OARDC: A Generator of Positive Economic Impacts for Ohio

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Acronyms

AMP	Agroecosystems Management Program
ATECH	Food and Agricultural Technology Commercialization and Economic Development Program
BL-3	Biosecurity Level-3
CAPPS	Center for Advanced Processing and Packaging Studies
CDC	Centers for Disease Control and Prevention
CIFT	Center for Innovative Food Technology
Cwt	hundred weight
DNA	deoxyribonucleic acid
FAES	Food, Agricultural, and Environmental Sciences (College of)
FTE	full-time employee
FY	Fiscal Year
IBDV	infectious bursal disease virus
LPCAT	Laboratory for Pest Control Application Technology
NIH	National Institutes of Health
NSF	National Science Foundation
OAES	Ohio Agricultural Experiment Station
OAP	Ohio Aquaculture Program
OARDC	Ohio Agricultural Research and Development Center
OCAMM	Ohio Composting and Manure Management
OFFER	Organic Food and Farming Education and Research
OPBG	Ohio Plant Biotechnology Consortium
OPGC	Ornamental Plant Germplasm Center
OSU	The Ohio State University
OSUE	The Ohio State University Extension
OSURF	The Ohio State University Research Foundation
PCR	polymerase chain reaction
R&D	research and development
REIS	Regional Economic Information System
SARS	severe acute respiratory syndrome
SIC	Standard Industrial Classification
TGBP	Tomato Genetics and Breeding Program
TPP	Technology Partnership Practice
USDA	U.S. Department of Agriculture

Executive Summary

An Industry Facing Intense Competition and Dramatic Change

Regions across the nation are facing a dramatic transformation as the United States moves to an economy driven by technology—through both the creation of new industries as well as the application of technology to traditional industries. This "Knowledge Economy" is increasingly less dependent on making and growing things and more dependent on ideas and innovation. Knowledge has replaced raw materials and physical labor as the source of value, wealth, and economic prosperity.

The agricultural bioscience (agbioscience) sector is a knowledge-based industry cluster that is constantly reinvented as scientists, engineers, and researchers gain new insights in plant and animal genetics, nutrition, and health. Advances in the agbioscience sector have shifted agriculture's focus beyond food and fiber production toward goals of improving public health, social well-being, and the environment. Agriculture is playing a new and different role in delivering nutritional, pharmaceutical, and bio-based products; in providing sound stewardship of resources; and in supporting rural communities. These technological breakthroughs take shape in new and innovative products used in everyday life.

In addition, globalization, trade liberalization, consumer preferences, public concern about food safety and the environment, and changes in the relationship between agriculture and rural communities have altered the context in which agbioscience research is being pursued and conducted. Emerging areas such as biotechnology, genomics, and ecosystem science have also transformed the practices and products of agriculture. Today, there can be no doubt that the Knowledge Economy is impacting our most traditional economic base—our agricultural sector.

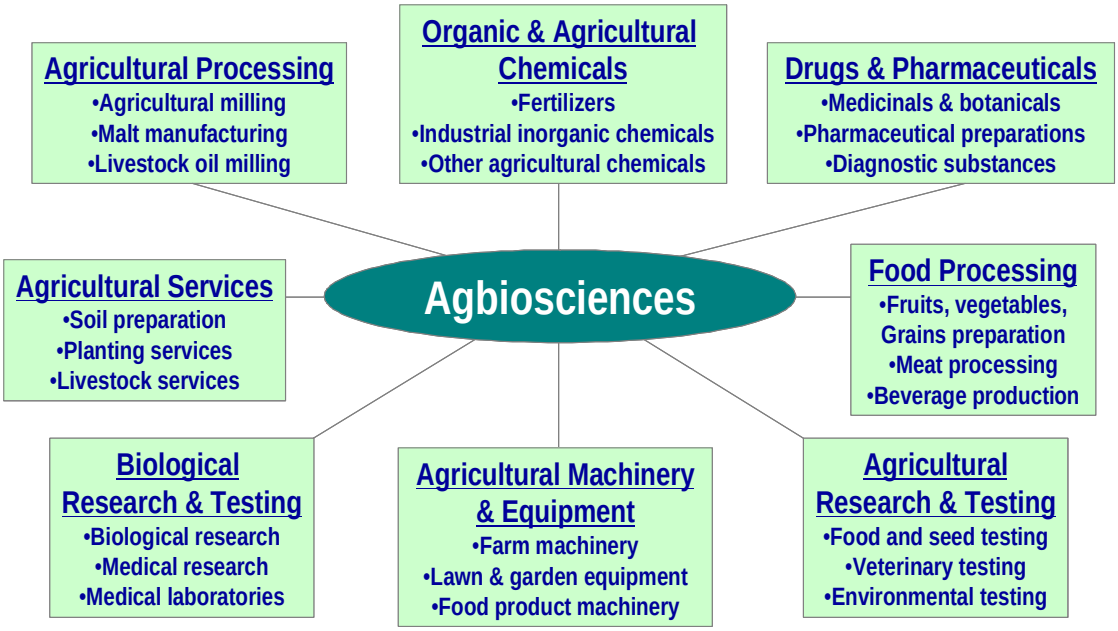
As with all industries that sell into worldwide commodities markets, the agbioscience industry is an exceptionally competitive field of business. For Ohio's industrial sector to remain competitive, the state's producers must be equipped with the knowledge, skills, tools, and inputs required to produce quality products at competitive prices. It may come as a surprise that agriculture, perhaps more than any other industry, requires specialized local industry research and development (R&D) to remain competitive. Unlike producers of the typical manufactured product, agricultural producers have to work within a production environment that contains great year-to-year variability, uncertainties, and risks.

An Important Industry for Ohio

Before one can understand the impact of the agbioscience sector on the state, a clear definition of the term must be articulated. This can prove problematic, however, since varying industrial classifications could be used to define the "agbioscience" sector of the economy. Categorization is particularly difficult due to the diversity of agbioscience activity. Continual innovation further complicates the industry definition. For instance, agbioscience advancements are constantly being applied in new and different ways, creating new industry segments, such as genetically improved foods, or alternate energy sources, such as agriculturally based fuels.

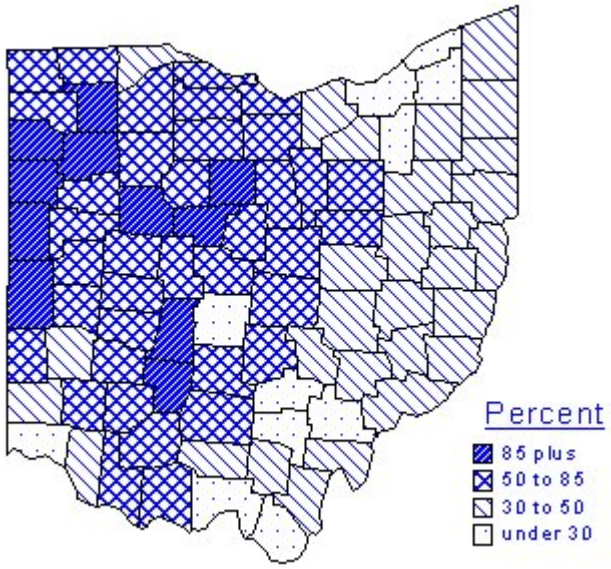
Figure ES-1 illustrates the eight major subsectors of agbioscience activity identified for this economic impact analysis.

Figure ES-1: Breakout of the Agbioscience Industry



The agbioscience industry is big business in Ohio. For instance, when the first component of the extremely vertically integrated market is examined, it is discovered that in 2002 Ohio contained 78,000 farms, with these commercial establishments covering a total of 14.7 million acres—fully 56% of Ohio's total land area of 26.4 million acres—impacting a widespread geographic area in the state and present in every Ohio county (Figure ES-2). Furthermore, a recent examination of

Figure ES-2: Geographic Distribution of Farm Land in Ohio



Source: Ohio Department of Agriculture.

the entire agriculture and food sector industry in Ohio revealed that it employs over one million Ohioans and has a total economic output of $79.6 billion—12 percent of the Ohio economy.[1]

Within the rapidly changing knowledge economy, Ohio's agbioscience industry has to operate at peak competitive efficiency in a production environment impacted by such significant and wide ranging variables as

- Climatic conditions, including rainfall, amount of sunlight, high and low temperatures, etc.
- The waxing and waning of bacterial, fungal, and viral diseases and pathogens
- The control of insects and other pests
- The maintenance of optimal soil fertility, drainage, and retention
- The impact of these variables on farmers in other regions, countries, and continents whose production will affect commodity prices and the Ohio farmer's return on investment.

The Ohio farmer thus faces an almost overwhelming series of decisions each year that may make or break his or her bottom line. What new crop cultivars have researchers developed that I should use this year? What variety will grow best and yield the highest returns? Which commodities will be in oversupply or scarce supply this year and what effect will this have on prices? What predictive computer models should I use to guide my planting? What diseases will my crops and animals face and what is my best approach to offset the threat of these? Should I invest in precision agriculture technology this year, and what would my return on investment be? What fertilizers and soil improvement strategies should I adopt based on my soil characteristics, crop rotation history, and recent environmental factors? What planting, harvesting, and processing technologies should I invest in to enhance my bottom line? What new crops, products, and varieties should I be considering based on changing consumer and market demands? No other category of business faces such a variable and risky series of decisions that must be made and repeated year after year.

THE OARDC—AN INDISPENSABLE RESOURCE FOR KEEPING OHIO AGRICULTURE COMPETITIVE

Ohio's agbioscience industry might be overwhelmed except for the sophisticated resource to which they can turn for help. Since 1882, Ohio has maintained the continuous operation of an institution dedicated to supporting the agricultural community with state-of-the-art research, analysis, information, and advice. Today, The Ohio State University's (OSU's) Ohio Agricultural Research and Development Center (OARDC), in combination with the agricultural extension service, provides a sophisticated suite of research, development, education, and advisory services dedicated to improving the competitiveness and sustainability of Ohio's agbioscience industry sectors.

The OARDC is a pragmatic, applied institution dedicated to finding workable solutions to the challenges facing Ohio agriculture and related industries. Via basic scientific research, and translational and applied R&D, the OARDC is a consistent source of new products, processes,

[1] Sporleder, Thomas L. 2003. "OHFOOD: An Ohio Food Industries Input-Output Model – Version 6.0." The Ohio State University Department of Agricultural, Environmental, and Development Economics. June.

and techniques that help make Ohio's agricultural producers among the most productive in the world. The OARDC provides a broad suite of services and benefits to Ohio; but, at its core, and central to its significant impacts, are the following activities:

- The development and breeding of new crop varieties displaying enhanced characteristics suited to the Ohio growing and production environment. These enhanced characteristics may be in the form of disease and pathogen resistance, pest resistance, enhanced yields, higher crop quality, or premium-price-commanding traits.
- R&D leading to new crop and livestock production strategies and technologies optimized for Ohio's environmental characteristics.
- Approaches to the diagnosis, prevention, and treatment of infectious food animal diseases, enhancing the health of Ohio's livestock population, protecting the food chain, and preserving food safety.
- The study of Ohio's soils and growing conditions resulting in the enhancement of soil quality, fertility, weed and pest reduction, rotation and till/no-till regimens, and environmental preservation.
- Work to maintain the economic sustainability, social fabric, and quality of life of Ohio's agricultural and urban communities.
- Dissemination of critical information and educational materials to enhance the knowledge base of Ohio's agricultural practitioners and increase their farming skills and competitiveness.

and increasingly:

- The development of novel plant and animal strains and new applications for agricultural output based on advanced R&D in genomics, post-genomic sciences, and biotechnology.

The OARDC is a critical link in Ohio's agriculture and agribusiness chain. Without the operations of the OARDC and its scientists, the state's agbioscience sector would be far less of an economic engine for the state than it is today. By improving agricultural efficiency, enhancing crop yields, preventing and reducing disease and pests, and educating farmers in the latest state-of-the-art technologies and techniques, the OARDC is central to maintaining the economic viability of Ohio's agricultural sector and the related sectors that provide services to farms, process agricultural products, and add value to crop and livestock output.

THE OARDC—A GENERATOR OF POSITIVE ECONOMIC IMPACTS FOR OHIO

As an operating entity, irrespective of the benefits of its scientific discoveries, the OARDC generates a significant economic impact for 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 biosciences 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 on an annual basis the OARDC generates the following impacts:

- **$142.3 million in total Ohio economic output (sales)**, comprising $67 million in direct economic output and $75.3 million in indirect output.
- The operations of the OARDC also support **1,576 jobs in Ohio**, comprising 762 direct jobs and a further 815 jobs generated in the Ohio economy via the employment multiplier effect.
- OARDC direct and indirect employment generates **personal income for Ohio residents amounting to $54.2 million annually**. This is divided between direct OARDC income at $27.5 million and indirect income at $26.6 million.
- 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 **$5.6 million in annual tax revenues**.

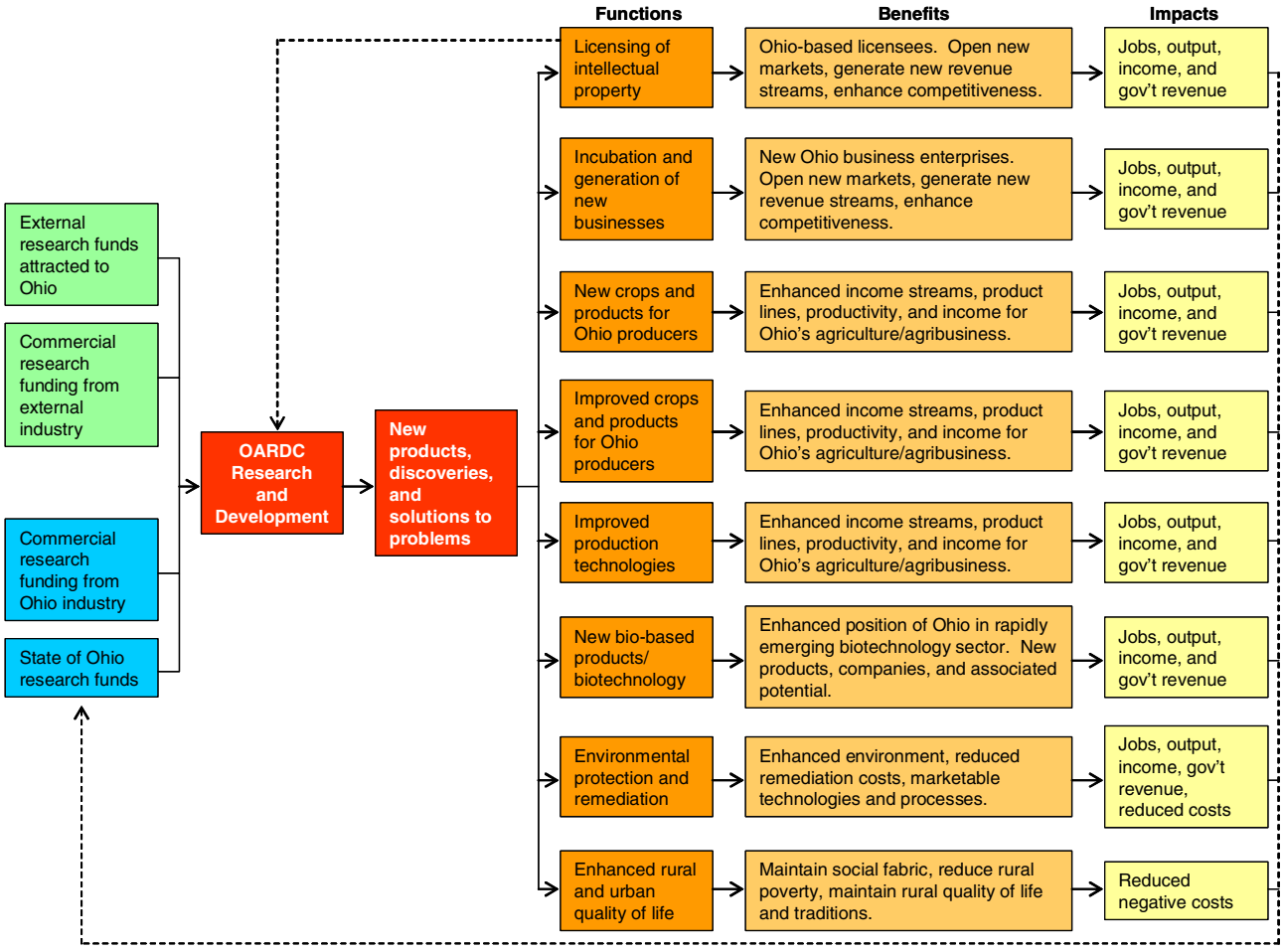
These are simply the impacts realized by the annual expenditures of the OARDC and its associated faculty and staff, and the follow-on multiplier effect of these original direct expenditures. The full impact generated by the Center's scientific discoveries, production enhancements, and practical solutions for the agricultural sector is, of course, far larger, but also much more difficult to quantify.

