in the previous report, OARDC's adoption of them in developing its ABIG centers and strategic directions, and the current vision for the entire college.

Figure 21: Considerable overlap between the 2008 OARDC technology platforms, signature focus areas of the College of Food, Agriculture and Environmental Sciences, and 2004 Technology Platforms demonstrates adherence to a single vision.



The 2008 OARDC technology platforms represent convergence points of OARDC's academic and commercial research strengths in the agbiosciences with existing and growing market opportunities. The targeting of state investments and resources to these key technology opportunities can result in major economic impact in the form of accelerated technology development and deployment, enhanced collaboration between academic and industrial organizations, increased entrepreneurial activities, and—ultimately—the emergence of a critical mass of enterprises in focused areas of the agbiosciences.

Each of the 2008 technology platforms is discussed at length in the following pages.

TECHNOLOGY PLATFORM: FOOD CROP & FOOD ANIMAL PRODUCTION & PROTECTION

Overview & Opportunities

This platform involves the research and development of crops and animals for the purpose of consumption. Because the world is facing a global food crisis and with the World Bank and United Nations both calling for increased food production, the need for improved crop yield and productivity is intense. Traditional plant breeding, together with marker assisted (molecular) techniques, continue to dominate the development of new plant varieties. However, genetically engineered food crops, which can have superior yield and growth potential compared to their wild-type counterparts, have been penetrating the market since the 1990s. These crops are the results of recombinant DNA technology and are engineered to express beneficial traits, such as higher yield, longer shelf life, or the ability to be farmed without the need for herbicides, pesticides, or other chemicals. However, many controversies surround such crops, including questions over long-term health effects and ecological safety.

Research initiatives related to production of food animals—chiefly poultry and livestock—are concentrated in two general themes: genetics and breeding for nutritional enhancement; and food animal health along with the development of infectious disease diagnostics, vaccines, therapeutics, and biologics. The benefits of transgenic food animals potentially include lower cost production with reduced environmental impacts, improved disease resistance, and heightened leanness and protein quality. No transgenic food animals are on the food market today, but several are in development, including a salmon that matures to its full size much more quickly than conventional salmon.[30]

Opportunities for OARDC within these markets include:

- **Enhanced food crops** – Since biotech crops were first commercialized in the 1990s, the total area devoted to growing them has increased 60-fold, to 252 million acres.[31] The U.S. leads all other nations in adopting biotech crops, accounting for more than two-thirds of all GMO crops planted globally and with a projected market value of $2.35 billion in 2009.[32] The primary crops grown by U.S. farmers include corn, cotton, soybeans, squash, and papaya. Increased demand for biofuels explains some of the dramatic growth of the biotech crops industry, with significant growth coming from introduction of soy and corn varieties engineered to resist pesticides and pests. However, no new genetically engineered crops that confer a nutritional advantage have yet to be introduced to the market, although a number are in advanced stages of development. In Ohio, the greatest market potentials lie in soybeans and tomatoes, two commodities for which research expertise and a strong history of new variety commercialization exists at OARDC.
- **Enhanced food animals** – The beef cattle, dairy cattle, and poultry industries play significant roles in the economy of Ohio. The total value of the state's 1.3 million head of cattle is $1.3 billion annually.[33] However, beef is considered a mature market and is facing competition from other proteins including organic beef, specialty red meat such as buffalo, and poultry. In dairy, Ohio ranks 11th in the nation for total milk production, 1st for Swiss cheese, 8th for cheese overall, and tenth in cottage cheese and ice cream. Dairy is considered by at least one estimate to account for a third of the

[30] Biotechnology Industry Organization
[31] International Service for the Acquisition of Agri-Biotech Applications
[32] USDA National Agricultural Library
[33] Ohio Beef Council

state's total agricultural income.[34] Annual broiler chicken production is valued at $94.3 million.[35] In addition, Ohio is ranked second nationally in egg production. In addition to basic commodity markets, experts predict a growing market for transgenic animals. These may include animals as "factories" for producing antibodies, vaccines, tissues, or nutraceuticals; animals with enhanced growth and nutritional value; and new genetic and breeding systems. The future of livestock production and protection will also include more emphasis on disease diagnostics and therapeutics, genomics and tracing systems to address food safety issues, and new economic opportunities from the production of energy or compost from animal waste. OARDC's expertise in food animal genetics, breeding, pathology, and health bodes well for the state to capture a significant share of this large and growing market.

- **Food animal disease diagnostics and therapeutics –** Food animal health is a major concern stemming not only from public health and food safety aspects, but from the costs to manage animal disease outbreaks and their affects on livestock productivity. The relatively recent outbreaks of food-and-mouth disease and bovine spongiform encephalopathy generated heightened awareness and concern of the potentially devastating impacts of these and other animal diseases. Disease surveillance, diagnosis, and treatment are extremely high priorities for the livestock and poultry industries, resulting in significant demand for advances in these technologies.

OARDC/OSU R&D Strengths

- **Plant Pathology** – The Department of Plant Pathology includes eight faculty on the Columbus campus and eight faculty on the Wooster campus. Research focus areas span basic research in molecular genetics and virology to applied studies of integrated disease and pest management, diagnostics, and epidemiology. A wide variety of food crop commodities are under investigation, from soybeans, wheat, and rice, to fruits and vegetables.
- **Horticulture and Crop Science** – Breeding and genetics of tomatoes, soybean tissue culture and genetic engineering, wheat performance trials, corn cropping systems, and vegetable physiology are among the numerous focus areas addressed by over 50 research faculty and extension specialists in the Department.
- **Entomology** – 27 faculty comprise the Ohio State University Department of Entomology, one of the nation's oldest and distinguished. Both basic and applied research is conducted across a wide range of fields, from ecology and evolutionary biology to molecular entomology and ecosystem management.
- **USDA/ARS Corn and Soybean Research Unit** – Faculty across Plant Pathology, Horticulture and Crop Science, and Entomology work collaboratively to understand basic biological processes involved in viral infectious of corn and soybeans, and to develop solutions to crop loss.
- **OSU Extension** – The mission of Ohio State University Extension is to interpret the research findings from OARDC and OSU to the farmers, gardeners, landowners and businesses of Ohio to strengthen agricultural practices, improve efficiency, and protect the environment. OSU Extension also performs research in the field, translating findings back to the lab. Extension specialists are tightly linked to OARDC through an extremely close working relationship with faculty and administrators.
- The **Food Animal Health Research Program** is a nationally recognized program emphasizing the pathogenesis, epidemiology, prevention and control of animal disease. Research spans basic and translational studies on enteric, respiratory and immunosuppressive diseases, the zoonotic potential of these diseases, and food and environmental safety. The FAHRP manages the world's only facility for

[34] OSU Extension and Department of Agricultural, Environmental, and Development Economics
[35] Ohio Produce Association

procurement and maintenance of germ-free food animals, as well as the world's only pathogen-free flock of turkeys, both of which are critical to studies of infectious diseases of food animals.

- **Center for Diagnostic Assays** – The Center for Diagnostic Assays, an Agbioscience Center of Innovation, is unique in its emphasis on the development, validation, and commercialization of molecular-based diagnostic assays and reagents for both plant and animal infectious agents. The Center links veterinarians, farmers, commodity groups, and crop/plant communities with Extension and research specialists, industry, and government. The Center also recently launched a first-of-its-kind internet forum, DiagnosticSpeak, aimed at bringing together animal and plant disease diagnostics professionals in a single place to share the latest information on diagnostic issues and technologies.

Prospect for External Funding

Federal funding for agriculture research has been flat for a decade. However, emerging research and technology areas, such as bio-renewable energy and biobased products are brining new funding streams to the agbiosciences. Support for research is still widely available through traditional key agencies and programs such as the Agriculture and Food Research Initiative of USDA's Cooperative State Research, Education, and Extension Service (CSREES) but it will increasingly be supplemented by additional funding from non-traditional sources such as the U.S. Department of Energy, the Environmental Protection Agency and Department of Homeland Security.

In FY 2009, CSREES anticipates that $190 million will be available for AFRI. AFRI replaces the former National Research Initiative and the Initiative for Future Agriculture and Food Systems programs and addresses six priority areas including plant health and production and plant products; animal health and production and animal products; agriculture systems and technology; and agriculture economics and rural communities.

Meanwhile, non-profit and industry-funded research on crop production and protection has increased dramatically.