THE IMPACT OF OARDC RESEARCH AND DEVELOPMENT

In FY 2003, the OARDC research complex has been working under 644 research contracts on projects funded in the amount of more than $16 million. It is not surprising, therefore, that Battelle finds that OARDC and OARDC-related R&D in Ohio is a generator of significant positive benefits for the state.

Figure ES-3 illustrates the main mechanisms and pathways by which OARDC R&D provides economic benefits to Ohio.

Figure ES-3: Principal Impacts Generated by OARDC Research and Development



These R&D impacts divide into four main categories:

- Technology commercialization
- New and improved crops, breeds, and products for Ohio producers
- New and improved technologies for Ohio industry
- An enhanced and protected environment and quality of life for Ohioans.

Some examples illustrate the size and scope of impacts that the science of the OARDC engenders in the state.

Technology Commercialization

In a knowledge-driven economy, intellectual property has become the most valuable property of all. While software and information technology dominated U.S. technology growth in the 1980s and 1990s, bioscience disciplines have been making the headlines more recently. The post-genomic era, with its quantum leap forward in the understanding of fundamental and functional life mechanisms, is spawning new avenues of discovery and innovation.

Against this backdrop of bioscience prominence, the importance of the OARDC as a generator of intellectual property and scientific discoveries comes clearly into focus. The Center has an established track record in developing new crop cultivars, animal disease diagnostics, vaccines, and related discoveries that proves the Center's potential as an innovation engine. Because the OARDC takes a pragmatic and applied approach to research, the Center and the College of Food, Agricultural, and Environmental Sciences have been particularly active generators of intellectual property within the OSU system.

Statistics from the OSU Office of Technology Licensing indicate that, in FY 2003, agricultural and ag-related intellectual property has been responsible for 22 invention disclosures, five patent applications, 11 executed license agreements, and more than 35% of all OSU licensing revenues. Multiple companies operating in Ohio have their roots in R&D conducted at the OARDC—companies such as Spray Redux and Kurtz Brothers Composting. In addition, Battelle anticipates that the productivity of the OARDC in terms of technology commercialization is likely to increase for the following reasons:

- Favorable changes have been made in Ohio's legislation governing the involvement of faculty in start-up commercial enterprises.
- The Food and Agricultural Technology Commercialization and Economic Development Program (ATECH) has been initiated by the OARDC and OSUE to foster and accelerate commercialization from food, agricultural, environmental, and life science expertise contained within the OARDC.
- A research park is being established at the Wooster OARDC campus to facilitate the incubation of companies and the attraction of co-locating companies taking advantage of OARDC R&D linkages. The first new company slated for occupancy at the park is already forming based on genetic marker technologies applicable to the livestock industry.
- Capital availability is being enhanced as increased volumes of equity and risk capital flow to agbioscience-related fields.

New and Improved Crops, Breeds, and Products for Ohio Producers

At its core the OARDC is an applied bioscience R&D institution, dedicated to improving agriculture, horticulture, and quality of life in Ohio. The R&D activities of OARDC are focused on finding ways to improve crop productivity, fight plant and animal diseases, improve the quality of agricultural products, and significantly increase agriculture and horticulture-related economic output for the state.

The OARDC is home to 256 research scientists focusing all or part of their time on OARDC-supported research projects. Typically, this research population is involved in conducting more than 400 OARDC-supported research projects at any given time. It should not be surprising that such an intensity of focused applied research has resulted in significant discoveries that have had far-reaching benefits for Ohio agriculture, horticulture, food-processing, and related industries.

Ohio's agriculture, horticulture, livestock, and ag-processing sectors operate at a high yield and level of efficiency in part because of the application of knowledge, techniques, technologies, and germplasm developed at the OARDC. Battelle's review of OARDC activities identified a legacy of positive impacts generated through OARDC work that has

- Improved Ohio's soil fertility
- Managed and controlled agricultural and horticultural pests
- Prevented, diagnosed, and treated animal infectious diseases
- Controlled the negative impacts and crop losses caused by plant pathogens
- Increased crop yields through breeding and developing enhanced crop cultivars
- Increased meat and poultry yields via enhanced breeding and specialized approaches to animal nutrition.

Through the application of traditional and genomic/post-genomic life science approaches, the OARDC's R&D continues to build on this legacy of positive impacts. While Battelle could not formally measure the benefits provided by all OARDC research projects, some specific case studies were undertaken to help illustrate the impacts generated by scientific R&D at the Center (see following text boxes).

Example 1—Soybean Impact

Soybeans represented an $837 million crop for Ohio's farmers in 2001 and covered fully 32% of all farmland in the state—making it the largest crop in Ohio agriculture. Yet, without the ongoing work of the OARDC, this sector of agricultural production could not survive in the state.

Soybeans are extremely sensitive to the length of day, temperature characteristics, soil types, pests, and pathogens that are unique from one environment to another. Soybean varieties that may be successful in Indiana or Michigan will likely not be successful in Ohio. **The OARDC serves a critical role in developing the specific high-yield, disease-resistant, high-quality strains of soybean that thrive in Ohio and maintain the viability of this industry.** To measure the impact of the OARDC on soybeans, Battelle produced an input/output model using data provided by the OARDC on soybean cultivar releases. The model provides a conservative estimate of OARDC soybean impacts since it does not account for private soybean varieties developed as hybrids of previous OARDC releases. The impact model shows that on an annual basis OARDC soybeans generate $191 million in Ohio economic output, create $67 million in income for Ohioans, and support 4,030 jobs. Thus, it can be seen that in only one crop, soybeans, the OARDC's R&D develops positive impacts for Ohio that exceed the institutional expenditure impacts of the Center.

Example 2—Tomato Impact

Ohio ranks third in the nation in producing tomatoes. OARDC R&D has contributed to the state's strong position with this crop based on developing higher-yield and high-quality tomato varieties suited to Ohio's growing environment. Since 1991, the OARDC has released 17 new varieties of tomato and tomato germplasm for adoption by Ohio's producers—the result of extensive R&D operated by the Tomato Genetics and Breeding Program.

Tomato production has steadily increased in Ohio as varieties resistant to tomato pathogens and displaying enhanced characteristics have been released by the OARDC. In 1998, tomato farming (of both fresh and processing tomatoes) represented a $40 million industry for the state; by 2002, this had increased to more than $100 million.

Example 3—Infectious Animal Diseases Impact

Infectious animal diseases are an agent causing dramatic negative impacts for livestock and poultry producers. They are also agents that would have a disproportionately harmful impact for Ohio, where fully 80% of all agricultural production is either animal husbandry or the production of crops for animal feed. Under the vertically integrated food animal production system that exists in Ohio, vigilance is required to prevent and react to disease outbreaks that may cause large-scale economic disruption in the $79.6 billion Ohio agriculture and food sector.

The OARDC's Food Animal Health Research Program has adopted a pragmatic approach in its animal research by focusing its resources intensively on the two leading causes of illness in food-producing animals—enteric and respiratory diseases. The expertise in these disease groups contained within the OARDC brings in considerable federal research funding to Ohio; but, more fundamentally, it is working to prevent the spread of diseases that have caused great economic damage in domestic and international outbreaks. To put the issue into perspective, Battelle examined the case of avian influenza, a disease that has seen recent outbreaks in U.S. states such as Virginia. Battelle calculates that a Virginia-style outbreak in the Ohio turkey industry would result in a 75% loss of Ohio's turkeys with direct sustained economic losses of $53.8 million. Furthermore, Battelle estimates that animal infectious diseases cost Ohio circa $315 million per year.

By working to develop diagnostics, vaccines, treatments, surveillance protocols, and culling strategies for the most common and threatening diseases that face, or may face, Ohio producers, OARDC scientists and researchers are helping to ensure against substantial economic losses.

New and Improved Technologies for Ohio Industry

Food processing in Ohio is a major industry segment accounting for $18.9 billion in Ohio economic output. While the OARDC is active in the primary production end of agriculture, its researchers and scientists are also actively involved in R&D for the value-added sectors engaged in the processing of agricultural products.

OARDC scientists, for example, are leaders in the federally funded Center for Advanced Processing and Packaging Studies (CAPPS) with leading-edge research taking place in

alternative sterilization, pasteurization, and preservation technologies designed to promote better packaged food quality and a safer food supply. Ohmic heating, pulsed electrical fields, and high-pressure sterilization technologies are each being developed within the OARDC/OSU scientific community.

OARDC biological research is also being applied to the food processing industry for the rapid detection of microbes. Large-scale economic losses are caused annually by foodborne pathogens, and OARDC research shows great promise for substantially reducing these losses via testing that can be accomplished on a food sample in minutes (when current standard methods take upward of 18 hours to conduct—time during which food stuffs may begin to spoil). Battelle's calculations indicate that enhanced food safety has the potential to save between $260 million and $532 million in economic losses to Ohio on an annual basis and prevent between 132,000 and 492,000 Ohioans from getting foodborne illnesses.

In addition to working with industry on food safety issues, OARDC research is also making contributions to processing technologies. CAPPS researchers at OSU, for example, are making important contributions via the use of pulsed electric fields for tomato and citrus juice processing applications.

The R&D and consulting work of the OARDC also makes strong contributions to other industries in the State of Ohio. The wine industry, for example, has seen resurgence in its contribution to the Ohio economy—a growth that has been supported via the OARDC grape research station and OARDC work on grape cultivars, viticulture, and education for persons entering the industry. Similar fundamental work is being, or has been, completed by OARDC researchers in establishing

- An economically viable aquaculture industry in the state
- New forms of disease-resistant potting soil, making horticulture via potted-plant pathways a viable industry for the state (the nursery industry now has sales of more than $2.7 billion in Ohio annually)
- Technologies, processes, and mechanisms for the remediation of agricultural and community waste via bioprocesses, and the development of bio-energy and bio-fuels from biomass wastes.

An Enhanced and Protected Environment and Quality of Life for Ohioans

Perhaps best known for its applied agricultural research, the OARDC is also a major producer of research related to environmental preservation, community sustainability, family studies, and rural/urban development economics.

OARDC researchers and development specialists are active in efforts to promote rural Ohio workforce preparation, protect agriculture and the environment at the growing urban fringe, improve the situation of low income rural families, and enhance family cohesion in an increasingly challenging social environment.

The OARDC also plays an important role in developing human capital in the state, contributing to workforce development through OARDC scientists holding joint teaching responsibilities within OSU, specific continuing education courses offered by the OARDC and Extension for Ohio practitioners, collaborative work with the Ohio Agricultural Technology Institute, and

maintaining an active communications program aimed at disseminating the latest research findings relevant to Ohio's farmers and industry.

Through environmental preservation research and activities (such as work on waste management, soil preservation, carbon sequestration, and reducing pesticide and fungicide runoff), OARDC research is directly contributing to the sustainability of Ohio's natural environment—a resource that has increased in importance as quality of life takes central stage in attracting skilled human capital. The OARDC's active work on ornamental plants and trees also has provided a base of knowledge that has helped Ohio's communities and individual households spend their money wisely on ornamentals best suited to survive and thrive in Ohio's environment and soils.

INTO THE FUTURE

Throughout its 121-year history, the OARDC has constantly adjusted its areas of program and research focus to match the current and emerging needs and opportunities facing agriculture bioscience and agribusiness in Ohio. Change has been a fairly constant companion for the Center, but perhaps no single decade has brought as much potential as the current one.

The 21st century has opened with dramatic advances in the biosciences. Advancements in genomics and post-genomic sciences have opened new avenues of study and paved the way for rapid progress in multiple areas of biology and the plant and life sciences. **In response to the opportunities presented in what has been termed the "Biotech Century," the OARDC has multiple new and emerging initiatives aimed at leveraging bioscience and biotechnology advances for the benefit of Ohio and Ohioans.**

Among the most prominent of the new and emerging scientific initiatives of the OARDC are

- The Ohio Plant Biotechnology Consortium—Administered by the OARDC and comprising 11 Ohio-based institutions working to pool scientific and human resources to accelerate Ohio's plant biotechnology research and advance Ohio's position in plant-based technologies.
- The Ornamental Plant Germplasm Center—A joint project of OSU and the U.S. Department of Agriculture, the OPGC is working to build the world's leading herbaceous ornamental plant genebank. The possession of germplasm forms the building block for active OARDC programs in the "mining" of germplasm for genes and markers having favorable application in agricultural, horticultural, and medical applications.
- Emerging infectious diseases research program and the Plant and Animal Agrosecurity Research facility—This project aims to protect the United States and Ohio from the devastating effects of emerging infectious diseases entering the United States via accidental or deliberate (e.g., terrorist) means. The program also aims to be a generator of licensable and commercializable technologies in diagnostics, environmental monitoring, vaccination, treatment, and incident response strategies.
- Bioenergy and Biofuels Program—An OSU- and OARDC-based initiative aimed at producing energy, fuel resources, chemical products, and other commodities from renewable biomass resources. The opportunity is to create new industries and revenues for Ohio, while at the same time reducing biomass waste.

- ATECH and the BioHio Research Park and business incubator—These initiatives are specifically aimed at increasing the licensing and technology commercialization benefits from the OARDC's research. Through developing formal commercialization professional positions, the OARDC expects to significantly increase the flow of new businesses created in Ohio and revenue streams back to the state from the licensing of intellectual property. The initiative is being bolstered by a formal plan to develop an agribusiness research park and business incubator adjacent to the OARDC in Wooster—providing a home for both spin-off companies and joint industry-OARDC R&D collaborations.

Each of these new initiatives and programs has the potential to generate significant, but as yet unquantifiable, economic impact benefits for the state.

CONCLUSION

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 $142 million in state output, $54 million in personal income for Ohioans, and almost 1,600 jobs. These expenditure impacts are, however, eclipsed in their importance by the benefits accruing to the state through the intensive R&D activities housed within the OARDC's campuses. The OARDC is a scientific institution with a uniquely practical mission—enhance agricultural and agribusiness productivity and sustainability through intensive programs of applied research. In terms of OARDC's work only in developing 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 preventing and responding to infectious food diseases saves Ohio's agriculture from the potential of large-scale economic losses, through disease outbreaks, that 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 sustaining and enhancing 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 preeminent biosciences and agbiotech R&D center as the U.S. economy moves into what has been termed the "Biotech 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 agbiosciences bodes well for Ohio to achieve a prominent, if not leading, position in the most promising area of the knowledge economy.

Introduction

Created by the Ohio General Assembly in 1882, the Ohio Agricultural Research and Development Center (OARDC) has a substantial track record of contributions to Ohio and the nation. As much as the OARDC has meant to the state in the past, it is likely to be even more important in Ohio's increasingly technology-driven economy. As "knowledge" and intellectual capacity become the foremost drivers of modern western economies, it is likely that research and development (R&D) centers, such as the OARDC, will grow in their central importance to economic progress. Innovating and enhancing productivity (activities at the core of OARDC's mission) are keys to the long-term competitive sustainability of Ohio's high standards of living. The degree to which the OARDC's work has, and is, contributing to economic progress in the State of Ohio is the subject of this report.

STUDY GOALS

The Technology Partnership Practice (TPP) of Battelle Memorial Institute was retained to perform an in-depth assessment of the many-faceted impacts of the OARDC on the State of Ohio. Specifically, the project seeks to provide the following:

- Measures of the quantitative impact of OARDC operations and activities on key economic metrics such as Ohio business volume, personal incomes, and employment
- Specific illustrations of the range of positive impacts generated in the state via OARDC's original research, applied development activities, technology transfer, and the actual commercialization of research discoveries (referred to as "discovery commercialization" in this report)
- Illustrations of the impact of OARDC initiatives and training programs on the state's human capital via workforce development and education
- An understanding of the broad range of social and community benefits afforded by OARDC's activities in the state
- A "tool" for OARDC to use in the future for estimating annual economic impacts.

The complete findings of this research are reported herein. This research constitutes Phase I of a two-phase scope of work being performed by Battelle. Phase I examines the current benefits generated in Ohio by the presence and operations of the OARDC—and completing this research brought Battelle researchers into intimate contact with the wide range of activities and initiatives performed by the OARDC. The knowledge gained in the Phase I assessment will further inform Phase II—wherein Battelle's researchers and strategists will examine the following:

- The existing and emerging comparative advantages unique to the OARDC
- The key high-growth market segments of the Ohio economy where the OARDC could have the most positive impact

- The critical investment points, within the identified markets and segments, which are likely to yield above average wages and job growth from OARDC research and initiatives.

This Phase I report thus focuses on the past and current economic impact of the OARDC, providing an overview and quantification of the varied impacts. Phase II will include a comparative analysis of OARDC's strengths and growth markets and will identify the key strategic investments required for the successful future pursuit of identified opportunities.

METHODOLOGY

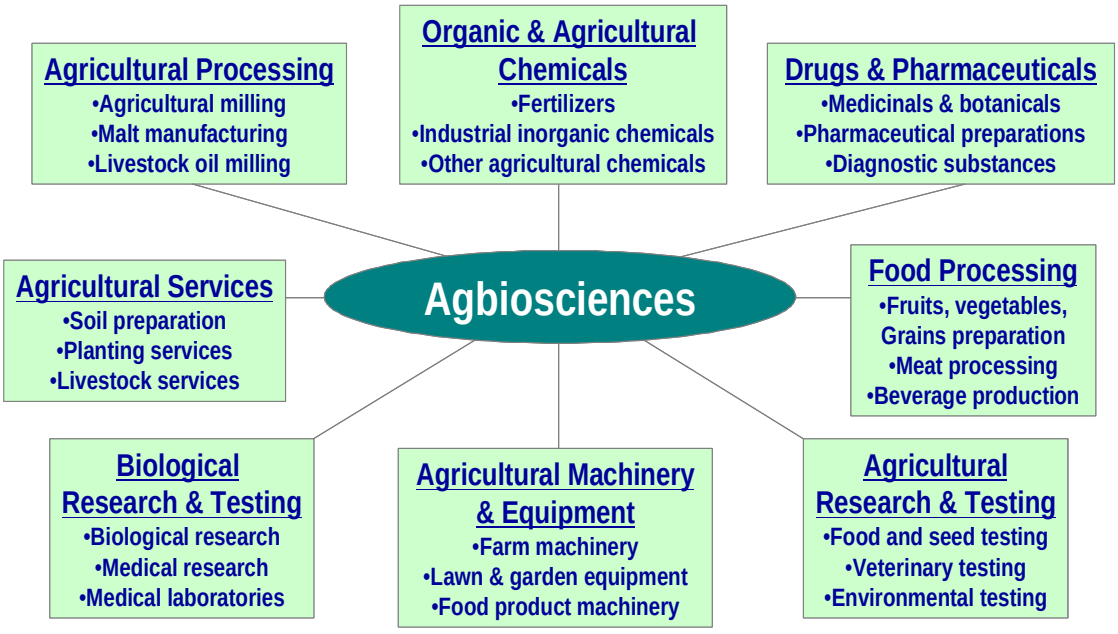
Battelle uses both quantitative and qualitative approaches in evaluating the OARDC's broad range of impacts. On a quantitative basis, Battelle reports the results of economic impact calculations using input/output analysis techniques. Qualitative research techniques are used to provide illustrative examples of the types of impacts provided by the OARDC through activities such as research, development, discovery commercialization, and workforce development.

Definition of Agbioscience Sector

Before one can understand the impact of the agbioscience sector on the state, a clear definition of the term must be articulated. This can prove problematic, however, since varying industrial classifications could be used to define the "agbioscience" sector of the economy. Categorization is particularly difficult due to the diversity of agbioscience activity. Continual innovation further complicates the industry definition. For instance, agbioscience advancements are constantly being applied in new and different ways, creating new industry segments, such as genetically improved foods, or alternate energy sources, such as agriculturally based fuels.

Figure 1 illustrates the eight major subsectors of agbioscience activity identified for this economic impact analysis.

Figure 1: Breakout of the Agbioscience Industry



Input/Output Analysis

The economic impact analysis section of this report relies on federal government data consolidated within the IMPLAN[2] regional economic analysis system. The IMPLAN data files include information for 528 different industries (generally at the three- or four-digit Standard Industrial Classification [SIC] code level), and 21 different economic variables. Along with the data files are national input/output structural matrices. IMPLAN sources its employment data from ES202 employment security data supplemented by county business patterns and REIS[3] data. Employment data utilized in the analysis include full-time and part-time positions.

The IMPLAN software performs input/output analysis for determining the economic impact of projects, economic sectors, new companies moving into an area, etc. For the OARDC project, Battelle researchers acquired the IMPLAN data file for the State of Ohio as a whole.

It should be noted that the most recent IMPLAN data files for Ohio are for 2000. While the data are not current, it is highly unlikely that the fundamental structure of Ohio's economic fabric has changed to an extent that would invalidate the analysis.[4] IMPLAN data and accounts closely follow the accounting conventions used in the "Input/Output Study of the U.S. Economy" by the U.S. Bureau of Economic Analysis and the rectangular format impact analysis recommended by the United Nations.

In addition to conducting input/output analysis, Battelle researchers and analysts also conducted a series of in-depth interviews with OARDC administrators, faculty, and research scientists. Through one-on-one interviews a detailed understanding of specific research focus areas at the OARDC was developed, allowing Battelle to further investigate potential impacts of these research and development initiatives.

[2] Minnesota IMPLAN Group, 1725 Tower Drive West, Suite 140, Stillwater, MN 55082.
[3] Regional Economic Information System—Bureau of Economic Analysis, U.S. Department of Commerce.
[4] The data set used in this study is the most current available for the methodology employed.

Roles and Responsibilities of the OARDC (The Scope of Benefits Provided by the OARDC to Ohio)

HISTORIC IMPACT OF THE OARDC

Established in 1882, the OARDC has more than 121 years of service to the people and State of Ohio. With such substantial longevity, the science and operations of the OARDC (known as the Ohio Agricultural Experiment Station [OAES] until 1965) have had a significant impact on agriculture, agribusiness, horticulture, and a broad variety of sectors of the Ohio economy. While this report focuses on the current economic impact of the OARDC, it is important to acknowledge the legacy of service, discovery, and innovation provided by this institution.

OARDC (as OAES) Originated in Columbus, Ohio

The OARDC originated as a pragmatic and practical institution dedicated to agricultural experimentation. Declining soil fertility, poor knowledge and quality of fertilizers, and a lack of practitioner knowledge of leading-edge crop rotation and other yield-enhancing techniques led to a need for a more scientific approach to agriculture in Ohio. Land-grant universities were formed in various states in the 1870s, by act of Congress, in hopes of bringing new scientific approaches to agriculture and farm management. In Ohio, the Ohio Agricultural and Mechanical College was formed; but, its mission rapidly expanded to provide liberal arts and professional education far outside the fields of agriculture and horticulture. By 1878, the college was renamed The Ohio State University (OSU) and included in its broad mission the goal of educating engineers, lawyers, and teachers—a far cry from the initial Congressional concept of land-grant institutions dedicated to promoting agricultural science and enhanced farm productivity.

Since the 1870s, The Ohio State University has grown into one of the world's preeminent Tier 1 research universities. While no one would doubt the vast benefits and positive impacts brought by the broad variety of academic and scientific programs contained within Ohio State, it became clear by the 1880s that a void in agricultural science and experimentation in Ohio remained to be filled. In 1880, *Ohio Farmer* endorsed the need to create a comprehensive agricultural experiment station, one that would serve as "a laboratory for soil and fertilizer analyses and germination tests of new seeds, as a farm for comparisons of new and traditional crop varieties and of crop rotations and fertilizers, and as a barn for selective breeding of livestock and comparisons of livestock rations."[5] It took until 1882 for the Ohio Legislature to pass a bill to meet these needs—creating the Ohio Agricultural Experiment Station, an independent institution separate from The Ohio State University (albeit "linked" to the university by a need to access university land, faculty, and staff).

The Experiment Station's impact on Ohio agriculture began in earnest as its first director, William Lazenby, distributed a survey to Ohio farmers seeking their assistance in identifying their most important problems and crops. By 1883, a focus for the initial experiments of the Station was prescribed, with the raising of corn and wheat, and determination of the optimal

[5] Cumo, Christopher M. 2000. *Seeds of Change: A History of the Ohio Agricultural Research and Development Center.* Wooster, Ohio: The Wooster Book Company, pp 10-11.

fertilizers to use, being at the forefront of the Center's work. Early work related to soil fertility was hampered by both a lack of funds and by soil at the OSU farmland in Columbus that was overly fertile and unrepresentative of soils in the rest of Ohio. Motivated by the soil issue, a need for funds, and a desire for asserting its independence from OSU, the Station solicited bids for a new location from Ohio's counties and ultimately accepted the bid of Wayne County, which offered 470 acres of land outside of Wooster. In 1894, the Ohio Legislature appropriated the $85,000 required to establish the new Station in Wooster.

OAES Established in Wooster, Ohio

Under its early leadership, the Experiment Station began research in earnest. By the early 1900s the institution was publishing research bulletins, monthly and bimonthly research summaries, and circulars. Then Director of the Station, Charles Thorne, became an advocate for agricultural extension; and Ohio formed the first agricultural extension service and created the forerunner to the 4-H clubs.[6] Extension became the vehicle for disseminating the Station's science and research discoveries. In these early years, the OAES began to establish its national reputation as a leader in agriculture and horticultural science. Pioneering, high-impact research occurred in multiple areas, including the following:

- The restoration of soil fertility. Director Thorne conducted extensive experimentation in crop rotation, fertilizers, and manure and established 14 research substations throughout Ohio to ensure that all of the state's major soil types were adequately researched. The quality and impact of this early work in soil science were acknowledged by the U.S. Department of Agriculture (USDA) and agronomists at leading universities.
- Pest control. The OAES's entomologists and chemists experimented with early pesticide formulations, such as lead arsenate, and became the first proponents of the use of aircraft for applying chemicals and pesticides by crop dusting (a legacy that continues to this day through research related to the advanced application of sprayed chemicals).
- Plant pathogens also became a major area of early OAES research. Leaders in botany and chemistry collaborated to produce departmental research focused on the diagnosis, eradication, and prevention of crop diseases.
- Animal nutrition increased in impact through the work of the Department of Nutrition established at the OAES in 1907. Pioneering work was performed in the roles of calcium for healthy hogs, mineral replacement for dairy cattle, and the supplement of soybeans and alfalfa into animal diets that previously had consisted only of grains. The institution's research was at the forefront in showing the benefits of animal feeds rich in vitamins, carbohydrates, proteins, fats, and minerals.

The now formalized relationship with The Ohio State University began to reassert itself in 1925 when trustees agreed that faculty could be exchanged between both institutions. OSU scientists could perform part of their research work at the Station, using Station resources and drawing part of their salaries from it. In return, OAES scientists could bring their specific expertise to Columbus and supplement their pay through teaching courses at the university. This agreement enhanced the intellectual and scientific resources of both institutions in agriculture, horticulture,

[6] Cumo, Christopher M. 2000. *Seeds of Change: A History of the Ohio Agricultural Research and Development Center.* Wooster, Ohio: The Wooster Book Company, pp. 46-47.

and related fields and helped pave the way for establishing Ohio's leadership position in these disciplines.

During this era the OAES's work on soil fertility, under the leadership of Charles Thorne, was so successful in Ohio that the institution could do little more to enrich the state's farmland. Attention therefore turned to the scientific problem of identifying, developing, and breeding higher-yield plants. In the 1920s, OAES scientists made highly important contributions in the development of leading wheat (under Carlos Williams) and corn varieties (under the leadership of USDA-appointed scientist Glen Herbert Stringfield). As Christopher Cumo notes in his history of the OARDC[7]:

> *During thirty-five years at the station, Stringfield derived nearly 200 inbreds and hybrids resistant to the European corn borer. Thanks in part to Stringfield, yields per acre of corn more than doubled during his years at the station. Between 1954 and 1965, borer damage to Ohio corn diminished from $8,500,000 to $600,000.*

The OAES/OARDC also has a long history of service and research targeted at improving the quality of life of rural families and communities. After World War I, federal funds helped establish departments of rural sociology and home economics. Under the work of these departments, OAES scientists demonstrated the importance of vitamin D to human nutrition, which led to the development of vitamin-fortified milk for U.S. consumers. Other OAES research driven through the 1920s and 1940s brought equally important discoveries, such as the following:

- Leonard Alexander's work in the breeding of tomatoes resistant to fusarium wilt and tomato mosaic virus—diseases that were destroying high volumes of Ohio's greenhouse-grown produce. Alexander discovered genes resistant to both diseases and bred 50+ tomato varieties that saved horticulturalists millions of dollars in losses.
- OAES animal scientists developed nutrition regimens and products that increased the health of horses, cattle, and poultry and enhanced milk and high-quality beef production.

The 1940s saw an even closer relationship develop between OSU and OAES, with the relationship cemented in 1945 when Leo Rummell was appointed as Dean of the OSU Agricultural College and Director of the Ohio Agricultural Experiment Station. The academic research model became more firmly implanted in 1954 when the OAES Board of Control passed a regulation that scientists could gain tenure at the Station only if they possessed a doctoral degree. Other changes occurred as well, including a move to make the work of the Station relevant to the increasingly urbanized, city-dwelling Ohio population. Thus, much of the rhetoric at the time emphasized the role of farm productivity and good crop yields in maintaining low consumer prices, and the role of animal and plant nutrition and vitamin/mineral supplements in keeping Ohioans healthy.

In the 1950s the OAES rationalized its substation operations (which had succeeded in their goal of restoring Ohio's soil fertility). Ten of 14 substations were sold; they were replaced with dedicated scientific substations in Huron, Wood, and Brown counties. During this era, the goal of OAES to serve society through enhancing the productivity of agronomy was again reasserted. OAES opened the Swine Evaluation Center, which managed over 10 years to breed hogs 40%

[7] Cumo, Christopher M. 2000. *Seeds of Change: A History of the Ohio Agricultural Research and Development Center.* Wooster, Ohio: The Wooster Book Company, p. 69.

leaner in their meat than the average hog of 1950. Other Station researchers pioneered work that allowed stockmen and poultry farmers to accelerate the growth of cattle, hogs, and turkeys and significantly speed their time to market. Advances were also made in the development and application of pesticides for both agricultural and domestic garden/lawn use. OAES scientists also identified the cause of a disease that ravaged much of Ohio's and Indiana's soybean crop—diagnosing the disease as *Phytophthora* root rot. OAES researchers developed more than a dozen varieties of soybeans resistant to the disease—helping to reestablish soybeans as a major cash crop for Ohio's farmers.