- The McKnight Foundation was recently granted $26.7 million through 2013 from the Bill & Melinda Gates Foundation for crop research funding. The funding will allow McKnight to augment its support for research on plant biology and crops, sustainable food production, and improved nutrition, focusing primarily on under-researched crops in impoverished areas of the world.
- In early 2008, the Bill & Melinda Gates Foundation promised $27 million to Cornell University to run an international research effort to thwart stem rust, which affects cereal crops.
- Monsanto, a worldwide leader in developing seed and plant varieties, announced in June 2008 that it would provide a five-year, $10 million grant to improve rice and wheat yields, focusing on improving production in poor countries. The company will also try to double yields of its genetically modified corn and soybeans.

Until recently, the National Research Initiative (NRI) Competitive Grants Program of the USDA was the single competitive grants program in the federal government that supported basic and applied research of reproductive efficiency in livestock and poultry breeding populations. However, the NRI was not reauthorized in the Food, Conservation, and Energy Act of 2008. Funding opportunities are instead available through the Agriculture and Food Research Initiative (AFRI) of USDA's Cooperative State Research, Education, and Extension Service, which supports research efforts in animal health and production and animal products. Additional funding opportunities for research related to food animal production and protection are available through the Center for Disease Control's National Center for Zoonotic, Vector-Borne or the Enteric Diseases, the National Science Foundation's Ecology of Infectious Diseases Program.

Competition

The development of genetically enhanced food crops is a major focus of most agricultural colleges at the nation's land grant universities. Thus, competition is intense. Research emphasizes the discovery, localization, and characterization of genes that encode novel agricultural traits. Some of the larger programs, as well as niche programs focusing on soybeans or tomatoes, include:

- **UC-Davis Departments of Plant Pathology and Plant Sciences** – The Department of Plant Pathology is the site of basic and applied research in plant-pathogen interactions, soil microbiology, the role of stress in plant disease, and many other areas. Of note, the USDA recently gave one of its highest research awards to department member Dr. Pamela Ronald for her work in developing new rice varieties that can withstand flooding. The Department of Plant Sciences is comprised of over 90 faculty members and combines research across four commodity-based programs: Agronomy and Range Science; Pomology; Vegetable Crops; and Environmental Horticulture. Research in agricultural plant biology includes fundamental knowledge of biological processes and translation of this knowledge into enhanced crop performance and agricultural sustainability. Research in crop sciences centers on plant genetics, genomics, physiology, ecology, understanding and improving field-crop production, vegetation management, and promoting the sustainable use of natural resources.
- The **Tomato Genetics Resource Center**, also at UC-Davis, is one of the world's most comprehensive genetic repositories of wild relatives, mutants and miscellaneous stocks of tomatoes. The Center is also integrated with the National Plant Germplasm System.
- **Cornell University Departments of Plant Pathology and Plant Breeding & Genetics –** The Department of Plant Pathology is extremely well-regarded with multidisciplinary research spanning diverse areas from the diagnosis and management of plant diseases to fungal genetics and genomics. A second Department of Plant Pathology is situated in Geneva, NY, where the research focus includes yield of agronomic crops, particularly fruit. The Department of Plant Breeding & Genetics is dedicated to the genetic improvement of crop plants. Research programs involve development of improved gene mapping methods, functional genomics, bioinformatics, quantitative genetics, utilization of wild germplasm, gene cloning strategies, genetics of crop quality, disease and insect resistance, and new breeding strategies.
- **The University of Minnesota Department of Agronomy & Plant Genetics** includes genetic engineering and new crop variety development among its research priorities, and research on soybeans encompasses the development of new high-yield general purpose and special purpose soybean varieties, the evaluation of exotic soybean germplasm, and the generation of new genetic and breeding methods.
- **The University of Illinois Laboratory for Soybean Disease Research** conducts research on soybean viruses and pathogens, the epidemiology of soybean diseases, host resistance, and pathogen variability. The University is also the site of the National Soybean Research Center, which brings together scientists working towards increasing the nutritional value of soybeans, soybean productivity and genetic improvement, new food uses, and processing and utilization.

Fewer academic centers dedicated to food animal production and health exist, but centers of note include:

- The Department of Animal and Avian Sciences at the University of Maryland – Research is concentrated in three major focus areas: nutrient utilization and metabolism; genetics and cell biology related to animal growth, disease resistance, and nutrient efficiency; and reproduction and development. Over 20 faculty across multiple disciplines work in specialized research facilities, including a new Animal Biotechnology building on the USDA campus in Beltsville, MD, where studies in cloning and transgenic biology are carried out.

- The Center of Excellence for Poultry Science at the University of Arkansas is recognized nationally and internationally as a leading comprehensive poultry program. The Center consists of over 30 faculty working in various fields including poultry pathology, microbiology, virology, immunology, nutrition, reproductive physiology, poultry production, and food safety. Specialized facilities include a poultry research farm, pilot processing plant, feed mill, poultry health and isolation unit, and commercial-style research farms for broilers and broiler breeders.
- Purdue University's Agriculture Research Program is a leader in research on agricultural homeland security protections, including focused efforts on rapid detection and diagnostics, plant pest and disease detection, and animal disease surveillance and response.
- The National Center of Excellence for Foreign Animal and Zoonotic Disease Defense at Texas A&M University, funded by the Department of Homeland Security, conducts basic research and develops rapid diagnostics of select foreign animal and zoonotic diseases.

TECHNOLOGY PLATFORM: POST-HARVEST FOOD SYSTEMS

Overview & Opportunities

This platform concerns the application of technologies to agricultural commodities after harvest for the purpose of loss prevention, preservation, food safety, and quality control or enhancement. The technologies involved relate to on-farm handling, food processing (such as drying or shelling), food packaging, storage, and distribution. Environmental control and temperature management are critical issues at each step. The development of new, efficient technologies and processes that maintain high food quality and/or destroy harmful pathogens now frequently requires the use of computer-aided simulations, robotics, sensors, and controls.

Market opportunities for OARDC within this technology platform include:

- **New food processing and preservation technologies** – Development of new food processing methods or improvements on existing methods such as vacuum-steam-vacuum (VSV) pasteurization, infrared surface heating, high pressure microfluidization, pulsed electric field processing, light technologies, and cold plasma. Also, use of technologies such as magnetic resonance imaging to observe changes in foods during processing. New technologies are also needed to prevent, detect or eliminate harmful abiotic compounds such as acrylamide and melamine.
- **Advanced food packaging** – Packaging trends include increases in package flexibility, advanced films (such as antimicrobial) that prevent produce spoilage, new package shapes that fit better in car holders or refrigerator doors, biodegradable or "green" packaging, and even edible packaging. Engineered nanoscale materials are also being developed for food packaging with enhanced mechanical and thermal properties to ensure better protection of foods from exterior effects.
- **Food safety biosensors and rapid foodborne pathogen detection** – Biosensors can be used to improve food safety by detecting and quantifying foodborne pathogens. Biosensor platforms employ techniques such as chemiluminescence and bioconjugated nanomaterials, and devices are often portable for on-site detection. Other detection platforms may involve molecular diagnostics such as immunochemical or nucleic acid technologies for screening food samples. The overall biosensors market has expanded significantly over the past decade, with a projected value of $8.2 billion in 2009.[36] Although this figure represents three major industrial sectors—pharmaceutical, medical, and food—the food testing market should only increase in response to growing global concerns over food and water security.

OARDC/OSU R&D Strengths

- **Food Science and Technology** – OSU's Department Food Science and Technology is world-renowned in food chemistry, food engineering, food packaging, food safety and microbiology, and nutrition. The department is closely linked with the food industry through such partnerships as the Center for Innovative Food Technology (CIFT), an industry member organization, the Midwest Advanced Food Manufacturing Alliance, and the Swiss Cheese Consortium.
- **CAPPS** (Center for Advanced Processing and Packaging Studies) is an NSF-funded industry-university partnership, comprising industry, OSU, the University of California-Davis, and North Carolina State University, around food science and food engineering R&D. OSU possesses broad expertise in emerging food preservation technologies including high-pressure processing and ozone

[36] Journal of AOAC International, May-June 2006

processing, and has state-of-the-art research facilities dedicated to testing and refining new processing and packaging technologies.

- **Center for Diagnostic Assays –** An OARDC Agbioscience Innovation Center, the Center for Diagnostic Assays develops reagents and molecular-based diagnostic assays for infectious pathogens with applications in food security, animal and human health. The Center brings together academic and extension specialists with veterinarians, private industry and commodity groups to commercialize and disseminate diagnostic assay technologies and to foster the development of a diagnostics-focused industry in Ohio.