OAES Renamed the OARDC

In 1965, the Ohio General Assembly recognized and reaffirmed the central research mission of the Station by renaming it the Ohio Agricultural Research and Development Center (OARDC). Under the leadership of Director Roy Kottman, OARDC had the mission to become the "world's finest research institution." The institution's budget expanded dramatically to help raise the OARDC's profile and scientific capabilities. When Director Kottman first arrived in 1960, the Center had a budget of $4 million; by 1979 this had grown to $15 million. Budget increases paid off for Ohio in the ability of the OARDC to respond to newly emerging pathogens. In 1964 the maize dwarf mosaic virus alone caused the loss of almost $6 million in Ohio corn, with the disease impacting 79 of Ohio's 88 counties. The OARDC's analytical and scientific resources were quickly mobilized and, by planting season of the following year, Ohio's farmers were equipped with OARDC-developed hybrids and inbreds containing Oh07—a corn variety that rewarded farmers with healthy crops once more. Similar success was achieved in 1971 through OARDC research on the maize chlorotic dwarf virus, where OARDC entomologists identified the disease-carrying vector and plant scientists bred resistant strains of corn. Other historical OARDC research discoveries have been equally important:

- USDA entomologists at Wooster harnessed female Japanese beetle pheromone and synthesized it as bait for a trap to attract and kill the male of the species. This opened the path to a realm of pest abatement systems that avoid the potentially negative environmental effects of heavily sprayed insecticides and fungicides.
- The OARDC established research substations to examine environmental remediation techniques using forestry and other plantings. Similarly, much research has been performed to examine the effects and potential remediation of fertilizer, herbicide, pesticide, and other agriculture and horticulture-based contaminants to groundwater, rivers, and lakes.
- To help beautify Ohio's urban environments, the OARDC worked to develop tree varieties with broad canopies to shade city streets, while other forestry programs have focused on refining crab apple trees to best meet the needs of Ohio's horticulturalists and home gardeners.
- The OARDC developed research on optimal forage grasses and legumes for production in southeast Ohio and established the Vegetable Crops Branch in northeast Ohio, with a major emphasis on field-grown tomatoes.
- Lowell Nault of the OARDC crossed Mexican teosinte (an ancestor of corn) with corn to produce plants immune to many viruses that were affecting Ohio corn crops.

Today, this legacy of OARDC research discovery continues with increasing vigor. In the early 1990s, Director Thomas Payne worked diligently to explain the scientific value of the OARDC and the role it plays in the Ohio economy. As a result, budgets increased and resources for scientific inquiry expanded. As Ohio moves through the first decade of the 21st century, new scientific terms are coming to the fore. Terms such as agricultural genomics, biopharming, and biomass fuels show the crossover from agricultural products as food to agricultural products as pathways for the production of pharmaceuticals, therapeutic compounds, chemicals, and alternative renewable energy sources. There is a revolution occurring in human understanding of the genetics and proteomics of plants, animals, insects, and pathogens—and The Ohio State University and the OARDC are very much a part of this revolution.

Throughout its 121-year history, OARDC has endeavored to improve the quality of life of Ohioans through enhanced economic well-being, better quality and lower priced foods, and enhanced environmental protection and beautification. Research has enhanced farm productivity; offset the devastating negative impacts of crop blights and diseases; and introduced new, high-value products for Ohio's farmers and agricultural industries. The OARDC thus has a historic legacy of positive impacts on the state; and this report seeks to examine, in detail, the impacts that are occurring today.

OARDC Science, Research, and Development Impacts

At the heart of OARDC's mission and impacts is innovation. Through the application of scientific and research principles, OARDC faculty and staff are leveraging the tools of scientific inquiry and the Center's human capital to create innovative approaches to practical problems.

OARDC is a pragmatic institution founded on practical values. Since the Center's inception, the faculty and staff have been dedicated to making scientific discoveries that can be rapidly translated from the benchtop, to the test plot, and then diffused into accepted agricultural practice through OSU Extension (OSUE). It is this pragmatic nature of the institution that makes Battelle's job of analyzing impacts at the OARDC somewhat easier than for many scientific and research institutions. It is difficult to demonstrate economic benefits from the discovery of a new quasar in a distant galaxy by an astronomer or the identification of a new genus of tube worm in a deep ocean vent by a marine scientist. It is far less difficult to draw attention to the practical economic and social value of developing a strain of corn that is completely resistant to a blight that destroyed an entire crop only the year before. OARDC undertakes practical science that has impacts and benefits that are readily understood, if not always easily quantified. For example, OARDC scientists have made discoveries leading to

- Substantially improved food processing technologies, industrial processes for adding value to agricultural products, and the application of advanced biotechnology techniques to agricultural processing and production
- The restoration of fertility in Ohio's soils
- The reduction, or eradication, of disease losses in multiple Ohio staple crops
- The destruction of insect pests, such as the Japanese beetle

- Greatly enhanced farm productivity via faster growing crops, and more rapidly developing and leaner meat-producing cattle, hogs, and poultry
- A cleaner, less polluted environment throughout the State of Ohio.

This is not science esoterica—rather, it is the application of science to the direct betterment of Ohio agriculture and economic well-being. Cattle that can be brought up to weight and leanness 20% faster means 20% higher productivity for the producer. Likewise, an increased crop yield from disease-resistant, faster-growing corn plants has a very real and tangible economic benefit for the farmer and for society. Ohio is receiving substantial benefits from its investment in the basic and applied science of the OARDC, a fact recognized by former Director Leo Rummell who noted that "science is ploughed deeply into farming." The extent of these benefits is the subject of investigation in this report.

The ongoing practical nature of OARDC's work can be seen in Table 1, which lists the 10 largest extramural grants received by OARDC scientists in 2002. These projects are indicative of the applied nature of OARDC research—highlighting projects to reduce pathogens, create new food products, enhance family nutrition, restore Ohio's ecosystems, and transfer technologies into new businesses. It should be noted, however, that these grants represent just the tip of the OARDC research iceberg, which at any given time is conducting more than 400 research projects.

Table 1: Largest Extramural Grants to OARDC, 2002

OARDC Principal Investigator	Subject	Dollar Award	Project Sponsor
Y. M. Saif	Effects of nutrition and waste management technologies on pathogens in animal excreta	$2.3 million	Initiative for Future Agriculture and Food Systems
Donald McFeeters	Technology training and business incubator	$1.9 million	Economic Development Administration
Joyce McDowell	Family nutrition program	$1.8 million	Ohio Department of Jobs and Family Services
Steven Schwartz	A model system for functional foods: Tomato products containing soy	$1.2 million	Initiative for Future Agriculture and Food Systems
David Francis	Improving efficiency of processing tomato production: Managing color disorders	$600,000	Initiative for Future Agriculture and Food Systems
Rattan Lal	Soil and ecosystem restoration using flue gas desulphurization by-products for soil carbon sequestration and biofuel production	$570,000	Ohio Coal Development
Steven Slack	Ornamental germplasm center	$440,000	Agricultural Research Service

Table 1: Largest Extramural Grants to OARDC, 2002 (continued)

OARDC Principal Investigator	Subject	Dollar Award	Project Sponsor
Mark Morrison	Sequencing the Prevotella ruminicola genome for functional and comparative analysis	$440,000	Initiative for Future Agriculture and Food Systems
Roger Williams	University partnership for management and economic analysis of forest products in the Tomsk Oblast	$290,000	Bureau of Educational and Cultural Affairs
Linda Saif	Pathogens of human caliciviruses on growth of field horticultural crops	$290,000	NIH, National Institutes of Allergies and Infectious Diseases

In recent years OARDC research has provided multiple scientific breakthroughs, with some of the most significant highlighted in Table 2. These research projects have resulted in problem resolution for Ohio's farmers, new and enhanced agricultural products for Ohio's producers, and technologies upon which new business enterprises may be built in Ohio. The nature and impact of many of these key breakthroughs are discussed in further detail in "The Impact of OARDC Science, Research, and Development."

Table 2: Leading OARDC Scientific Breakthroughs in Past Decade

Project Title	Nature of Discovery/Advance	OARDC Role	Principal Investigator or Contact
Production systems for Ohio grapes and wines	Produced systems that allowed Ohio to become a major wine producer.	Principal investigator with multiple scientists contributing to several discoveries.	Dave Ferree
High protein food grade soybean	Developed variety of soybean high in protein and can be used for a variety of food grade products.	Principal investigator.	Steve St. Martin
Phytophthora resistant soybean	Initially discovered fungal disease (*Phytophthora*) that had the potential to cause significant damage to Ohio soybeans. Discovered gene responsible for resistance.	Principal investigator.	Anne Dorrance
Detecting beef tenderness and marbling	Discovered genetic markers that, in part, control a cow's ability to produce high-quality, tender beef.	Principal investigator with two scientists contributing.	Daral Jackwood and Francis Fluharty
Infectious animal disease diagnostics	Developed several diagnostic tests for animal diseases.	Principal investigator with multiple scientists contributing to several discoveries.	Mo Saif

Table 2: Leading OARDC Scientific Breakthroughs in Past Decade (continued)

Project Title	Nature of Discovery/Advance	OARDC Role	Principal Investigator or Contact
Composting systems for urban waste	Developed composting systems that have been adopted by urban waste management agencies.	Principal investigator with multiple scientists contributing to several discoveries.	Harry Hoitink
Seed vigor analysis system	Developed computer-based visual-ization system to rapidly determine the vigor of a high volume of seeds for different species of plants.	Principal investigator with multiple scientists contributing to several discoveries.	Miller McDonald
Development of plant varieties to improve Ohio's agriculture	Developed numerous plant varieties with enhanced abilities for yield, disease resistance, and other sources or plant stress through this large-scale program.	Principal investigator with multiple scientists contributing to several discoveries.	Ray Miller
Preservation technologies for a safer food supply	Developed multiple technologies to preserve foods and maintain high quality. Examples include high pressure, ozone, pulsed electric field, low temperature approaches.	Principal investigator with multiple scientists contributing to several discoveries.	Sudhir Sastry
Systems to enhance sports turf applications.	Developed multiple technologies to enhance sports turf applications including varietal development and management systems.	Principal investigator with multiple scientists contributing to several discoveries.	Karl Dannenberger

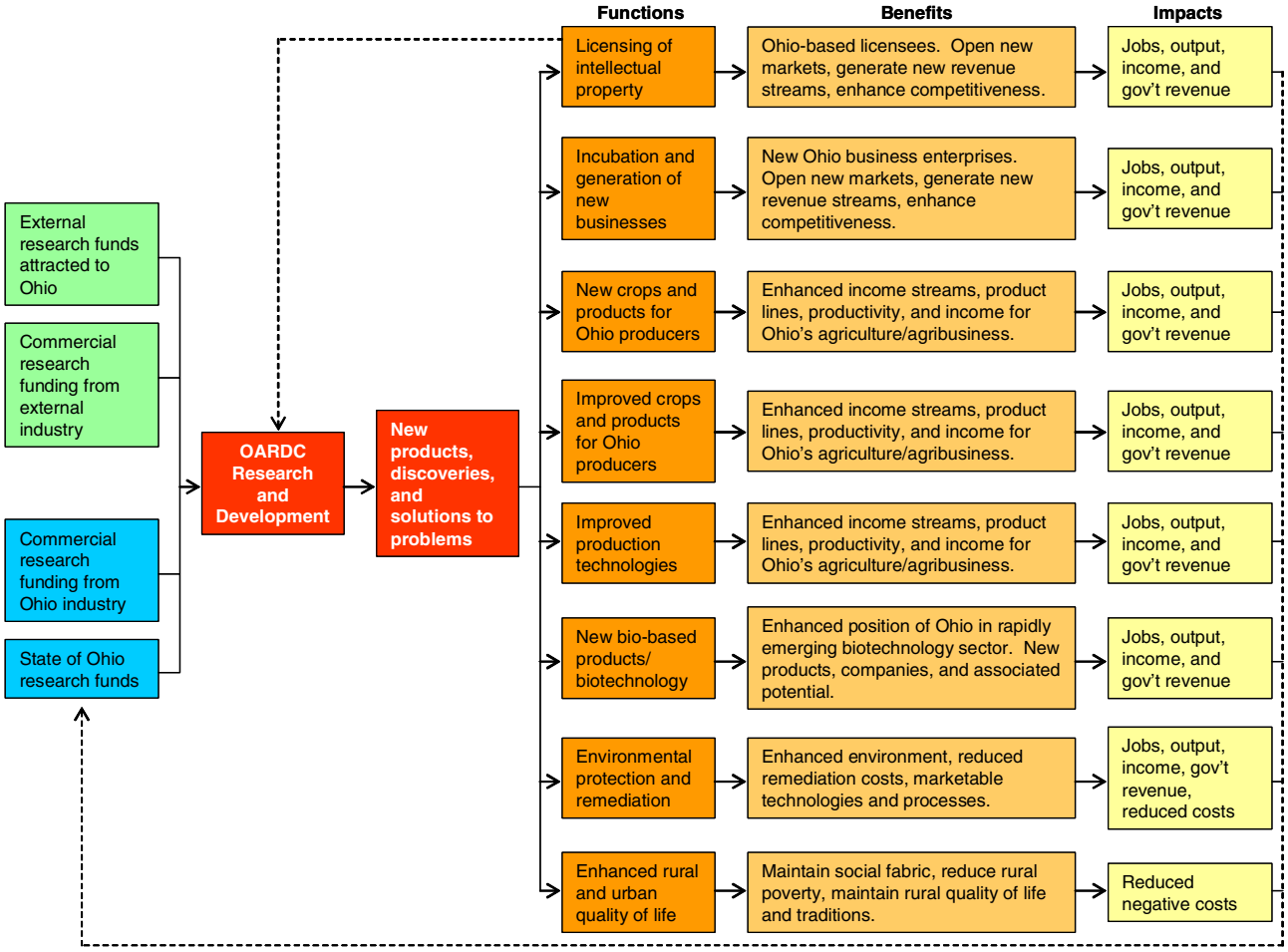
OARDC research and development thus has multiple, positive impacts on the State of Ohio. Figure 2 illustrates the primary impacts generated via OARDC R&D activities and clearly shows that R&D generates a broad range of functions and benefits. Each of these functions and benefits is discussed below.

Licensing of Intellectual Property

In a knowledge-driven economy, intellectual property has become the most valuable property of all. Centers of innovation and economic growth in the United States, be they Boston, San Francisco, the Research Triangle, or Austin, are being driven by clusters of industrial and academic R&D that produce a regular stream of new patentable ideas, technologies, and products. Clearly, the presence and successful operations of high-quality research and development institutions have become a prerequisite for economic advancement in the 21st century.

While software and information technology dominated U.S. technology growth in the 1980s and 1990s, more recently the headlines have been made by life science disciplines. The post-genomic era, with its quantum leap forward in the understanding of fundamental and functional life mechanisms, is spawning new avenues of discovery and innovation.

Figure 2: Principal Impacts Generated by OARDC Research and Development



Against this backdrop of life science prominence, the importance of the OARDC as a generator of intellectual property and scientific discoveries comes clearly into focus. The OARDC has long been a producer of new high-yield plant strains, pest reduction technologies, meat-producing animal varieties, and disease-resistant crops—so the OARDC is an institution with a solid track record of intellectual property generation. **In the current and future decades, the importance of innovation and creativity will continue to rise; and it is likely that the OARDC, with expertise in agricultural life sciences and agricultural biotechnology, will become increasingly important to the Ohio economy.**

The benefits stemming from intellectual property generation are many and include licensing revenue streams to fund further institutional research, partnership relationships with licensing corporations, and gaining a "lock" on a technology enabling further development advancements to be made in a protected environment.

Incubation and Generation of New Businesses

Related to the benefits of intellectual property, OARDC R&D may also directly generate new business enterprises for Ohio. **Technology may be licensed to existing industry, helping them to expand; but, it may also engender the development of new companies dedicated to**

developing, producing, and marketing the OARDC technology or product commercially. While only a relatively recent area of emphasis for the OARDC, business spin-offs from OARDC research are beginning to occur with new companies being formed within the State of Ohio (see Table 3).

Table 3: Ohio-Based Company Formation Based on OARDC Research and Relationships

Company Name	Role of OARDC in Formation
Kurtz Brothers Composting, Columbus, Ohio	Basic science behind composting processes.
Multiple waste management agencies/corps.	Basic science behind waste management processes.
Grape and wine industry in Ohio	Basic science behind grape and wine production processes.
Spray Redux	Basic science behind processes and scientist initiated the business. First OSU start-up company.
ValuMark	Basic science behind processes and scientists initiated efforts to begin business.
Cargill in Sidney, Ohio	Basic science behind processes. High protein food grade soybean.
Motz Turf Systems	Joe Motz is a graduate of the college and OARDC scientists work with him on his products.