Prospect for External Funding

The FDA and USDA are the two chief federal agencies involved in funding food safety initiatives. In recent years, the FDA has received increased funding for its food safety program, which will support research to prevent food contamination and the development of rapid pathogen detection methods. The FDA awards grants to fund research pertaining to food and agricultural feed safety, food screening capabilities, food security monitoring, and the development of rapid responses to food hazards. The USDA's Agriculture and Food Research Initiative (AFRI) competitive grants program supports fundamental and applied research and extension on a number of priority areas including food safety, nutrition and health. The overarching objectives center on the reduction of food-borne illness.

SBIR funding may be available for advanced food packaging R&D. The company EcoSynthetix is a recipient of two SBIR grants for research on the use of nanoparticles coated with biobased adhesive in food packaging.

Venture funding for post-harvest food technology is scarce with few firms working in agbioscience, but new opportunities may be slowly emerging. In December 2008, a new Carmel, Indiana venture-capital firm focused on food and agriculture closed its first fund with $27.8 million. The firm, IN Partners LLC, will target companies operating in food safety, animal health, environmental technologies, production technologies and bio-based products and processes.

Competition

Competition in food processing, packaging, and safety-related R&D is fairly intense and located at a few key academic institutions:

- Michigan State University School of Packaging – The School of Packaging focuses on testing and developing new packaging technologies and involves multidisciplinary research in materials science, food science, chemical engineering, food engineering, and other areas. The School's Mass Transport Laboratory offers specialized analytical tools including electron microscopy and mass spectrometry for measuring package permeability, shelf life of packaged products, and product-package compatibility.
- The National Food Safety & Toxicology Center at Michigan State University comprises faculty across multiple departments and colleges focusing on fundamental and applied research related to emerging foodborne pathogens, zoonotic diseases, E. coli outbreaks, packaging for food protection, and many other areas.
- The Indiana Packaging Research and Development Center at Indiana State University conducts testing and research on packaging for the food industry, hospitals, pharmaceutical companies, and government. Other core activities at the Center include package design, prototyping, packaging fabrication, packaging system development.
- In October 2008, Clemson University and Cryovac announced the completion of a joint, multiuse food-packaging laboratory in Clemson's Center for Flexible Packaging. The laboratory includes a

Cryovac Flavour Mark food packaging system and will be used as a research, instruction, and service facility.

- Postharvest engineering research at the UC-Davis Department of Biological & Agricultural Engineering focuses on techniques for predicting fruit and vegetable quality when marketed, magnetic resonance imaging for sorting fruit, diverse packaging and stacking techniques for long-distance produce shipment, and determining temperature profiles of various packaging configurations. And from 1996 to 2000, UC-Davis was the most prolific research institution in publishing food science and technology research papers according to the Institute for Scientific Information.
- The Center of Excellence for Post-Harvest Technology, operated by North Carolina A&T University, focuses on R&D of processing, preservation, storage, and safety technologies with emphasis on fruits and vegetables. The composition, recovery, and identification of bioactive compounds with pharmaceutical or nutritional qualities are additional areas of emphasis.

TECHNOLOGY PLATFORM: NONFOOD CROP GENETICS & BREEDING

Overview & Opportunities

Nonfood crops are agricultural crops with applications other than human or animal consumption. This platform refers to research on understanding the genetics of nonfood crops and the development of new or enhanced crops with desirable traits, such as increased yield, oil content, fiber content, carbohydrate content, altered lignocellulosic ratios, insect or disease resistance, temperature tolerance, improved appearance, delayed ripening, or production of high-value industrial or pharmaceutical compounds. It also applies to improved plant breeding technologies, evaluation of plant germplasm, enhanced seed production, and the development of improved agronomic processes for field and greenhouse systems. Advances in this platform will rely on expertise in classic and molecular plant breeding, genetics, genomics, biochemistry, horticulture, plant pathology, and agronomy.

Market opportunities for OARDC within this platform include:

- **Transgenic plants with improved yield, resistance, or other desirable traits** – Since the first commercial cultivation of transgenic plants dates to the 1990's, 12 million farmers in 23 different countries have chosen to plant genetically modified crops (both food and nonfood) to overcome various growing challenges and to conserve the environment.[37] Continued research on genetically engineered nonfood crops aims to develop plants that can grow in harsh environments and require less or no pesticide application.
- **Transgenic plants that produce industrial or pharmaceutical products** – The high cost of traditional methods of producing industrial and pharmaceutical compounds has led to the intensification of research into plant-based production systems. Recombinant DNA technologies can be used to engineer plants to produce plastics, rubber, resin, growth hormones, vaccines, enzymes, and many other compounds. Controversy surrounds the potential mixing of bio-industrial or pharmaceutical-producing crops ("biopharming") with food crops, but many experts argue that the potential benefits of using plants to produce high-value compounds far outweigh the risks. Frost & Sullivan has predicted that the plant-made pharmaceutical market could realize revenues of over $98 billion by 2011.
- **Germplasm and germplasm mining** – Crop germplasm resources are the genetic material used for crop breeding and genetic improvement. Germplasm mining is the discovery and utilization of useful genes that can confer enhanced traits such as disease resistance or seed quality. Molecular biologists and plant breeders can mine germplasm collections, and via gene mapping and cloning may develop unique crop breeding lines with marketable properties.
- **Floriculture and ornamental plants** – Floriculture concerns the breeding and cultivation of cut flowers, potted flowering plants, foliage plants, bedding and garden plants, and ornamental plants. The U.S. Department of Commerce's Bureau of Economic Analysis estimates the size of the floriculture industry to be roughly $19 billion. However, the industry faces a number of challenges including high production costs, pests and diseases, natural disasters, and water and fertilizer management. Key R&D issues center on optimization of tissue culture for higher rooting and multiplication rates, development of novel cultivars, and sustainable native floriculture practices.
- **Turf grass R&D –** The U.S. turf grass industry has undergone rapid growth in recent years and today is estimated at roughly $40 billion annually.[38] Its benefits include reduction of soil erosion, filtration

[37] http://www.monsanto.com/biotech-gmo/asp/globalOutlook.asp
[38] http://www.turfresearch.org/initiative.htm

of groundwater, and trapping dust and dirt. While southern regions have an advantage in the ability to grow and harvest turf grass year round, Ohio is better positioned to advance R&D in areas such as the use of turf grass in site reclamation, collection and management of turf grass germplasm, genetic improvement of turf grass, and characterization of turf grass's environmental impacts.

OARDC/OSU R&D Strengths

- **Ornamental Plant Germplasm Center** – Based in Columbus, the OPGC is part of the U.S. National Plant Germplasm System and works to conserve, assess and distribute ornamental plant germplasm and to develop new techniques for conserving germplasm. Core activities involve research on seed germination, x-ray analysis of seeds, seed cleaning, and seed storage.
- **Plant Pathology –** Research in the Department of Plant Pathology at OSU is exceptionally diverse, spanning basic studies in plant-pathogen interactions to applied research in integrated management systems and improved disease control methodologies. Research priorities for nonfood crops include the integrated management of fungal turf grass pathogens, soil microbial ecology, and diseases of ornamentals and landscape plants. The department also participates in several multidisciplinary collaborations including the Ohio Plant Biotechnology Consortium and the USDA/ARS Corn and Soybean Research Unit.
- **Horticulture & Crop Science –** With close to 50 faculty, the Department of Horticulture and Crop Science at OSU is the site of extensive research on seed biology, plant breeding and genetics, environmental and landscape horticulture, and crop production.
- **Ohio State University Turf Grass Science Program –** The Waterman Agricultural and Natural Resources Learning Lab at OSU has a state-of-the-art turf grass research building where a number of researchers across several different departments, as well as extension agents, conduct novel research on areas such as pest management and turf grass physiology.

Prospect for External Funding

Federal funding opportunities for research in nonfood crop genetics and breeding come primarily from the USDA. The USDA's Agriculture and Food Research Initiative (AFRI) competitive grants program supports fundamental and applied research and extension on a number of priority areas including agricultural systems and technology and plant health/production/plant products. The USDA's Specialty Crop Research Initiative (SCRI) funds research directed at improving specialty crop characteristics through genetics and breeding, addressing specialty crop pest and disease management, improving production efficiency, and developing new agricultural technologies. Recently funded projects center on sustainable production systems for turf grass and advanced sensing and management to optimize water and nitrogen use in trees.