Business incubation has become a planned emphasis for the OARDC. The institution has been working closely with the Wayne Development Council in preparing plans for an agricultural bioscience research park to enhance the opportunity for housing business spin-offs close to the Wooster campus and for attracting existing corporations to co-locate, facilitating collaborative R&D with OSU and the OARDC.[8]

New Crops and Products for Ohio Producers

At the very heart of the mission of the OARDC is the provision of service and advice to Ohio's agriculture, agribusiness, and horticultural producers. Since its inception, the OARDC has worked to develop higher-yield crops; disease-, and pest-resistant plant strains; and faster-growing and leaner meat-producing cattle, hogs, and poultry. **As markets become increasingly global, it is important for Ohio producers to differentiate their products as higher quality, of more nutritional value, having more of the characteristics wanted by consumers and processors, or simply of better monetary value—the OARDC helps Ohio's producers achieve these goals.** It has also been a goal of the OARDC to help introduce completely new cash-producing crops and agricultural products to help diversify the income base of Ohio's agricultural producers.

[8] Battelle Technology Partnership Practice. *An Agricultural Bioscience Research Park—Conceptualization Strategy for Wayne County.* Battelle Memorial Institute, June 2003.

The OARDC, as will be discussed in further detail in "The Impact of OARDC Science, Research, and Development," has enjoyed considerable success in the introduction of new crops and products for Ohio producers. Some notable examples include the following:

- The work of the OARDC Grape Research Branch in helping to recreate a successful industry for Ohio in the production of table grapes, grape juice, and wine
- Research on the cultivation of plantation-grown Christmas tree varieties suited to Ohio's climate and soils
- The introduction of aquaculture to Ohio, with OARDC scientists providing advice to producers on fish and fresh water shrimp production methods, nutritional requirements, systems design, systems maintenance, species selection, and water quality management
- The study of the suitability of introducing new berry, vegetable, and fruit crops for farmers in southern Ohio.

Improved Crops and Products for Ohio Producers

While the introduction of new crops and species to Ohio agriculture provides diversity in the agricultural, livestock, and horticultural base of the state, the OARDC's work on improving the characteristics and production of existing crops is also of great economic importance. **To survive in a highly competitive agricultural product marketplace, Ohio's farmers must be at the forefront of productivity and quality in their products; and the OARDC helps them achieve, maintain, and build upon this position.**

The OARDC has a substantial history of providing solutions to productivity and quality issues affecting Ohio's crops and livestock. These solutions fall under several categories:

- *Higher-yield plant varieties*—OARDC scientists have, for example, been active in researching and introducing new varieties of soybean that have optimal yield and protein and oil content characteristics well-suited to the state's growing environments. Similar work has occurred with corn, tomatoes, various vegetable crops, and fruits.
- *Higher-yield livestock and poultry*—OARDC research has been instrumental in increasing the leanness, and therefore value, of Ohio's hogs. The institution has likewise been highly active in beef and dairy cattle breeding—seeking to enhance the volume, quality, and tenderness of beef and the quality and output of milk. Similar work has evolved in poultry production, with important studies enhancing the growth of poultry breast meat and strengthening the legs of birds to support the increased weight.
- *Disease-, pest-, and stress-resistant crops*—From time to time, nature finds a way to decimate key agricultural crops. The failure of a crop can mean economic hardship and even bankruptcy to farmers producing in highly competitive markets. In the 1960s, the OARDC responded rapidly to produce new corn varieties resistant to the maize dwarf mosaic virus that was ravaging Ohio's corn crop. Similar advancements have continued; today, the OARDC is working on disease- and pest-resistant soybeans, strawberries, tomatoes, parsley, grapes, turf grasses, and many other grain, vegetable, root, and horticultural plants. The OARDC also plays an important role in evaluating plants for stress resistance, such as recent Center research on the genetics of cold temperature, drought, and flood tolerance.

- *Responses to livestock diseases*—As with crops, Ohio's farm animals and livestock can be victims of newly emerging or resurrected diseases. OARDC scientists have been active in the early diagnosis of disease and the development of treatments and disease management. A current program, for example, is focusing on rapid detection of prion-based neurodegenerative diseases such as scrapie, bovine spongiform encephalopathy, and chronic wasting disease. Another OARDC scientist is a world leader in the development of vaccines for rotaviruses and caliciviruses, which cause often fatal intestinal disease in young livestock and in human children.

Improved Production Technologies

Production efficiencies and increased quality and capacity may not be accomplished only through higher-yield plant varieties or disease-, pest-, and stress-resistant strains—they may also be accomplished through research into optimal growing conditions, soil management, nutrition, and crop-rotation strategies. Since its dramatic early success in restoring Ohio's soil fertility, the OARDC has remained active in optimizing the growing environment for Ohio's farmers, agronomists, and horticulturalists. OARDC research is taking place, for example, on the application of animal manures, soil carbon sequestration, soil nutrients, soil conservation, till/no-till practices, water quality, composts, crop residue management, and soil microbiology.

New Bio-Based Products and Biotechnology

The lines between agricultural bioscience, human and animal biotechnology, and industrial biotechnology are blurring. Indeed, the agglomeration of these disciplines can be observed in the large-scale mergers occurring in the corporate arena. Novartis, for example, formed from the $27 billion merger of pharmaceutical company Sandoz and agrochemical company Ciba-Geigy. Novartis is now the world's largest agrochemical company, the second largest seed company, the second largest pharmaceutical company, and the fourth largest veterinary medicine company. Monsanto and DuPont have been equally involved in the acquisition and merger of biotechnology assets into their corporate portfolios. The reason for these mergers can be found in the bioproduct potential of the global gene pool—be it plant, animal, insect, or other forms of life. While there are certainly risks to populating the planet with genetically engineered life, there are considerable economic and social benefits to be realized from the revolution occurring in agricultural-biotechnology and the life sciences.

Because a genetically engineered seed, plant, or organism can be patented, the global gene pool presents considerable opportunity for the generation of commercially protected transgenic, bio-based products. Many areas of opportunity exist, with some examples including the following:

- *Novel plant products*, either existing plants with enhanced favorable characteristics or new plant "species" generated through gene splicing (such as crossing soybeans with tomatoes or inserting the "antifreeze" gene from a fish into vegetables to promote cold resistance)
- *Nutraceuticals*, comprising foods or parts of food providing medical or health benefits such as dietary supplements
- *Drugs and therapeutics* produced through plant pathways (biopharming)

- *New uses for traditional crops* (such as the generation of biofuels and the manufacturing of plastics)
- *Bioremediation*, which uses plants or microorganisms to clean up pollution or waste or to solve other environmental problems
- *Transgenenic livestock*, producing therapeutic biologics, such as anti-thrombin and human hemoglobin and organs for xenotransplantation
- *Genetically engineered predator insects* for pest control.

To many readers, these biotechnology concepts may read like science fiction. But, in every one of the above cases, experiments have been successfully conducted and, in many of these cases, products have been successfully brought to market.

The 21st century is being called the "Biotech Century," and it is extremely important to acknowledge that agricultural research and development organizations have as big a role to play as academic medical centers and other leaders. The planet's biomass presents a gene pool of almost unimaginable size and potential—having a resource with experience to analyze, assess, synthesize, transform, and realize pragmatic, commercial opportunity from these biomass resources is likely to be a substantial economic development advantage. Ohio has this resource within the OARDC and The Ohio State University. Indeed, Ohio's academic community has recognized the preeminent importance of biotechnology by forming the Ohio Plant Biotechnology Consortium, whereby 11 universities in Ohio are pooling their plant technology resources under the administrative leadership of the OARDC.

The promise of biotechnology is beginning to be realized through work at the OARDC. Examples include work on rapid deoxyribonucleic acid (DNA)-based identification of foodborne pathogens, bioremediation technologies, the genetic engineering of soybeans and other crops with enhanced favorable characteristics, and the biotechnology of cold tolerance and chill resistance in food crops.

Environmental Protection and Remediation

Preserving Ohio's environment and ecosystems is an integral part of the mission and operations of the OARDC. Research in these areas is benefiting Ohio through multiple pathways including enhanced public health, reduced environmental degradation and associated costs, a more appealing environment for attracting human capital, and new environmental technologies and discoveries that present commercialization opportunities.

Human and environmental health risks from solid waste landfill leachate have been the subject of OARDC study, for example, with investigations conducted of more rapid bioreactor degradation of community waste. OARDC researchers are also leaders in examining the potential for carbon sequestration in soils—an activity that would reduce carbon's negative impact on water quality and the ozone layer and enhance the quality and water absorption rates of soil. At the OARDC's North Appalachian Experimental Watershed substation, research is being conducted on slope soil and water conservation via crop production methods and on the movement of pesticides and fertilizers through ground and surface water.

The link between biotechnology and bioremediation will likely intensify over the next decade. The use of organisms and plants to sequester and degrade noxious and hazardous chemicals and

other pollutants may evolve into a major industry. The United States generates more than 200 million tons of hazardous materials annually, and the cost of remediating toxic waste is estimated to be in excess of $1.7 trillion.[9] The OARDC, with expertise in a wide range of environmental science fields, may be well positioned to assume a leading position in this area.

Enhanced Rural and Urban Quality of Life

The OARDC's research also has an important role to play in enhancing the quality of rural and urban life. This is addressed through multiple fields of study at OARDC, ranging from agricultural economics and economic development assessments, to family welfare social studies and fatherhood projects. OARDC's research also contributes to the quality of Ohio's urban and rural landscape via intensive horticultural and forestry studies aimed at identifying, promoting, and promulgating the best ornamental plants, shrubs, and trees for Ohio's individual community growing conditions.

Education and Workforce Development Impacts

If research and development activities are of critical importance to Ohio's future, so too are initiatives aimed at enhancing the quality and educational attainment of Ohio's workforce. Indeed, innovation and creativity will be less likely to occur without a highly skilled and educated "creative class."[10] The application of ever-advancing agricultural science and technology at the production and processing level requires a technologically and functionally literate workforce. If former OARDC Director Leo Rummell was correct in noting that "science is ploughed deeply into farming," then it should also hold that science must be ploughed deeply into the farmer.

Practitioner education, workforce development, and even consumer education are, therefore, important components of a well-rounded OARDC mission. To a degree, the majority of education occurs outside of the true day-to-day operations of the OARDC. Undergraduate education in agricultural sciences is the responsibility of the OSU College of Food, Agricultural, and Environmental Sciences and the Ohio Agricultural and Technical College in Wooster (which does use the resources of the OARDC), while the instruction of farming practitioners on new techniques and advanced practices falls under the remit of OSU Extension. The OARDC does provide, however, an integral and important link in this educational chain. OARDC scientists and researchers are also faculty within the OSU College of Food, Agricultural, and Environmental Sciences with significant teaching responsibilities. The OARDC, an important participant in advanced postgraduate education in agricultural and life sciences, maintains a highly active communications program that publishes and disseminates frequent bulletins and reports containing information on recent discoveries, technologies, advanced agricultural practices, and techniques. The OARDC is also the producer of leading-edge research on agriculture, horticulture, livestock, and agribusiness that feeds into the curricula of education programs in the state.

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[9] Rifkin, Jeremy. 1998. *The Biotech Century: Harnessing the Gene and Remaking the World.* New York, NY: Putnam Publishing, p. 17.

[10] Florida, Richard. 2002. *The Rise of the Creative Class, and How It's Transforming Work, Leisure, Community and Everyday Life.* New York, NY: Basic Books.

COMMUNITY SERVICE IMPACTS

While physical sciences lie very much at the heart of the OARDC's activities, the social sciences also play a very important role in the knowledge produced by the OARDC and the benefits provided by the Center to society in Ohio. The OARDC's mission statement emphasizes that the institution works "to enhance the well-being of the people of Ohio, the nation and world through research on foods, agriculture, family and the environment."[11] The OARDC sees enhancing and preserving the quality of life of rural and urban families as clearly within its remit and accomplishes its goal through research and practice in a broad range of related fields:

- The OARDC conducts research and publishes bulletins on economic development and rural and agricultural economics serving to inform and educate Ohio's farming and horticultural families and communities.
- The OARDC investigates and resolves land-use problems at the rural/urban interface where sprawl threatens the availability of land for agricultural production.
- The OARDC conducts risk assessments, analyses of futures markets, and other pragmatic analyses aimed at giving Ohio's farmers and producers a competitive edge.
- The OARDC studies the social conditions and underpinnings of rural and urban families and provides solutions to contemporary societal problems negatively impacting family and quality of life in Ohio.
- The OARDC actively studies changing patterns of rural workforce employment and develops strategies aimed at enhancing community response to labor market and employer shifts, changes, and closures.

In traditional economic impact terms, many of these benefits are hard to measure quantitatively in terms of their dollar impact on Ohio. While we can accurately measure the impact of research dollars brought into the state, a new company formed from OARDC technology, or the net gain in producer productivity realized through an OARDC discovery, **it is extremely difficult to apply quantitative metrics to families held together or rural societal structure being preserved. These "softer" social goods are no less important, however, just because the impacts are challenging to measure.**

EMERGING OPPORTUNITIES, RESPONSIBILITIES, AND NEW INITIATIVES

OARDC has a long history of being at the leading edge of agricultural and horticultural science. **In the genomic and post-genomic era, the rapid advancement in the life sciences will likely bring many new challenges and opportunities to Ohio and the OARDC.**

The genomic and biotech revolution is paving the way for the creation of significantly altered plant, and animal, life forms. Gene transfer can now be achieved across totally unrelated species and previously impenetrable biological boundaries. Before the genomic revolution, disease- and pest-resistant crops had to be developed through traditional plant breeding techniques. Post-revolution, positive genetic traits of one species can be transferred to the DNA of a completely unrelated species—allowing, for example, "antifreeze" protein genes from flounders (a fish) to

[11] OARDC Website at http://www.oardc.ohio-state.edu/www/missvis.asp.

be transferred to a tomato to engender enhanced frost resistance. This one example serves to show the almost infinite possibilities for novel plant and animal strain development that may result from gene transfers.

Tremendous benefits may result from the application of genomics to plant and livestock biotechnology, some examples being

- Substantially enhanced crop and meat yields
- Production of drought- and flood-resistant crops
- Production of disease- and pest-resistant crops and animals
- Introduction of vitamins and other nutrients to supplement human or livestock diets via their normal staple crops
- Production of vaccines, enzymes, proteins, and drugs via plant and animal pathways
- Production of crops with optimized biomass fuel potentials.

In the field of plant biotechnology, as noted earlier, Ohio has formed an alliance of higher education and research institutions targeted on advancing Ohio's position. The Ohio Plant Biotechnology Consortium pools the intellectual and scientific infrastructure resources of 11 institutions[12] in efforts to optimize Ohio's early position in plant biotech. The Consortium's early areas of exploration include novel plant products, nutraceuticals, new uses for traditional crops, plant nutrition, plant bioremediation, pest resistance, and recombinant DNA technology.

The OARDC will play a central role in Ohio's future plant and animal biotechnology initiatives. This central role is dictated by OARDC's institutional emphasis on agriculture and the life sciences and by the considerable infrastructure of science and investigational assets owned and operated by the OARDC. The OARDC brings a formidable arsenal of major scientific and research resources and equipment to facilitate the enhancement of Ohio's position. These resources include the following:

- The Molecular and Cellular Imaging Center, including scanning electron microscopes, transmission electron microscopes, a confocal microscope, DNA sequencer, and Q-Pix
- STAR laboratory for soil and organic materials testing
- Germ-free laboratory operated by the Food Animal Health Research Program
- Compost Research Facility and Experimental Outdoor Pad
- Krauss Dairy
- Greenhouses
- Food Science Pilot Plant (Columbus campus)
- Waterman Research Farm (Columbus campus)
- Wetlands Research Park (Columbus campus)

[12] Membership of the consortium includes The Ohio State University (with consortium administration operated by OARDC), Bowling Green State University, Cleveland State University, Kent State University, Medical College of Ohio, Miami University, Ohio University, University of Cincinnati, University of Toledo, Wright State University, and Youngstown State University.

- Laboratory for Pest Control Application Technology (LPCAT)
- Miscellaneous equipment, including, for example, real-time LightCycler polymerase chain reaction (PCR), C/N Analyzer, Tandem mass spectrometer
- Wooster campus service departments—Library, Computing and Statistics, Communications and Technology, Facilities Services, Human Resources, Fiscal Office
- OARDC Branches (10 research farms distributed across Ohio)
- The Secrest Arboretum and its botanical resources.