The Horticultural Research Institute (HRI), the research affiliate of the American Nursery & Landscape Association, funds, promotes, and communicates horticultural research focusing on the propagation, production, distribution, marketing, and sale of woody ornamental plants and perennials. In 2008, HRI granted $425,000 to research projects throughout the U.S. Meanwhile, government funding of floriculture R&D has steadily declined over the past thirty years.[39]

The National Turf Grass Research Initiative (NTRI), a cooperative effort of the turf grass industry and USDA Agricultural Research Service actively promotes the importance of turf grass research funding. Most funding is provided by the turf grass industry, state turf grass associations, or nonprofit organizations such as the Golf Course Superintendants Association of America, the United States Golf

[39] International Society for Horticulture Science

Association, and Turf Grass Producers International. It is estimated that private companies and nonprofits fund $10 million in turf grass research every year.[40]

COMPETITION

Competition in R&D on transgenic nonfood crops is extremely high and tends to fall to academic research centers. This is because academia, with its broad and diverse research base, is better equipped to tackle the increasing need for specialized crops—crops with unique traits that can grow in unusual conditions or produce novel compounds—than industry, which has tended to mass-produce single types of value-added crops. Major academic centers conducting research on transgenic crops include:

- Institute of Food and Agricultural Science, University of Florida/Florida Agricultural Experiment Station – With over 1000 faculty across 17 academic disciplines including plant molecular biology, plant pathology, entomology and nematology, and horticultural sciences, the University of Florida ranked first in the nation in agricultural R&D expenditures for FY 2007.
- College of Agricultural & Environmental Sciences, UC-Davis – The University of California-Davis ranked second in the nation in agricultural R&D expenditures for FY 2007; the College is renowned for its expertise in a wide range of programs including plant genetics and genomics. The Seed Biotechnology Center focuses on molecular marker identification, trait integration, and the development of new crop products. In addition, the USDA's National Plant Germplasm System is housed on campus.
- Purdue University has one of the largest and most comprehensive Colleges of Agriculture in the U.S. Key research programs where there is a focus on nonfood crop applications include the Indiana Center for New Crops & Plant Products (plant genetics and breeding) and the Department of Forestry & Natural Resources (wood products, forest tree breeding & improvement).
- The Center for Crops Utilization Research (CCUR) at Iowa State University is a research, development, and technology transfer program focused on adding value to Midwest crops and the development of biorenewables.

Key institutions with robust floriculture R&D programs include Purdue University with 30 faculty members in the Department of Horticulture and Landscape Architecture, North Carolina State University with 11 faculty in the Commercial Floriculture Group, and Colorado State University with 12 faculty in the Applied Research Program in Floriculture. The University of Florida's Institute of Food and Agricultural Science houses a program in environmental horticulture where faculty research diverse topics ranging from foliage production and postharvest floriculture to turf grass and landscape plants.

There are numerous turf grass research initiatives across the U.S. including programs at Penn State University, Clemson, the University of Massachusetts, North Carolina State University, Purdue, UC-Davis, Michigan State University, the University of Illinois, the University of Arkansas, Kansas State University, and Rutgers. Many emphasize the applications of turf grass for the golf course industry.

[40] The National Turf Grass Research Initiative

TECHNOLOGY PLATFORM: BIOENERGY & BIOBASED PRODUCTS

Overview & Opportunities

Biobased products are those other than food or feed that are composed, in whole or in significant part, of renewable biological, agricultural, or forestry materials. Examples include biofuels, supplements, soy-based adhesives and lubricants for industrial uses, biodegradable mulches, biodegradable plastics, corn starch-based packaging, and many others.

As substitutes for fossil fuel-based products, biobased products are sustainable, generate less waste, use less energy and water, reduce global warming, and increase energy security by reducing dependence on foreign fossil fuels. A shift from fossil fuel-based products to bioproducts promises to add new markets and jobs to the domestic economy. In 2005, biobased products constituted about 8% of the total market for conventionally or renewably produced products, but the U.S. Department of Energy's Biomass Research and Development Technical Advisory Committee has set a national goal for the fraction of biobased products to triple by 2030.[41]

Market opportunities for OARDC related to bioenergy and biobased products include:

- **Algae-based biofuel** – There is intense interest in using algae for the production of biodiesel and even bio-based jet fuel. Algae have much faster growth rates than crops, and higher oil yield. They can also grow in installations placed on sub-prime land, whereas crops require arable land. The major barriers in efficient algae-based biodiesel production include identifying the best algal strains, designing the best equipment to grow the algae in large quantities and developing optimized cultivation systems (photobioreactors). However, with over $180 million in venture capital invested in algae-based biofuel technologies in 2008 alone, the market seems poised to explode.[42]
- **Cellulosic biofuel** – Increasing R&D in cellulosic materials, which make up the majority of most plants, offers greater energy potential and is less controversial than using food crops to meet energy needs. Hardwoods are an especially abundant source of cellulose. Currently, major research initiatives are being directed toward collection, pre-treatment, treatment, digestion, and fermentation of cellulosic materials to produce ethanol. A senior VP of Shell Global Solutions recently predicted that the global market for cellulosic biofuels could exceed $10 billion by 2012. In fact, a major goal of the White House's Advanced Energy Initiative is to "foster the breakthrough technologies needed to make cellulosic ethanol cost-competitive with corn-based ethanol by 2012."
- **Biorefinery byproducts** – Biorefineries can produce multiple products in addition to bioenergy, maximizing the value derived from the original feedstock. Such byproducts may include high-value chemicals, amino acids, feed, nutraceuticals, or materials that would otherwise be produced from petroleum.
- **Biopolymers, bioplastics, and biocomposites** – Products made in whole or in part from renewable biomass resources such as agricultural byproducts, non food crops, or wood. They are renewable, biodegradable, and may be compostable. Applications for biopolymers and bioplastics include films for wrapping, packaging materials, disposable tableware, compost bags, and even medical products such as sutures and stents. Polylactic acid is a well-known biopolymer/bioplastic produced from corn starch or sugar cane. A biocomposite is a biobased resin or matrix reinforced with plant-based natural fibers; applications include industrial uses such as replacements for fiberglass, or biomedical uses such as drug delivery, bone rebuilding, or tissue engineering. One current disadvantage of many biopolymers, bioplastics, and biocomposites is that they are often reliant on fossil fuel-derived energy

[41] http://www1.eere.energy.gov/biomass/pdfs/final_2006_vision.pdf
[42] RenewableEnergyWorld.com

for their manufacturing, reducing their cost and environmental advantages over their petroleum-based counterparts.

- **Compost** – Compost can be derived from any organic matter and generally includes municipal solid waste, agricultural residues, and pre-consumer food waste. The diversity of uses for compost range from general landscaping and soil improvement to erosion control, storm water management, and weed control. More than 72 percent of all materials entering landfills can be diverted through composting.[43] Compost research trends range from development of "backyard" or on-site compost systems to innovations in turning equipment and facility structures. Potential markets include agriculture, residential retail, nursery sod and ornamentals production, and landscaping. Growing interest in composting comes from communities, businesses, institutions, and individuals wishing to divert materials from landfills, lower pesticide and fertilizer use, and/or reduce waste management costs. Growth is also driven by environmental policy and legislation.
- **Nutraceuticals and functional foods –** Nutraceuticals are naturally occurring food supplements such as anthocyanins from berries and resveratrol from red grapes that are believed to have health benefits. Similarly, functional foods are foods or food ingredients, such as probiotics-fortified bread, that may provide a health benefit beyond basic nutrition. Despite the lack of scientific evidence supporting many of the health claims of nutraceuticals or functional foods, the market for nutraceuticals is positioned to explode, from a $76 billion U.S. industry in 2007 with prospects of growing to $167 billion by 2010.[44] Meanwhile, the combined U.S., Western Europe, and Asian markets for functional foods is estimated at $72 billion, with the majority of demand coming from Asia.[45]

OARDC/OSU R&D Strengths

- The **Ohio BioProducts Innovation Center (OBIC)**, funded in 2005 by the Ohio Department of Development through an $11.5 million Wright Center of Innovation (Third Frontier) award and leveraged with matching funds from external partners, focuses on integrating academia and industry toward the development of renewable specialty chemicals, polymers/plastics and advanced materials.
- **Ohio Composting and Manure Management Program (OCAMM)** – An interdisciplinary OARDC group focusing on microbial ecology, biological processes, and bioremediation with the overall goals of reducing the need for chemical inputs, improving soil fertility, and improving environmental stewardship. OCAMM facilities include a pilot-scale composting facility used for development and testing of products involving various levels of animal manure.
- **Soil Science Program** – A graduate program in the School of Environment and Natural Resources. Research focus areas include soil physics, soil biochemistry, soil-plant relationships, ecosystem modeling, carbon sequestration and carbon cycling, and soil fertility and waste management.

Prospect for External Funding

The opportunity for external funding for bioenergy projects is high. Multiple federal agencies fund research pertaining to bioenergy and biofuels and, in addition, major energy corporations such as BP and ConocoPhillips are boosting their investments in this area. The level of external funding available is expected to increase due to growing awareness of global warming, diminishing natural resources, the effects of urbanization and growing world population, and the need for independence from foreign energy sources.