OARDC is also in the process of adding additional infrastructure and scientific resources. These include a Plant and Animal Agrosecurity Research facility, which is initiated and in the design phase and will contain Biosecurity Level-3 (BL-3) containment. In addition, the commercialization of research discoveries and the facilitation of industry-OARDC interactions would be enhanced through the BioHio Research Park in Wayne County, which is currently in the feasibility and planning stages.

Multiple areas of research and institutional focus are emerging within the OARDC and serve to highlight areas of future science likely to emanate from the Center. These initiatives include the following:

- The emerging infectious diseases research program, which will be further facilitated by the assets of the Plant and Animal Agrosecurity Research facility
- The OARDC/OSUE Economic Development Initiative (funded in part by FY 2004–2005 Ohio State Budget)
- A bio-based energy program
- An Ornamental Plant Germplasm Center, serving as a central resource and repository of unique and valuable genetic material
- Multiple OARDC-funded interdisciplinary programs
    - The Agroecosystems Management Program (AMP)
    - Ohio Composting and Manure Management (OCAMM) Program
    - Organic Food and Farming Education and Research (OFFER) Program
    - Further development of the Ohio Plant Biotechnology Consortium
- Multiple extramurally funded interdisciplinary programs
    - Ornamental Plant Germplasm Center (USDA)
    - Ohio Aquaculture Program (federal)
    - Center for Advanced Processing and Packaging Studies (CAPPS), National Science Foundation (NSF)
    - Center for Innovative Food Technology (CIFT) (USDA)
    - Infectious Diseases Program (federal).

SUMMARY

In the OARDC, Battelle therefore finds an institution that has several defining characteristics. The OARDC is an institution:

- Conducting leading-edge scientific research aimed at enhancing agriculture, agribusiness, and biotechnology in Ohio
- Having a pragmatic mission—working to translate its research findings into practical solutions for Ohio's agricultural practitioners and agribusinesses
- Generating new patentable intellectual property and commercializable discoveries for implementation in the state
- Consulting and working with Ohioans to find solutions to their agricultural, horticultural, livestock, environmental, and social problems and challenges
- Working to educate and enhance the skills of Ohio's workforce
- Dedicated to meeting the social challenges of rural communities in an increasingly urbanized and globally competitive society.

The opportunities and potential impacts presented by these various new and emerging OARDC initiatives are examined further in "Additional Impacts of the OARDC." The Battelle Technology Partnership Practice will also be working with the OARDC in a Phase II project to determine the core competencies of the OARDC and how these may best be directed toward generating new markets and opportunities for agricultural and biotechnology-oriented businesses in the state.

The Current Economic Impact of the OARDC on the State of Ohio

INTRODUCTION

R&D activities undertaken by the OARDC produce measurable economic impacts in two general areas:

- Backward Effects. Research projects funded by local, state, and federal institutions and by private industry bring in dollars that are used to support R&D teams and associated ancillary staff activities creating salary, wage, and other related impacts on the state economy.
- Forward Effects. Funded research produces technologies, expertise, and services that may increase the efficiency and productive capacity of client industries, which in turn impact the economy of the state.

This section of the report describes the data and methods used to estimate backward effects, together with a description of the results and findings of the analysis. Forward effects are discussed in "The Impact of OARDC Science, Research, and Development." Estimation of the backward effects associated with OARDC research and development activities includes

- Direct impacts of OARDC wage, salary, and other spending associated with the Center, using expenditure data provided by the OARDC[13]
- Indirect impacts of OARDC research activities using an IMPLAN input/output framework. [14]

DATA, METHODOLOGY, AND IMPACT MEASURES USED TO ESTIMATE OARDC IMPACTS

Expenditure data used to estimate impacts were provided by the OARDC and included detailed accounting of wages and salary expenditures, benefits, capital projects, and materials and supplies. The OARDC receives funding for research and development activities from two separate sources:

- Direct funding from state and local sources (OARDC)
- Funding support from The Ohio State University Research Foundation (OSURF). The Foundation provides support to faculty and staff at the Center from funding it receives from various federal government and other national research funding institutions in support of research activities in the University as a whole.

A number of adjustments were made to the detailed data provided on wage and salary expenditures from OSURF funds. These data included all project expenditures for university faculty and staff members receiving funding through the OARDC, with many faculty and staff wages and salaries funded from multiple sources. These data were therefore adjusted to include

[13] In 2003, OARDC provided to Battelle Excel spreadsheets detailing annual labor, capital, and materials and supplies expenditures, and employment.

[14] IMPLAN 2003, Minnesota IMPLAN Group, 1725 Tower Drive West, Suite 140, Stillwater, MN 55082. State of Ohio data files on CD-ROM.

only that portion of project expenditures funding Center activities, using the annual OSURF research expenditure total and assuming the same cost breakdown structure for these expenditures as those made using OARDC funds. A similar approach was followed for materials and supplies and capital expenditures. Current year capital expenditure data used a five-year average figure (to smooth any atypical construction or capital equipment expenditures).

For wages and salaries, capital projects, and materials and supplies, it was assumed that all Center expenditures occurred within Ohio, while it was assumed that all employee benefits paid from OARDC funds and a small amount of funding for independent contractors supported with OSURF funds were spent outside the state (with national service providers) and therefore excluded from the impact analysis.

The Data: OARDC Institutional Expenditures

Direct funding from state and local sources currently stands at about $51 million, supporting approximately 75% of overall OARDC expenditures (Table 4). The remaining $16 million comes from OSURF. Total funding from both sources has risen slightly for FY 2003 compared with a steady funding level over the previous two fiscal years. OSURF funding for Center activities has risen over the past three years, from $11 million in FY 2001 to the current level of $16 million.

Table 4: Total OARDC Expenditures, 2001–2003 (millions of dollars)

	2001	2002	2003
OARDC-Funded Activities	51.7	50.0	50.8
OSURF-Funded Activities	11.1	12.9	16.2
OARDC Total	**62.8**	**62.9**	**67.0**

Source: OARDC 2003.

In 2003, 532 full-time employees (FTEs) were supported by OARDC funding (Table 5), with an additional 230 FTEs receiving support through OSURF.

Table 5: Current OARDC Employment (number)

	OARDC-Funded	OSURF-Funded	Total
Research Faculty and Staff	532	230	762

Source: OARDC 2003.

Approximately half of the OARDC's expenditures in 2003 ($34 million) supports the wages and salaries of faculty, staff, and students working on research projects (Table 6). The research mission of the Center also means that capital projects, which include both renovation of existing facilities and the construction of new research facilities (almost $6 million), and the laboratory materials and supplies used to operate these facilities (more than $20 million), constitute almost 40% of overall annual Center expenditures.

Table 6: Direct OARDC Expenditures, 2003 (millions of dollars)

	OARDC-Funded	OSURF-Funded	Total
Salaries and Wages	27.7	5.9	33.6
Independent Contractors	0.0	0.1	0.1
Benefits	7.5	*	7.5
Capital Projects	5.6	0.1	5.7
Materials and Supplies	10.0	10.2	20.2
Total	**50.8**	**16.2**	**67.0**

** included in the entry for "materials and supplies."*
Source: OARDC 2003.

Methodology Used to Estimate Indirect Impacts

Estimations of indirect impacts were based on direct labor expenditure data for specific income categories and procurement data for capital projects and materials and supplies. Expenditure information was associated with the relevant Bureau of Economic Analysis (BEA) sectors in an IMPLAN input/output model specified for the State of Ohio.

The IMPLAN input/output model is a PC-based program that allows construction of input/output models for counties or combinations of counties for any location in the United States. Input/output data are the economic accounts of any given region and show the flow of commodities to industries from producers and institutional consumers. The accounts also show consumption activities by workers, owners of capital, and imports from outside the region. The IMPLAN model contains 528 sectors, representing industries in agriculture, mining, construction, manufacturing, wholesale and retail trade, utilities, finance, insurance and real estate, and consumer and business services. The model also includes information for each sector on employee compensation; proprietary and property income; personal consumption expenditure; federal, state, and local expenditure; inventory and capital formation; and imports and exports.

The model was used to estimate multipliers for each sector where labor and procurement expenditures occur. Multiplying expenditures in these sectors by the sector multipliers and summing across all sectors impacted by Center expenditures produces estimates of impacts of the OARDC on the state.

Impact Measures

The impacts of OARDC research and development activities on Ohio are measured using four economic and two fiscal variables. The economic variables are

- **Output.** The total value of production (sales) in all industries as a result of expenditures by the OARDC.
- **Value added.** An overall measure of individual and institutional income produced by OARDC activities. Value added includes labor income (employee compensation), income to self-employed persons (proprietor income), rents, royalties and dividends, and indirect business taxes (primarily property taxes).
- **Income.** Employee compensation. In addition to being included in value added, the impact of the Center on labor income was also specified separately in the analysis.

- **Employment.** The total number of jobs in all industries created by the OARDC. To include both full- and part-time workers, jobs are measured in terms of full-time equivalents.

In addition, the analysis also estimated the tax impacts of OARDC activities:

- **Sales taxes.** The analysis estimated direct sales tax revenues by multiplying the value of capital project expenditures and materials and supplies expenditures by the current sales tax rate in Ohio of 5%. Indirect sales taxes were calculated using the value of the additional indirect output (sales) generated by OARDC wages and salary spending, procurement of materials and supplies, and capital projects and the Ohio sales tax rate.
- **State personal income taxes.** State income tax revenues were estimated by multiplying the value of direct and indirect personal income generated by OARDC activities by the state tax rates for six separate taxpayer income categories.

THE IMPACT OF THE OARDC ON THE OHIO ECONOMY

Taking OARDC and OSURF funds together, **OARDC research and development activities in FY2003 will produce almost 1,580 full-time equivalent total (direct and indirect) jobs in Ohio, and more than $54 million in total income** (Table 7). **The Center will produce more than $81 million in value added and more than $142 million in output in the state, $3.1 million in total sales taxes and $2.5 million in total state personal income taxes.**

Disaggregating these funds shows that funding of OARDC activities by state and local government produces more than 530 direct jobs and almost $23 million in direct income. Direct expenditures on wages and salaries, capital projects and materials and supplies by the Center produce an additional 579 indirect jobs and more than $18 million in indirect income in the state. More than 1,100 total (direct plus indirect) jobs and more than $41 million in total income are created. OARDC funding by the Center produces almost $63 million of direct and indirect value added, and almost $107 million in total output in the state. State and local government funding of the Center also produces $1.9 million in personal income taxes and $2.1 million in sales taxes.

Furthermore, funding by OSURF creates 230 direct FTEs and almost $5 million in direct income for Ohioans. Direct expenditures supported by OSURF funding produce an additional 236 indirect jobs and more than $8 million in indirect income. Almost 470 total (direct plus indirect) jobs and $13 million in total income are created. OSURF-funded research and development activities produce more almost $19 million in direct and indirect value added and more than $35 million in output. OSURF support to the Center also produces almost $0.6 million in income taxes and $1million in sales taxes.

Table 7: Total Impact of the OARDC on the Economy of Ohio, 2003
(millions of dollars, except where noted)

	Output (Sales)	Value Added	Income	Employ-ment (number)	State Income Tax Revenues	Sales Tax Revenues
OARDC-Funded Activities						
Direct Impacts	50.8	34.5	22.7	532	1.1	0.8
Indirect Impacts	56.1	28.1	18.4	579	0.9	1.3
OARDC Total	107.0	62.6	41.2	1,111	1.9	2.1
OSURF-Funded Activities						
Direct Impacts	16.2	7.3	4.8	230	0.2	0.4
Indirect Impacts	19.2	11.2	8.2	236	0.4	0.6
OSURF Total	35.4	18.6	13.0	466	0.6	1.0
Aggregate OARDC Impact	**142.3**	**81.2**	**54.2**	**1,576**	**2.4**	**3.1**

Note: Data in tables may not sum to column totals due to independent rounding.

It is important to note that Center activities funded by OARDC funds have a somewhat different impact to those activities supported through the University by OSURF funds. From Table 7, it will be seen that the indirect employment and output impacts of OARDC-funded activities are larger than the corresponding direct effects, while the indirect value added and income impacts are smaller than their direct counterparts. In contrast, the indirect impacts of OSURF-related expenditures are larger for each measure than the corresponding direct impacts. Differences in the relative importance of the indirect impacts of expenditures between funding sources are due partly to differences in the labor expenditure profile supported by each source, and partly to the relative importance of expenditures on capital projects and materials and supplies expenditures.

OARDC funding supports a large number of relatively highly-paid faculty and staff positions, producing larger direct income and value added impacts, while the majority of OSURF labor expenditures support lower income positions, particularly those held by students. This is also reflected in the relatively small direct personal income tax revenue impact of $0.2 million of OSURF-funded activities. Expenditures on materials and supplies also make up a larger portion of total OSURF expenditures, which together with larger multipliers associated with spending in these sectors of the economy, boost the indirect impact of funding from OSURF sources.

The input/output modeling shows the linkages in the economy between the OARDC's expenditures and each sector of the Ohio economy. The sector impacts of the OARDC expenditures on employment across other Ohio sectors are shown in Appendix A.

The Impact of OARDC Science, Research, and Development

In the previous chapter, Battelle outlined the economic impacts generated for Ohio by the operating expenditures of the OARDC and the spending of its scientists, faculty, and staff. In and of itself, this expenditure impact is significant, accounting for $136.7 million of Ohio economic output and more than 1,600 jobs for Ohioans. It is, however, only one dimension in a much larger, multidimensional impact generated for Ohio by the OARDC.

As noted in the introduction to this report, the 21st century will see the U.S. economy increasingly driven by "knowledge" and technology. **The major leaps forward being accomplished in the plant and life sciences (both genomic and nongenomic) are going to be particularly strong drivers of North American progress. As such, having a solid base of research, development, and innovation in plant and life sciences and associated technologies may be considered a prerequisite for a state's future economic competitiveness.**

OARDC—A Valuable R&D Asset for Ohio

The OARDC is, therefore, a valuable asset for Ohio—an applied plant and life sciences research and development institution, dedicated to improving agriculture, horticulture, and quality of life in Ohio. The R&D activities of the OARDC are focused on finding ways to improve crop productivity, fight plant and animal diseases, improve the quality of agricultural products, and significantly increase agriculture and horticulture-related economic output for the state. The OARDC's most prominent impacts are rooted in the scientific inquiry and applied R&D activities conducted in Wooster, Columbus, and the OARDC branch stations. These R&D activities are a key component in an integrated circle of service conducted by The Ohio State University under its land grant mission—a circle in which

- OARDC scientists and researchers discover knowledge and produce practical solutions to challenges facing Ohio.
- OSU and Agricultural Technical Institute (ATI) students learn the latest in scientific discoveries and take them into the workforce.
- Ohio State extension professionals disseminate the information to adult learners and agricultural practitioners.
- Extension, through its presence in every Ohio county, learns the emerging needs of Ohioans and feeds that information back to researchers to initiate the next circle of progress.

It is unusual in the field of science for the work of an academic institution to be so dedicated to the discovery and dissemination of solutions to industry and community challenges. In the OARDC, Ohio has such an institution; and Battelle has worked to identify some key examples of OARDC R&D and other benefits for the state that may serve to illustrate the size and scope of impacts realized.

The OARDC is home to 256 research scientists focusing all or part of their time on OARDC-supported research projects. Typically, this research population is involved in the conduct of more than 400 OARDC-supported research projects at any given time. It should not be

surprising that such an intensity of focused applied research has resulted in significant discoveries that have had far-reaching benefits for Ohio agriculture, horticulture, food-processing, and related industries.

IMPACT CASE STUDIES

Given the volume of R&D activities performed by the OARDC, it was not practical for Battelle to track the impact or potential impact of each and every OARDC research initiative. Rather, Battelle TPP researchers examined recent and current research projects undertaken by the OARDC and selected a range of projects in which to undertake "impact case studies." Using interviews, fieldwork, and impact estimation tools, the Battelle team investigated multiple OARDC R&D initiatives to examine the core scientific underpinnings of the research, the key discoveries involved, the practical impact of the discoveries on Ohio, and the future opportunities this R&D may present. It should be noted that these are just examples of the type of research conducted by the OARDC—they represent only a handful of initiatives among the 400+ projects taking place at any given time.