- The U.S. Department of Energy's Renewable Energy Biomass Program, run by the Office of Energy Efficiency and Renewable Energy, includes major programs for developing and improving

[43] Cooperative Extension Service, the University of Georgia College of Agricultural and Environmental Sciences
[44] Australian Journal of Basic and Applied Sciences, 1(4): 637-649, 2007
[45] Datamonitor

technology for biomass power, for producing bioethanol and biodiesel, and for making plastics and chemicals from renewable, bio-based materials.

- The Sun Grant Initiative, through funding the U.S. Department of Transportation, conducts a competitive research program for land-grant universities and their federally funded laboratory partners to establish a bio-based economy. The Sun Grant Initiative awards research and education grants for projects on biofuel feedstock development; biofuels conversion; biofuel system analysis; economics, marketing and policy; and environmental impacts.
- The fraction of U.S. venture capital going to "cleantech" and bioenergy investments could reach 10% by 2009 with total investments near $1.5 billion.[46,47]

The outlook for federal funding for biobased products R&D is positive. Funding opportunities can be found through the USDA Agriculture and Food Research Initiative (AFRI) competitive grants program, the USDA Small Business Innovation Research (SBIR) Program, the DOE's Office of Energy Efficiency and Renewable Energy (EERE), and the Biomass Research & Development Initiative (BRDI), a multi-agency effort administered by the USDA and DOE. Key technical areas funded by BRDI relate to feedstock production, cellulosic biomass conversion, biobased product diversification, and improved sustainability of biomass technologies.

On the contrary, the prospect for nutraceuticals R&D funding is small, although it is improving as it is becoming increasingly recognized that nutrition plays a beneficial role in some diseases. Institutes of the NIH funding nutraceuticals and functional foods research include the Office of Dietary Supplements, National Center for Complementary and Alternative Medicine, NCI, NIDDK, NINDS, NICHD, NIA, and NHLBI.

- The USDA's Agriculture and Food Research Initiative (AFRI) competitive grants program supports fundamental and applied research and extension on a number of priority areas including plant products and renewable energy.

Competition

Competition for bioenergy and biobased products R&D funding is high, with major centers in a number of states. Examples include:

- The U. S. Department of Energy's three designated Bioenergy Research Centers to accelerate basic research in the development of biofuels, each funded by roughly $125 million over five years.
- The University of Minnesota's Department of Bioproducts and Biosystems Engineering with nearly 30 faculty conducting research across a range of areas including sustainable and environmentally friendly manufacturing, use and application of bio-based products, and enhanced agricultural production.
- The University of Minnesota's Initiative on Renewable Energy and the Environment (IREE), funded by the Xcel Energy Renewable Development Fund and a portion of Xcel Energy's annual Conservation Improvement Program obligation, has provided nearly $17 million to renewable energy-related research projects at the University of Minnesota. The majority of these projects focus on bioenergy and bioproducts.
- The newly-launched Oklahoma Bioenergy Center, located at Oklahoma State University with partners at Oklahoma University and the Samuel Roberts Noble Foundation, is a $1.2 million bioenergy laboratory focused on competitive and sustainable production of biofuels. The Bioenergy

[46] Cleantech Venture Capital Report 2006
[47] Cleantech Investor Network

Center has recently secured 1100 acres of land for one of the world's largest stands of switchgrass that will be devoted to cellulosic ethanol production.

- BP has selected the University of California Berkeley, together with the University of Illinois at Urbana-Champaign and the Lawrence Berkeley National Laboratory, to join in a $500 million research program designed to explore how bioscience can be used to increase energy production and reduce the impact of energy consumption on the environment. The BP-funded initiative has formed the Energy Biosciences Institute with the mission of performing ground-breaking research aimed at the production of new and cleaner energy, initially focusing on renewable biofuels for road transport. The EBI will also pursue bioscience-based research in three other key areas: the conversion of heavy hydrocarbons to clean fuels; improved recovery from existing oil and gas reservoirs; and carbon sequestration.
- The Laboratory of Renewable Resource Engineering at Purdue University's Integrative Center for Biotechnology and Engineering carries out multidisciplinary research in bioenergy, bioprocessing, and bioproducts, with current emphasis on ethanol and plant- or fermentation-derived nutritional animal feed supplements and energy sources.

There are relatively few academic centers focused on other biobased product research areas. Centers of note include:

- Industrial Agricultural Products Center – The goal of the University of Nebraska-Lincoln's IAPC is to develop new uses from agricultural commodities. Focus areas include biopolymers and biofuels; current research centers on production of microcrystalline cellulose, biobased Films, coatings and adhesives, biobased packaging material, and compost.
- The Cornell Waste Management Institute (CWMI) is a program in the Department of Crop and Soil Sciences at Cornell University. CWMI R&D concentrates on a broad range of areas including the science of composting, manure, yard and food wastes, and livestock mortalities for both small- and large-scale composting.
- The Institute for Nutraceutical Research at Clemson University is a university-industry-government partnership focusing on bringing nutraceuticals into the mainstream of U.S. healthcare by providing support for basic and clinical research, basic agricultural and plant biotechnology, and quality assurance and standards.

TECHNOLOGY PLATFORM: ENVIRONMENTAL PROTECTION & SUSTAINABLE DEVELOPMENT

Overview & Opportunities

This platform refers to effective protection of the environment, for example, limiting global warming, considerations of urbanization and the built environment, safeguarding from poor air and water quality, agriculture and ecosystems, natural resource endowments, pollution control, improved energy efficiency, and more efficient use of resources such as recycling and waste management. Growing environmental concerns, heightened public pressure, and stricter regulations all lead to increased interest in environmentally conscious technology development and advancing competitiveness in the development of innovative technologies that can address environmental management. Effective environmental protection is critical to sustainable development, which acknowledges the needs of the current generation without compromising future generations' abilities to meet their own needs.

Relevant market opportunities for OARDC include:

- **Urban land management** – Involves activities such as the promotion of land transformation decisions that minimally impact the ecosystem; food security and local production using urban farms or "micro gardens;" evaluation and mitigation of nutrient runoff from urban watersheds into agricultural areas; urban waste and wastewater recycling and reuse; and predictive modeling to assess the effects of climate variability on urban water resources.
- **Soil quality** – High-quality soils make agriculture and farming systems more productive, resist erosion, absorb rainfall, enhance biodiversity, and degrade or immobilize pollutants. Current research trends include development of new soil quality indicators (often measures of soil microorganisms or assays of soil microbial enzyme activity), development of alternative cropping systems that reduce surface runoff and soil erosion, and activities in emerging interdisciplinary fields such as biogeoscience.
- **Water quality** – R&D focus areas in water quality improvement involve rapid diagnostic tests, real-time sensor networks, computer modeling of pollutants in the water to predict their behavior, and hydraulic and hydrologic design for urban site development and storm or waste water management.
- **Bioremediation** – Involves the degradation or detoxification of contaminants in soils, water, and waste water using fungi, plants, bacteria, or other biological factors. Bioremediation is considered to be environmentally friendly and economically advantageous as it does not require heavy machinery or skilled labor. A key thrust in bioremediation R&D involves screening or engineering microorganisms for the ability to absorb or degrade pollutants.
- **Sustainable agriculture** – Sustainable agriculture refers to the ability of a farm to produce food or fiber indefinitely without degrading the natural resource base. Technologies involved in sustainable agriculture include conservation tillage, integrated pest management, and precision agriculture. In conservation tillage, crops are grown with minimal soil cultivation, resulting in reduced soil erosion. Integrated pest management utilizes a combination of mechanical, chemical, biological, and physical methods to measure and control pests. Precision agriculture allows the farmer to gauge the level of fertilizer required by different sections of the field through GPS-guided grid sampling, resulting in better nutrient usage and reduction of agricultural impacts.

OARDC/OSU R&D Strengths

- **The Center for Urban Environment and Economic Development –** An Agbioscience Center of Innovation, the Center for Urban Environment and Economic Development focuses on developing and commercializing new technologies that meet the pest-, disease-, weed-control, energy usage, and pollution mitigation needs of growing urban landscapes. Signature strengths of the Center include R&D on organic fertilizers, pelleted compost, and zero-pollution lawns.
- **School of Environment and Natural Resources** – The School's approach to research, teaching and service focuses on "production of natural resource commodities in an economically viable framework with added emphasis on protecting environmental quality and addressing the human component." Research in the School focuses on six areas of study: ecological restoration, ecosystem science, environmental social science, fisheries and wildlife science, forest science, and soil science.

Prospect for External Funding

With multiple federal agencies supporting research on environmental protection and sustainable development, the prospect for external funding is very good:

- The USDA's Agriculture and Food Research Initiative (AFRI) competitive grants program supports fundamental and applied research and extension on a number of priority areas, including natural resources and the environment.
- The Environmental Sustainability program of the NSF supports research on innovative biological, chemical, and physical engineered systems that can restore polluted land, water, or air resources. The four principal research areas that are supported include industrial ecology (e.g., materials flow analysis, input-output models), green engineering (e.g., next-generation water and wastewater treatment), ecological engineering (stream and wetland restoration), and earth systems engineering (e.g., mitigation of greenhouse gas emission).
- The mission of the Department of Energy Office of Biological & Environmental Research is to advance R&D on energy and the environment focusing on the development of biofuels, carbon sequestration, subsurface contaminant mobility, understanding relationships between climate change and ecosystems, and developing new tools for environmental remediation.
- The EPA supports research on pollution prevention and source reduction, energy efficiency, and water conservation
- The National Oceanic and Atmospheric Administration supports a broad array of research activities focusing on the relationships between the ecosystem, water quality, and human health.
- The U.S. Fish and Wildlife Service funds research on wetlands conservation, such as the effects of pesticides from urban lawns on wildlife.

Competition

The number of universities with one or more research centers dedicated to basic and applied research on environmental protection and/or sustainability is increasing. Prominent centers include:

- Research at the University of Maryland's Center for Integrative Environmental Research (CIER) centers on urban environmental change, material flows, energy systems, and climate adaptation. Faculty span numerous disciplines from environmental engineering and geology to urban studies and public policy.
- Purdue University's Agronomy Department maintains two water quality research facilities where field-scale studies of agricultural effects on surface and subsurface water quality are conducted. Rainfall and soil water samples can be analyzed for nutrient, pesticide, and metabolite transport.

- The NSF-funded Arizona Water Quality Center, comprised of microbiologists, chemists, physicists, hydrologists, and engineers from both the University of Arizona and Arizona State University, is a leader in the analysis of biological contaminants and the development of solutions to water quality problems. Active research efforts involve remediation of commercial and industrial contamination, molecular detection of waterborne pathogens, and comprehensive watershed management.
- Over 40 faculty are members of Michigan State University's NSF-funded Center for Microbial Ecology, where bioremediation is a major research focus area. Multidisciplinary research into bioremediation incorporates expertise in microbial ecology and physiology, engineering, molecular biology, biochemistry, environmental chemistry, mathematics, and computer science. The Center also integrates DNA microarray technology to evaluate gene expression of a microorganism engineered to remove toxic compounds.
- The UC-Davis Agricultural Sustainability Institute carries out research and extension efforts in agricultural and food systems sustainability throughout the UC system. The Institute incorporates partners across the state, including the UC Sustainable Agriculture Research & Education Program (SAREP). A major focus area of SAREP is biologically integrated farming systems, which involves extension services, training, and financial incentives for farmers who voluntarily participate in demonstration pilot projects to reduce their use of agricultural chemicals.
- The University of Georgia Center for Urban Agriculture facilitates interdisciplinary research and extension on home and garden landscapes, erosion and sediment control, waste water management, environmental horticulture, plant breeding, soil quality, turf grass management, and integrated pest management.

VIII. Positioning OSU Agbiosciences for the Future

The scope and diversity of ongoing research efforts at OARDC are broader than any other center of its kind. As the state's land-grant institution, the mission of OSU is to connect research with the needs of the state and to focus on commercialization and market entry of new products relevant to Ohio's economy. The agbiosciences are clearly a major target of opportunity for Ohio, and indeed, the dramatic increase in non-federal (e.g., ODOD) funding for OARDC research initiatives signals the state's recognition that agbiosciences are a key driver for future economic growth. However, the bigger picture of the agbiosciences includes a growing emergence of serious global issues such as food security and climate change. Because of OARDC's sizable research base, the center should be—and by some arguments already is—at the forefront of R&D and the deployment of solutions to these issues, but if sufficient resources and attention are not upheld, the center could lose its leadership position to another institution.

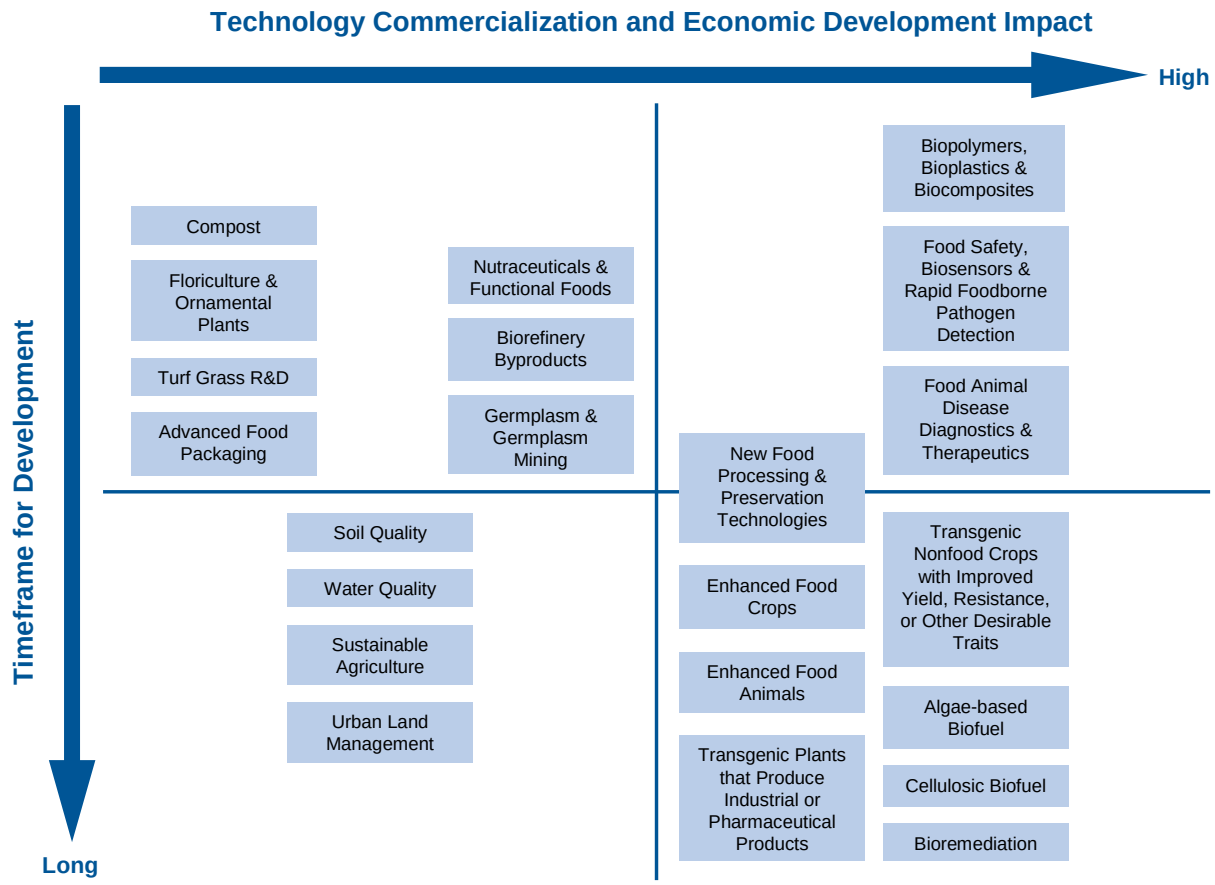
To assist in positioning OARDC and OSU to compete globally in addressing major agbioscience-related issues and contributing significantly to Ohio's agbioscience sector, Battelle suggests a prioritization of technology opportunity areas, a profiling of the resources and investments that are required, and recommendations to enhance the emphasis on technology commercialization and economic development.

Strategic Focus

While each technology platform presents significant opportunity for technology-based economic development, certain platforms may provide more nearer-term opportunity and/or greater potential economic impact. Prioritization of the 2008 technology platforms, based on current OARDC research focus, technological barriers, and estimated market size, is largely consistent with Battelle's recommendations for prioritization of the 2004 OARDC technology platforms. Figure 22 depicts development opportunities pertaining to each of the technology platforms as they vary across the size of their potential economic impact and the time required to realize such impact.

It is apparent that the most promising focus areas for OARDC, in terms of both potential economic impact and the nearness of the opportunity, surround biobased products, food safety, and food animal health. However, each of these areas merits the needed resources and attention as important elements of a comprehensive, flexible, and dynamic R&D portfolio.