Under the heading of "Basic and Applied Scientific Research," Battelle introduces multiple impact case studies, covering

- Soybeans
- Tomatoes
- Livestock, poultry, and animal health
- Ohio's grape and wine industry
- Food safety and processing technologies
- Composting and potting soil technologies.

Under the heading of "Technology Transfer and Commercialization," case studies investigate the work of the OARDC in developing valuable intellectual property for the state and in seeding new commercial ventures to expand Ohio's business base. Three recent projects are examined:

- Double nozzle spraying technology by Spray Redux
- Beef marbling, tenderness, and animal health diagnostic and predictive technologies
- Technologies for the enhancement of seed vigor analysis.

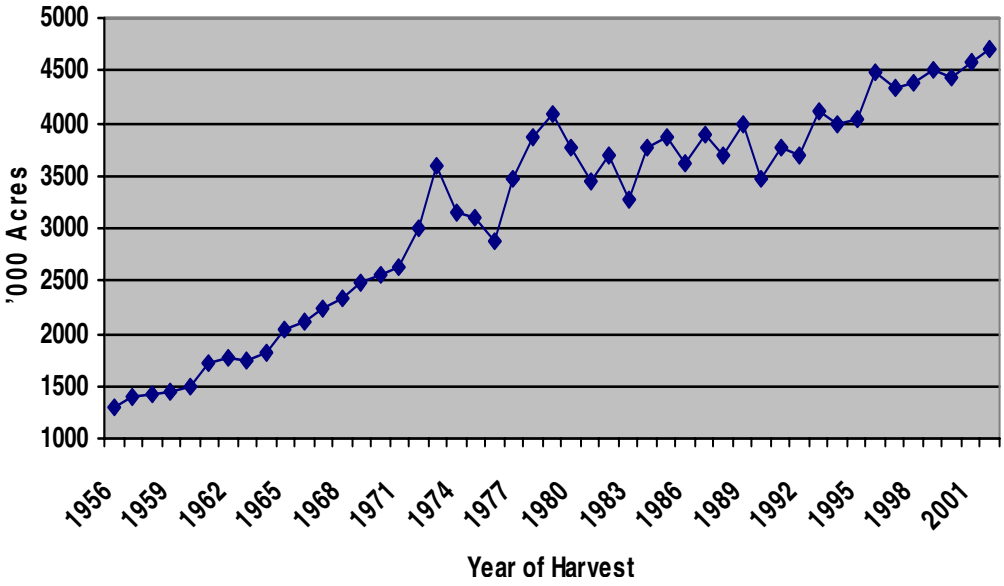
BASIC AND APPLIED SCIENTIFIC RESEARCH

At the heart of the OARDC mission is the application of advanced scientific research expertise to finding solutions for challenges facing agriculture and related sectors of the Ohio economy. This is the institutional mission envisioned by Congress when it passed legislation establishing America's land grant universities, and it is a mission that has been central to the OARDC since its establishment as the Ohio Agricultural Experiment Station in 1882. Some specific examples show the types of positive impacts that may be generated by applying R&D.

OARDC Impact on Ohio Soybeans

In terms of acreage planted, soybeans represent the leading use of agricultural land in the State of Ohio. In 2002, soybeans were harvested from 4,710,000 acres of Ohio farmland, an all-time high for the state. With total farm land in Ohio covering 14,700,000 acres, the importance of soybean farming is placed in perspective—accounting for 32% of all farmland in the state. Soybeans have grown steadily in importance as a staple crop for Ohio, with this growth trend illustrated in Figure 3.

Figure 3: Ohio Soybean Harvest Growth Trend, 1956–2002



Source: Ohio Department of Agriculture, 2002 Annual Report and Statistics.

Soybean yields, in terms of bushels per acre, also have increased significantly over this same time period. Ohio's soybean producers have been harvesting circa 40 bushels per acre in recent years, versus an average of 35 in the 1970s and 1980s, and under 30 in prior decades.

In 2001, the 4,580 acres of Ohio soybeans harvested yielded an average of 41 bushels per acre (higher than the U.S. average of 37.8 bushels per acre). **At a market price per bushel of $4.46, soybean farming alone represented an $837 million business enterprise for Ohio.**

Soybean plants are highly sensitive to soil and environmental conditions. Because of this, soybean varieties that grow well in Indiana or Michigan will not necessarily thrive, or even survive, in the specific growing conditions of Ohio. In-state soybean R&D is critical to maintaining a competitive soybean crop in Ohio. Major seed producers, such as Monsanto and DEKALB, seek to provide high volumes of seed suited to a broad range of environments—but, the environment-sensitive characteristics of soybeans make them a poor candidate for such "generic" production. It is, therefore, uneconomic for the major seed companies to engage in the intensive R&D required to develop soybean varieties suited to the huge variety of climatic, soil, pest, and endemic disease characteristics that exist across the states. A homegrown soybean R&D initiative is thus a prerequisite for maintaining a competitive soybean industry in a state.

In Ohio, the soybean industry is made possible by the continued R&D of the OARDC, which has bred and developed the leading varieties of high-yield, disease-resistant soybeans required for successful production under the state's growing conditions.

OARDC research has led to the release of key varieties of soybeans suited to Ohio's conditions. Table 8 (on following page) presents the acreage of OARDC-developed certified soybean seed produced in Ohio from 1985 through 2002. Using these data in combination with State of Ohio data on total soybean production, Battelle calculated the amount of each year's harvest likely to comprise OARDC-developed soybean varieties. These data show the importance of OARDC-derived varieties on the soybean industry in the state. Indeed, the impact of OARDC varieties is likely significantly higher than that shown because many private varieties of soybean grown in Ohio are hybrids of earlier OARDC varieties or contain the germplasm from OARDC varieties that are not accounted for in the table. The calculations also do not account for any yield advantages of the OARDC varieties or quality characteristics that may result in a higher than average crop price. The data presented should thus be viewed as the low end of estimated direct farm revenue impacts of OARDC soybean research.

To further investigate the actual dollar impact of OARDC-released soybean varieties, Battelle developed an input/output model of the state's soybean industry. The model produces conservative estimates of impact, using just one extra bushel per acre yield premium for OARDC varieties and not accounting for private soybean seeds that may be hybrids of earlier OARDC varietal releases. The results of this analysis are shown on Table 9.

Table 9: Economic Impact of OARDC-Developed Soybean Production on the Ohio Economy, 2003

	Output (Sales)	Value Added	Proprietor Income	Income	Employment
Direct	$72.5	$29.1	$13.3	$5.0	1,730
Indirect	$118.5	$55.2	$16.0	$32.4	2,300
Total	**$191.0**	**$84.3**	**$29.3**	**37.4**	**4,030**

Figures in millions, except for employment.

The input/output analysis shows that, under a conservative model, OARDC soybean releases account for $191 million in annual economic output and generate over 4,000 jobs in Ohio. This impact considerably exceeds the institutional expenditure impact of the OARDC, thereby demonstrating the substantial extended positive impacts engendered by the institution in the state via its R&D activities.

OARDC's impacts on Ohio soybeans are further extended through multiple additional research and development pathways, including disease and pest resistance and varieties for export.

Table 8: A Conservative Estimate of OARDC-Derived Soybean Impacts

Based on producing acreage of certified seed from OARDC-developed varieties

Year	Ohio FG1	Ohio FG2	Century 84	Chapman	Darby	Defiance	Edison	Erie	Flint	Flyer	General	Kottman	Resnik	Sandusky	Sherman	Thorne	Tiffin	Vertex	Zane	Totals
1985			2																140	**142**
1986			3,289												14				4,811	**8,114**
1987			9,440												336				1,956	**11,732**
1988			14,225										58						2,006	**16,289**
1989			10,882										13,586						790	**25,258**
1990			6,029							4,941			16,181						381	**27,532**
1991			3,596							4,303			18,663						37	**26,599**
1992			1,220	1,808			2,553			6,171			22,586						34	**34,372**
1993			828	2,120			4,552	251		6,070			24,573						35	**38,429**
1994			672	2,678			4,447	297		5,457			22,316			3,378			30	**39,275**
1995	28	14	363	1,187			3,447			4,321			13,737	2,995		5,672		524	20	**32,308**
1996	342			1,239			2,259			3,459	2,047		12,709	6,145		5,811		1,333	14	**35,358**
1997	1,946			833			1,252		36	2,048	4,571		9,324	6,804		2,622		978		**30,414**
1998	3,958			195		3,827	90		1,427	896	2,577		3,856	5,904		714		859		**24,303**
1999	7,899			204		1,462	220		438	422	1,509		2,669	3,776		294		980		**19,873**
2000	6,552				653	1,064	105		199	411	1,370		2,781	4,196		254	99	805		**18,489**
2001	5,520				314	306	48		63	77	769	1,584	1,374	2,060		201	11	149		**12,476**
2002	3,879				149	20	67			30	422	1,153	1,013	1,331		183	18	72		**8,337**

Notes: Harvest yield is an average for all soybeans grown in Ohio for the specified year. OARDC soybeans may have been higher yield due to enhanced disease resistance and other characteristics, therefore a conservative adjustment of +1 bushel was made for OARDC varieties.
Average price is for the "average soybean"—enhanced crop characteristics of OARDC soybeans may have resulted in higher prices than those used in the model. FG1 and FG2 were given a $1 per bushel premium.
It is likely that much of the non-OARDC–developed seed would still contain OARDC-originated germplasm. In other words, private seed companies may have modified OARDC-originated varieties and the volume of this produce is not represented in the model.
Therefore, this model is most likely providing a conservative estimate of OARDC-derived soybean varieties for each year (i.e., it underestimates the impact of OARDC soybeans).

Table 8: A Conservative Estimate of OARDC-Derived Soybean Impacts (continued)

Based on producing acreage of certified seed from OARDC-developed varieties

Year	Acres Lo	Acres Hi	Acres Mid	Tot Harvest	% OARDC	OARDC Hvst	Bushels Yr	OARDC Bshl Prem	OARDC Bshl	Avg $ Bshl	Avg $ Bshl (HP)	OARDC Value (HP)	OARDC Value
1985	**4,260**	**5,680**	**4,970**	3,870,000	0.1%	**4,970**	41.5	42.5	**211,225**	$5.10	$1.00	$0.00	**$1,077,248**
1986	**243,420**	**324,560**	**283,990**	3,620,000	7.8%	**283,990**	40	41	**11,643,590**	$4.86	$1.00	$0.00	**$56,587,847**
1987	**351,960**	**469,280**	**410,620**	3,900,000	10.5%	**410,620**	37	38	**15,603,560**	$5.94	$1.00	$0.00	**$92,685,146**
1988	**488,670**	**651,560**	**570,115**	3,700,000	15.4%	**570,115**	27	28	**15,963,220**	$7.54	$1.00	$0.00	**$120,362,679**
1989	**757,740**	**1,010,320**	**884,030**	3,980,000	22.2%	**884,030**	31.5	32.5	**28,730,975**	$5.73	$1.00	$0.00	**$164,628,487**
1990	**825,960**	**1,101,280**	**963,620**	3,480,000	27.7%	**963,620**	39	40	**38,544,800**	$5.81	$1.00	$0.00	**$223,945,288**
1991	**797,970**	**1,063,960**	**930,965**	3,770,000	24.7%	**930,965**	36	37	**34,445,705**	$5.69	$1.00	$0.00	**$195,996,061**
1992	**1,031,160**	**1,374,880**	**1,203,020**	3,680,000	32.7%	**1,203,020**	40	41	**49,323,820**	$5.65	$1.00	$0.00	**$278,679,583**
1993	**1,152,870**	**1,537,160**	**1,345,015**	4,110,000	32.7%	**1,345,015**	38	39	**52,455,585**	$6.42	$1.00	$0.00	**$336,764,856**
1994	**1,178,250**	**1,571,000**	**1,374,625**	3,990,000	34.5%	**1,374,625**	43.5	44.5	**61,170,813**	$5.51	$1.00	$0.00	**$337,051,177**
1995	**969,240**	**1,292,320**	**1,130,780**	4,030,000	28.1%	**1,130,780**	38	39	**44,100,420**	$6.70	$1.00	$57,330.00	**$295,530,144**
1996	**1,060,740**	**1,414,320**	**1,237,530**	4,490,000	27.6%	**1,237,530**	35	36	**44,551,080**	$7.42	$1.00	$430,920.00	**$330,999,934**
1997	**912,420**	**1,216,560**	**1,064,490**	4,340,000	24.5%	**1,064,490**	44	45	**47,902,050**	$6.49	$1.00	$3,064,950.00	**$313,949,255**
1998	**729,090**	**972,120**	**850,605**	4,390,000	19.4%	**850,605**	44	45	**38,277,225**	$4.99	$1.00	$6,233,850.00	**$197,237,203**
1999	**596,190**	**794,920**	**695,555**	4,500,000	15.5%	**695,555**	36	37	**25,735,535**	$4.72	$1.00	$10,229,205.00	**$131,700,930**
2000	**554,670**	**739,560**	**647,115**	4,440,000	14.6%	**647,115**	42	43	**27,825,945**	$4.63	$1.00	$9,860,760.00	**$138,694,885**
2001	**374,280**	**499,040**	**436,660**	4,580,000	9.5%	**436,660**	41	42	**18,339,720**	$4.40	$1.00	$8,114,400.00	**$88,809,168**
2002	**250,110**	**333,480**	**291,795**	4,580,000	6.4%	**291,795**	41	42	**12,255,390**	$5.45	$1.00	$5,702,130.00	**$72,494,006**

Variables:

Acres Lo	Low estimate of total acres of soybeans planted using certified OARDC seed (assuming 30 bushels per acre [source = Steve St. Martin/OARDC])
Acres Hi	High estimate of total acres of soybeans planted using certified OARDC seed (assuming 40 bushels per acre [source = Steve St. Martin/OARDC])
Acres Mid	Mid-range estimate of total acres of soybeans planted using certified OARDC seed (35 bushels per acre)
Tot Harvest	Total Ohio soybean acres harvested for specified year (source = Ohio Department of Agriculture)
% OARDC	Mid-range OARDC seed planted acreage divided by total Ohio soybean acreage for specified year
OARDC Hvst	Estimated total harvest of soybeans grown using OARDC-derived seed at mid-range yield (35)
Bushels Yr	Average bushel yield of soybeans per acre for specified year (source = Ohio Department of Agriculture)
OARDC Bshl Prem	Conservative estimate of additional $1 yield realized by OARDC soybean varieties vs. traditional varieties
OARDC Bshl	Total estimated bushels grown in Ohio from OARDC-derived certified seed
Avg $ Bshl	Typical market price for Ohio soybeans in specified year (source = Ohio Department of Agriculture)
Avg $ Bshl (HP)	Avg bushel premium for high protein food grade varieties (FG1 and FG2)
OARDC Value (HP)	Value of FG1/FG2 premium high protein soybeans at $1 additional per bushel
OARDC Value	Total estimated cash value of soybeans grown in Ohio from OARDC-developed certified seed varieties

Disease and Pest Resistance

Specific genes imparting disease- or pest-resistance characteristics must be identified and then incorporated into commercial soybean seed and plant varieties. Such discoveries help OARDC scientists develop approaches to disease and pest resistance that can prevent hundreds of millions of dollars in crop losses.

Varieties of soybean, such as Century 84 and Resnik, have been produced by the OARDC that proved to be resistant to the highly destructive *Phytophthora* fungal water mold that has been responsible for major crop losses among less resistant varieties. In the last major *Phytophthora* blight that struck Ohio, more than 300,000 acres of crop were lost to this disease. The OARDC has been instrumental in working to engender resistance to this disease, which is particularly endemic in Ohio because of high water retention characteristics in Ohio's soils.

The OARDC's latest offensive against *Phytophthora* comes in the form of genetics research. OARDC researchers traveled to Asia to collect multiple specimens of old-line soybean varieties and then mined these plants to discover genes with promising characteristics. The result is the recent discovery of RPS8, a genetic marker that OARDC scientists have found to engender high levels of resistance to almost all strains of *Phytophthora.* The resulting RPS8 germplasm has been patented by Ohio State and is being licensed by the University for incorporation into existing commercial lines of high-yield soybeans.