Figure 22: Agbioscience Opportunity Areas Classified by Economic Impact and Timeframe for Development.



Existing Resources & Required Investments

Despite the constantly evolving nature of the agbioscience field, OARDC is well-positioned to maintain its competitive advantage and capitalize on its resources to continue to deliver solutions to Ohio agricultural issues and needs. OARDC is the nation's largest academic agricultural R&D center and as such has a wealth of resources that contribute to its national stature and its ability to connect the needs of the agricultural community with research expertise. Since the previous Battelle report, a number of resources have been completed or added at OSU, resulting in added capacity for research excellence and technology development. Resources and programmatic initiatives of note include:

- **ABIG** – The AgBiosciences Innovation Grant (ABIG) Program, first proposed by Battelle in 2003, is a structure facilitating interdisciplinary work, industrial collaboration, innovation, and commercialization of agbioscience-related discoveries. The initiative was intended not to replace existing departments but to boost interdisciplinary research, technology commercialization, and linkages with external entities around three key areas: food, biobased products, and the environment. Following the 2003 report, ABIG was implemented as a competitive grants program to establish centers of excellence in these three areas. ABIG funded six centers with two

years apiece of operational support. The six centers are the Center for Advanced Functional Food Research and Entrepreneurship, Center for Diagnostic Assays, Center for Food Safety and AgroSecurity, Center for Innovation-based Enterprise (CIBE), the Center for the Urban Environment and Economic Development, and the Ohio Bioproducts Innovation Center (OBIC). Five of these centers have made impressive progress in the development of innovative technologies relevant to Ohio agbiosciences, while the sixth, CIBE, provides cross-cutting aid to the others in the form of strategic planning and business development support. Of note, OBIC—a Third Frontier Wright Center of Innovation funded with nearly $12 million of state capital—has generated significant momentum in building Ohio's biobased economy.

- **ATECH** – A unique agbioscience-focused business development arm of OARDC and OSU Extension, ATECH was designed to link industry with OARDC researchers, market OARDC capabilities, facilitate technology commercialization, prospect for sponsored research, and plan the BioHio Research Park.
- **Development of the BioHio Research Park** – An effort of the CFAES, BioHio, located in Wooster, will foster economic development from university research on food, agricultural, and environmental areas by providing space for private companies commercializing technologies from university research, as well as for university efforts oriented to commercial application. BioHio is expected to attract companies working in areas in which CFAES and OARDC have specific expertise, such as plant and animal disease diagnostics, food safety, food packaging, and biobased products.
- **BSL3 core facility** – Managed by the Center for Microbial Interface Biology in Columbus, the facility enables research on high-risk microbial pathogens. Relevant OARDC research includes, among other studies, characterization of microbes that cause acute and chronic human or zoonotic diseases.
- **Feedstock processing research facility** – A new $5M research facility, located in Wooster, can process a wide range of feedstock, making possible the development of high-quality feeds and biobased products such as compost, chemicals, and polymers. The facility is a critical component of OSU's emerging leadership position in bioconversion technologies.
- **Molecular and Cellular Imaging Center** – Although the Molecular and Cellular Imaging Center (MCIC) in Wooster is not a new resource, its value was noted frequently during Battelle's interviews with internal and external stakeholders, and thus deserves special mention. The MCIC provides services in microscopy (light, confocal, transmission and scanning electron microscopy), and in the areas of genomics and molecular biology. The center is a highly valued resource for OARDC researchers and continued investments in its staff and instrumentation are vital to many research efforts.

Despite these unique resources and efforts dedicated to the advancement of agbiosciences-related research and economic growth, budget cuts and the increased costs of doing business are a real threat to the ability of OARDC to generate value for the state and beyond. There are clear gaps that must be addressed in order to increase OARDC's effectiveness in spurring interdisciplinary research, facilitating technology transfer and commercialization, and continuing to lead agbioscience-based economic growth for the state. These gaps exist largely in two areas: technical support staff; and instrumentation. First, OARDC research relies heavily on experienced, technical support staff in areas such as bioinformatics, genomics, imaging, and robotics. Such staff can maximize the quality and impact of research conducted by faculty

and research scientists and can bring a range and depth of expertise that makes them essential to many research efforts. While OARDC technical support staff are exceptionally talented, their numbers are shrinking, increasing the burden on the remaining staff as well as on faculty endeavoring to carry out their research responsibilities. Second, updated or new instrumentation is required in several areas, including DNA microarrays for characterization of microbial populations, high-throughput genotyping capabilities, rapid chemical assessment of soil and water, bioinformatics, and engineering design and development services (e.g., for biosensor and bioprocess engineering prototypes). Modern instrumentation can improve the quality and expand the scope of research and research training. While it is not always necessary to have the newest and best piece of equipment on site, *access* to such equipment—through academic or industrial collaborations—is often crucial.

Above all, the greatest challenge faced by OARDC is in continuing to attract, cultivate, and retain top talent. Current faculty are stretching to meet their many teaching, training, research, and other responsibilities, yet the constantly evolving nature of the agbiosciences landscape requires dedication to the needs of agricultural constituents. In order for OARDC to continue to address these needs, it must remain committed to building critical mass in R&D around each area that addresses important state and global issues. Such critical mass requires additional faculty lines and the recruitment of star faculty, for whom the availability of technical support staff and state-of-the-art instrumentation are absolutely critical.

Economic Development and Commercialization

OARDC has always been focused on real-world solutions to the needs of Ohio's agriculture and farm communities. In recent years, the increased emphasis by OARDC and OSU on technology commercialization and entrepreneurship is evident through a greater push to license OARDC-developed technologies, spin-offs to create new companies, and collaborative R&D efforts with other academic and commercial organizations. The funding of ABIG centers was a particularly noteworthy event facilitating interdisciplinary research and technology commercialization. While they are still considerably new in their existence, the centers are keenly focused on transferring OARDC-developed technologies and assisting companies in product testing, development and commercialization. The creation of ATECH, jointly funded by OARDC and OSU Extension, was also another significant step towards increased agbioscience-based economic impact.

While impressive strides have been made towards economic development and commercialization, significant operational and institutional barriers exist that limit the center's ability to achieve its economic development goals. These barriers, and strategies to overcome them, were identified through extensive interviews, surveys, and focus groups with both internal and external OARDC stakeholders. Comments generally fell across the following areas:

- **Increase business expertise** – With a significant and growing focus on delivering technologies to end-users, OARDC needs additional capacity to develop technologies with real-world applications, commercialize them, and to work with outside constituencies. Specifically, the size of the OSU TLC staff dedicated to agbioscience technologies must be increased. Candidates' business experience should be taken into account when making new staff and faculty hires. Training for faculty and administration on business practices and the role of the university in economic development is also recommended.
- **Increase visibility and marketing to industry** – Connections with industry are invaluable for economic growth and technology commercialization: they can yield operating partnerships,

productive research collaborations, internships, product testing, and technology deployment. OARDC has a rich portfolio of specific expertise across a wide range of agbioscience areas; increasing the promotion of this expertise will result in even greater industry contact and collaboration. Such promotion is one of the responsibilities of ATECH. With added capacity, ATECH could amplify its marketing outreach across the state, not only to the private sector but also to the public sector such as to CDC labs and hospitals. Other strategies to increase visibility and marketing—much of which already happens by way of networking—involve OSU Extension, the ABIG centers, OBIC, and the OARDC support council.

- **Improve linkages to other programs and organizations** – Linking with other entities wisely leverages each partner's respective strengths without duplicating resources. With strong ties to other academic organizations (e.g., the University of Akron, the Center for Innovative Food Technology, the OSU Colleges of Medicine and Public Health) and economic development groups (e.g., Tech Columbus) already in place, OARDC must maintain these linkages, and forge new relationships where synergies lie and the potential for accelerating technology development is strong. One prime example is with the OSU Department of Chemical and Biomolecular Engineering, with obvious implications for advancing the research being coordinated by OBIC around biobased products.

Battelle concurs that each of these recommendations should be a top priority for OARDC. Overall, the keys to continued economic impact for OARDC are a strategic focus on targeted areas within the agbiosciences (in contrast with "being everything to everyone"), building critical masses of activity around these core R&D areas—which relies greatly on added faculty lines, technical support staff, and improved instrumentation—and continued emphasis on addressing the needs of state, national, and international stakeholders by delivering innovative and practical agbioscience technologies.

Appendices

Appendix A: Cluster Analysis

Battelle used the visual intelligence software tool OmniViz™ to provide unique insight into focused areas of research activity. OmniViz™ analyzed the abstracts of 610 records including:

- 492 OARDC publications from 2004 to July 2008
- 118 competitive research grants awarded by USDA, NIH, NSF, and EPA to OARDC from 2004 to July 2008

The OmniViz™ cluster analysis and corresponding interpretation by experienced research analysts resulted in the identification of key themes and groupings or "meta-clusters." These are depicted visually in Figure A1 and the details presented in Table A1:

Figure A1: Cluster "map" of major groupings, or meta-clusters, resulting from OmniViz™ analysis of research grants, publications, and patents.

Table A1. Associated research terms and topics and number of records per meta-cluster.

Meta-cluster	Key Associated Terms/Topics	# of Records
Economics of Agbiosciences	Economic, market, environment, producer, crop, grower, grow, food, consumer, benefit	14
Animal & Human Virology	Chicken, virus, vaccine, strain, infectious, protein, antibody, pig, human, gnotobiotic, infection, enteric, sequence, gene, amino acid, cow, diarrhea, rotavirus, immunity, serum, intestine, animal health, avian, gastroenteritis, microbiology, coronavirus, respiratory, monoclonal antibody	79
Compost & Nutrient Cycling	Temperature, compost, moisture, environment, water, pathogen, manure, inoculate, carbon, availability, nutrient, net, biomass, microbiology, ecology, decomposition	17
Crop & Soil Sciences	Crop, grow, cultivar, value, planted, index, fruit season, soil, organic, compost, range, linear, vine, phytopathology, stage, herbicide, ecology, soybean, agronomy	66
Dairy Sciences	Cow, protein, mRNA, cycle, tissue, proliferation, immune, inhibit, dairy, milk, environment, protein, metabolism, feed, bacterial, diet, fat, dietary, energy, plasma, cattle, reproduction, leuteum, estrous, nutrition, food science, intake, holstein	48
Ecosystem Management	Environment, farm, land, economic, natural, ecosystem, water, farmer, biological, forest, landscape, tree, old, grow, damage, abundance, landscape, pattern, ecology, spatial, riparian, diversity, species, restoration	37
Entomology/EPNs	Pest, biological, nematodes, host, entomopathogenic nematodes (EPNs), larva, insect, gene, sequence, protein, metabolism, clone, entomology, pesticide, mortality, expose, insecticide, behavior, dose	35
Food Safety	E. coli, prevalence, cattle, food, dairy, cow, fecal, farm, environment, safety, human, consumer, vegetable, variety, operation, economic, microbiology, culture, salmonella, beef, transmission, livestock, target, range, evaluation	40
Genetics & Molecular Biology	Sequence, gene, DNA, genome, genetics, strain, genomics, protein, pathogen, resistance, phytophthora, Arabidopsis, host, molecular, microbiology, diversity, polymorphism, epidemiology, nucleotide	76
Pathology/Microbiology	Protein, tissue, bacterium, bacterial, inhibit, strain, infection, pig, genetics, detection, culture, microbiology, assay	40
Plant Breeding for Resistance	Resistance, pathogen, host, resistant, environment, infection, pathogen, grow, crop, bacterial, susceptible, pine, plant science, disease, pattern, ecology	64
Plant Virology	Virus, protein, mosaic, gene, RNA, infect, viral, vector, sequence, host, genetics, infection, transmission, molecular, microbiology	23
Poultry Science	Plasma, egg, cycle, blood, turkey, poultry, broiler, feed, bird, age, muscle, differentiation, proliferation, genetics, sex, cross, reproductive, lay, regulate, skeletal, growth, range, weight, body, animal sciences	44
Seed Genetics	Seed, crop, soil, location, genetics, germplasm, trait, gene, map, fruit, cross, breed, genotype, range, horticulture, production, plant, germination, crop science, agronomy, phenotypic, variation, tomato	27

Appendix B: Publications and Citations Analysis

This analysis examines the level and impact of OSU's publications and citations in agbioscience-related research fields (and other research fields indirectly related to agbio, such as oncology) from 2003 through 2007. To assess performance across publications and citations, Battelle considers both the level of publications, measured as OSU's share of total U.S. publications in a field, as well as OSU publications' relative impacts in each field, measured by comparing the ratio of citations per OSU publication to that of the U.S. average:

- Level of publications measures OSU's share of U.S. publications for that research field. This adjusts for the overall number of publications in a field across the nation and so more accurately gauges OSU's strength in that field. From 2003 to 2007, OSU's share in 40 agbioscience-related fields was 1.5% of all U.S. publications in these fields. In general, Battelle would consider shares over 2% to be significantly high, and shares between 1% and 2% to be above average.
- Relative impact measures citations per publication for OSU compared with the U.S. average for a specific field. If equal to 1, then OSU is equal to the U.S. average; if greater than 1, OSU exceeds the U.S. average in citations per publication; if less than 1, OSU is below the U.S. average in citations per publication.

Key Findings from Publications Analysis

In terms of level of publications, OSU has a significantly high level of publication in five agbioscience fields. Of note:

- The field of Soil Sciences stands out with the greatest share of U.S. publications at 3.9%, followed by Dairy & Animal Sciences (3.6%), Agricultural Economics & Policy (3.4%), Veterinary (3.3%) and Food Science & Technology (3.2%). OSU's level of publications in Agricultural Engineering, Horticulture, Agriculture-Multidisciplinary, and Plant Sciences are also above average.

In 11 fields, OSU publications exceed the U.S. average of citations per publication. Of note:

- The fields of Water Resources and Soil Sciences each out with the greatest relative impact, at 1.52 or 52% greater rate of citation per publication than the national average. OSU publications in Mycology, Environmental Engineering, Chemical Engineering, Environmental Studies, Entomology, Agricultural Economics & Policy, Cardiology & Cardiovascular Sciences, Plant Sciences, Dairy & Animal Sciences, Genetics & Heredity, Oncology, Environmental Sciences, Microbiology, and Limnology exceed the national average of citation per publication.

In four fields, OSU publications account for at least 2% of all U.S. publications in that field *and* have a relative impact greater than the national average:

- Soil Sciences (3.9% share of U.S. Soil Sciences publications; 52% higher level of citations per publication)
- Dairy & Animal Sciences (3.6%; 5%)
- Agricultural Economics & Policy (3.4%; 8%)
- Plant Sciences (2.2%; 6%)

Table A2 presents a summary of these key measurements of OSU publications and citations across USI-designated categories from 2003 to 2007.

Table A2: Publications and Citations Analysis for OSU Institutions, 2003–2007

Field	Citations	Publications	OSU Share of U.S. Publications	Relative Impact
Agr Dairy & Animal Sciences	702	207	3.6%	1.05
Agr Economics & Policy	74	40	3.4%	1.08
Agr Eng	92	65	2.9%	0.64
Agr Multidisc	276	79	2.5%	0.85
Agr Soil Sciences	824	161	3.9%	1.52
Agronomy	348	149	1.9%	0.78
Biodiversity Conservation	121	43	0.9%	0.77
Biology	380	91	0.9%	0.58
Biotech & Applied Microbiol	1946	346	1.4%	0.68
Cardiac & Cardiovascular Sys	2755	287	1.1%	1.07
Chem Medicinal	767	132	1.2%	0.92
Chem Organic	1269	274	1.4%	0.74
Ecology	1129	257	1.1%	0.73
Eng Biomed	218	100	1.1%	0.45
Eng Chem	661	155	1.3%	1.24
Eng Environmental	480	78	0.9%	1.31
Entomology	529	161	1.7%	1.20
Env Sciences	1483	304	1.0%	1.03
Env Studies	241	92	1.7%	1.20
Fisheries	182	61	1.1%	1.00
Food Sci & Tech	1168	378	3.2%	0.88
Forestry	119	47	0.9%	0.85
Genetics & Heredity	4523	359	1.1%	1.04
Horticulture	181	104	2.9%	0.67
Infectious Diseases	1021	124	0.8%	1.00
Limnology	115	28	0.8%	1.01
Marine & Freshwater Biology	270	82	0.7%	0.89
Mat Sci Biomaterials	92	43	1.4%	0.32
Microbiology	2985	316	1.4%	1.02
Mycology	48	9	0.6%	1.43
Nutrition & Dietetics	867	143	1.4%	0.90
Oncology	8742	757	1.7%	1.04
Ornithology	65	28	1.5%	0.98
Parasitology	146	39	1.2%	0.75
Plant Sciences	2888	395	2.2%	1.06
Polymer Sci	327	85	0.8%	0.66
Veterinary	1251	548	3.3%	0.84
Virology	1062	144	1.3%	0.74
Water Resources	212	48	0.5%	1.52
Zoology	539	156	1.1%	0.95

Source: Thomson Reuters University Science Indicators, 2003-2007.