OARDC's investment in molecular marker technologies and gene sequencing equipment is rapidly accelerating the rate at which discoveries will be made and significant contributions provided to Ohio producers. One OARDC scientist noted to Battelle researchers that she has been able to conduct research in two years using these technologies that would have previously required a decade. These technological resources, in combination with the soybean germplasm collected and stored by the OARDC, are likely to produce many more significant discoveries along the size and scope of RPS8. OARDC scientists are currently mining the germplasm looking for traits that impart partial field resistance and other favorable characteristics in the soybean plant. In addition, OARDC researchers also are approaching diseases via examining the genetics and genetic markers of the diseases themselves—looking for potentially exploitable weaknesses or traits that may help in eradicating or suppressing the disease. This represents a new working paradigm for the OARDC, whereby the institution's scientists will work to identify genetic sources of resistance to diseases and pests and will then work to rapidly license the gene/germplasm to commercial seed production companies for incorporation into existing high-yield soybean varieties (as opposed to the OARDC doing the entire variety development work).

In addition to *Phytophthora* research, OARDC plant pathologists, crop scientists, and entomologists are working on approaches to multiple additional diseases and pests that affect Ohio soybeans. For example, active work is being conducted on brown stem rot and the evaluation of lines that may have resistance to Sclerotinea stem rot. Approaches also are being investigated for tackling problems related to the soybean cyst nematode, a pest that is increasing in its distribution in Ohio soils, having spread from Michigan.

Some of the thematic approaches being taken by OARDC scientists in approaching soybean diseases and pests are highlighted below in a series of specific research summaries.

Genomic Analysis of *Phytophthora*

Phytophthora-related diseases result in estimated yearly worldwide losses of more than $10 billion. *Phytophthora* pathogens affect multiple plants such as potatoes, cocoa, and strawberries—but, it is soybeans that are most affected in Ohio. While *Phytophthora* are a widespread species and unique group of fungus-like plant pathogens, little study has been performed of their genetic makeup. In collaboration with researchers at several national and international institutions, as well as industrial partners, OARDC scientists have engaged in a project aimed at identifying all the genes of *Phytophthora*. So far, several thousand *Phytophthora* genes have been uncovered. In the long term, this project will likely lead to novel approaches for genetic and chemical disease control.

Generating Nonhost Resistance to *Phytophthora* in Soybeans

Phytophthora root rot results in more than $120 million in annual soybean losses in Ohio. OARDC researchers are investigating whether soybeans can gain resistance through other plants such as tobacco or weeds. Plants, like animals, have an immune system to fight off invaders. This may explain why most plants are resistant to the races of *Phytophthora* that infect soybeans. Using modern tools of molecular biology, OARDC scientists have reported important progress in understanding this form of resistance, known as nonhost resistance. The long-term objective is to turn soybeans into nonhosts of *Phytophthora*, just like the weeds that grow in infested soils.

Soybean Cyst Nematode Threats in Ohio

With the support of the Ohio Soybean Council, more than 5,000 soil samples have been assayed for soybean cyst nematode in the past 12 months. About 40% of the samples had detectable populations of the pest, and fully 10% had populations above levels that would permit even the use of nematode-resistant soybean cultivars. The pest was found in soil samples from all but one of Ohio's major soybean-producing counties, and the threat is now such that OARDC scientists are working on approaches to eradicate the threat of this pest to the Ohio soybean crop.

New Sources of Resistance to *Phytophthora* Root Rot in Soybeans

Typically, *Phytophthora sojae* pathogen causes major losses in wet springs; but, even in a drought year like 1999, some Ohio losses occurred. The OARDC and the OSU Department of Plant Pathology have identified 38 potential new sources of resistance to this pathogen in various soybean lines. The analysis of these lines has led to the RPS8 discovery and its licensing to seed companies—also, these sources may contain further novel resistance genes or combinations of genes. In addition, OARDC researchers have identified more than 390 new sources of partial resistance to *Phytophthora.* These new sources of resistance are being incorporated into soybean lines in cooperation with breeders in OARDC Horticulture and Crop Science.

Molecular Mechanisms of General, Broad-Spectrum Resistance in Soybeans

OARDC scientists have been studying the genetic and biochemical bases of general (sometimes called partial) disease resistance in soybeans. General resistance is thought to be a more durable and broad-spectrum form of resistance. For this reason, it may provide effective resistance against many pathogens and be more stable once introduced. Early research by the OARDC team suggested that the soybean defense end-products that actually confer general resistance may not be the most effective ones to alter in strategies to increase general resistance. For this reason, the soybean genes that regulate the establishment and deployment of the defense end-products have been emphasized recently. This strategy has led to important breakthroughs in the molecular bases of general resistance, including the discovery of at least three critically important genes that control the deployment of general resistance. These genes are being studied in soybean lines with high and low general resistance to determine whether enhanced expression of the genes is associated with this form of resistance. If so, both traditional breeding and genetic engineering efforts may lead to the development of novel and improved resistant cultivars of soybean.

Systemic Disease Resistance in Soybeans

The development of systemic disease resistance is a highly desirable goal for any plant species. Soybeans are unusual in that they do not show systemic acquired resistance, a phenomenon that has proven useful in developing genetic or chemically induced systemic resistance in many other plants. Recent research has established that an induced form of systemic resistance is present in soybeans. The soybean signal molecules responsible for setting up this resistance appear to be ethylene and jasmonic acid, which are responsible for a new form of systemic resistance called induced systemic resistance in certain other plants. A series of novel chemicals also has been found that can activate some or all of the components of this response. OARDC researchers are now working with industrial partners on a compound that may induce a similar resistance response in field-grown soybeans. Of particular importance, preliminary results suggest that systemic resistance in soybeans may involve a general disease-resistance mechanism, which is related to durable, broad-spectrum soybean disease control. If so, the benefits of both systemic and general resistance could be combined in future soybean lines.

High-Quality Soybean Varieties for Export

In addition to working on resistance to, and control of, soybean pests, diseases, and pathogens, OARDC scientists also have placed an emphasis in their research on discovering ways to improve soybean crops through characteristics such as enhanced yields, higher-quality beans, and optimized plant coloring. One such research project has resulted in developing high-quality, high-protein soybeans suited for human food production, most notably for tofu.

The OARDC's FG1 soybean is the most recent notable example of the institution's work in this area. Released for production in 1995, FG1 certified seed was cultivated on a peak of 7,899 acres in 1999, producing seed sufficient to plant upward of 300,000 acres of Ohio soybean fields. While the food grade quality plants typically have a lower yield, at circa 30 bushels per acre, they are able to command a price premium of between $1 and $2 per bushel over standard yellow soybeans.

OARDC research also has made significant contributions to other leading field crops in Ohio. In 2001, the state's farmers harvested 900,000 acres of wheat, of which an estimated 40% to 60% is the OARDC-developed Hopewell variety introduced in 1995. Hopewell has proven to be a high-yield variety, consistently achieving crop yields up to 25% higher than the previous favored varieties. OSU is anticipating the release of another wheat variety in the Fall of 2003 that, in testing, has achieved even higher yields.

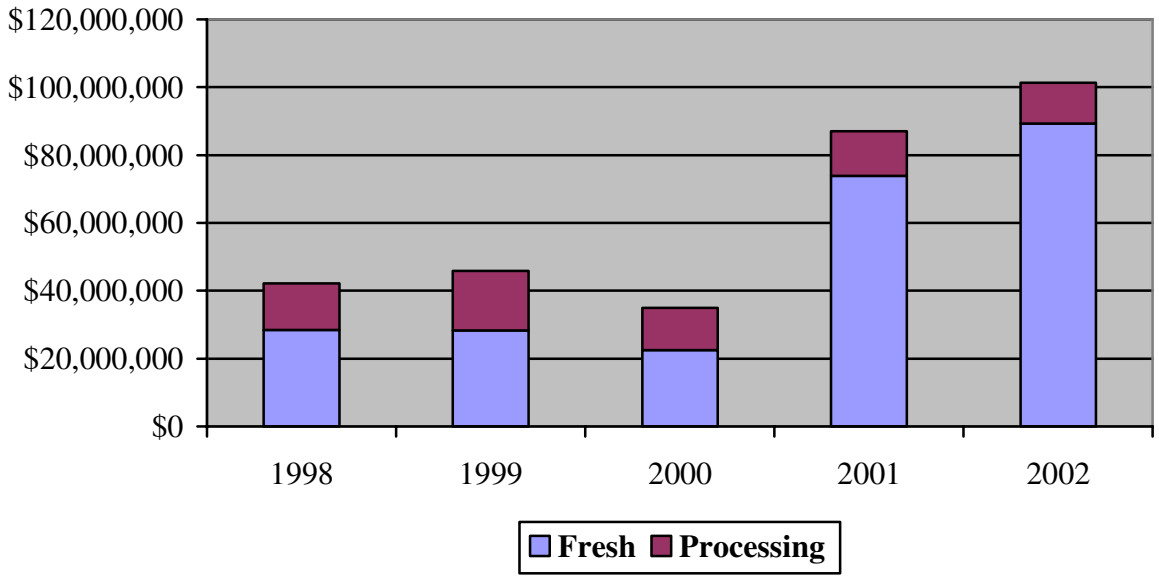
With the preponderance of Ohio's FG1 output being exported to Japan and Korea, these crops are earning significant export dollars for the Ohio economy. FG1 has performed extremely well in producing a soybean with appropriate characteristics in terms of protein composition and plant/bean coloring that greatly influence consumer bean selection in Japan. In fact, soybeans in general are a significant export income earner for Ohio and the leading agricultural export for the state. In 1999, Ohio's exports of soybeans, soybean meal, and soybean oil totaled $459.4 million, rising to $461.1 million in 2001.

With over 32% of Ohio's farmland used for soybean production, and soybeans representing a leading export product for the state, the emphasis of the OARDC on soybean research is well founded. The focus on soybeans is indicative of the institution's active response to its mandate of serving the specific needs of Ohio agriculture.

OARDC Impact on Ohio Tomatoes

Tomatoes, of both the fresh-market and processing variety, are an important agricultural product for Ohio. In 2002, the state ranked third in the nation in the production of both categories of tomato fruit. Ohio's tomato farmers achieve an average yield per acre that is significantly higher than the national average. In 2002, Ohio tomatoes generated a yield of 370 hundred weight (Cwt) per acre, whereas the national yield was only 299 Cwt per acre. Ohio's tomatoes also commanded a price premium, with their product quality generating a price per Cwt of $36.00 versus the national average of $31.40. The total value realized from Ohio's 2002 tomato crop was $101 million—up from $87 million in 2001 (see Figure 4). These statistics suggest an impressive performance by Ohio's tomato growers.

Figure 4: Value of Ohio Tomato Production, 1998–2000



Source: National Agricultural Statistics Service

Note: Low production value in 2000 is the result of nationally low prices for tomatoes that year.

Battelle finds that the performance of the growers is underpinned by a strong program of tomato research and development conducted by the OARDC. Since 1991, for example, the OARDC has released 17 new varieties of tomato and tomato germplasm—most of these via public release for widespread use by Ohio's growers. Releases are shown in Table 10.

Table 10: OARDC Tomato and Tomato Germplasm Releases

Year	Release	Release Type
2002	Ohio Bicentennial Tomato	Public release
2001	Ohio 9834 and Ohio 9816	Germplasm
2000	LA407	Inbred BC pop'n
2000	OX23	Branded release
1999	Ohio 9241, Ohio 9242, and Ohio E3259	Public release
1999	Ohio 9242	Public release
1999	OX150	Public release
1999	OX52	Public release
1995	Ohio OX38	Public release
1995	Ohio OX42	Exclusive release
1995	Ohio OX88	Exclusive release
1993	Ohio 8556	Public release
1992	Ohio 7983	Public release
1991	Ohio 8245	Public release

These releases stem from an intensive R&D program operated at the OARDC under the Tomato Genetics and Breeding Program (TGBP). The TGBP researches the genetic basis of field resistance, humid environment adaptation (a characteristic of Ohio's summers), and fruit quality while working on various strategies for crop improvement. The "products" of the team's scientific work are tomato varieties exhibiting enhanced fruit quality and disease resistance. An example of the improvements generated by OARDC research can be seen in the recently released Ohio Bicentennial Tomato, a multi-use home-consumption fruit with multiple positive characteristics:

- Consumer panels rated the new tomato superior in taste and color to the currently standard VF Roma and Roma-style tomatoes.
- Vines exhibit uniform row area coverage at maturity and have excellent foliage cover characteristics.
- The tomato plant is resistant to multiple diseases and pathogens including fusarium wilt, early blight, bacterial diseases, anthracnose fruit rot, and weather-related cracking.

Similar advancements are evident in the other tomato releases of the OARDC, including the important "tomatoes for processing" category. Ohio OX52, for example, is an early season processing tomato found to have superior characteristics for machine harvest and bulk handling under humid growing environments. The tomato has proven suited to the production of peeled, whole-canned, and diced tomato products. OX150 exhibits similar processing characteristics, but is also suited to both early and mid season growing conditions.

Current research within the TGBP is aimed at further improving the product of Ohio's tomato growers. Examples of current OARDC tomato research include

- Resistance to bacterial canker
- Tomato vascular development and its relationship to disease resistance
- Clavibacter genomics
- Measuring the effect of genetic variation on tomato color
- Breeding of tomatoes with superior color and enhanced lycopene content (a proven antioxidant/anticancer agent).

Tomato research projects span departments at the OARDC and the OSU College of Food, Agricultural, and Environmental Sciences:

- Researchers in the Department of Plant Pathology are investigating optimization of pest, nutrient, and water management tools for fresh-market tomatoes—work that is expected to result in alternative biological and cultural methods for weed and disease management in tomatoes.
- Faculty in the Food Science and Technology Department are using tomato products containing soy as a model system in the development of functional foods (whole foods carrying beneficial vitamins, minerals, and nutrients for enhanced human health). The research is anticipated to produce a new, value-added product from Ohio tomato and soy for potential use in multicenter clinical trials related to prostate cancer.
- The Department of Horticulture and Crop Science is performing work to improve the efficiency of processing tomato production through managing color disorders. This research has the potential to generate substantial impacts for tomato farmers who are currently faced with up to 65% of their processing tomato crop having value-reducing color disorders.
- In Food, Agriculture, and Biological Engineering, hydroponic tomato research is an area of focus. The goal is to introduce hydroponics as a means for small farm operators to diversify away from commodity crop production into higher-value products.
- OARDC researchers are investigating the genetics of fruit shape and morphology and working to develop a software system to semiautomatically quantify fruit morphology characteristics. The goal is to produce a fruit shape to better fit the needs of processing and packaging manufacturers.

OARDC Impact on Livestock, Poultry, and Animal Health

The OARDC's Food Animal Health Research Program was established with a central focus on infectious diseases in food-producing animals. Both livestock and poultry are an important component of Ohio farming, and the state ranks as follows:[15]

- Second in the nation in egg production
- Sixth in chickens sold
- Eleventh in turkey production

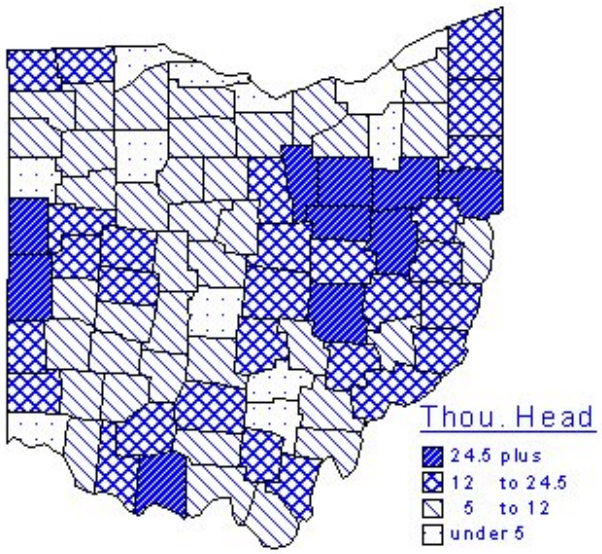
[15] Ohio Agricultural Statistics Service.

- Ninth in hog and pig production
- Eleventh in sheep and lamb production
- Tenth in milk cow inventory.

Ohio is also a major processing center for food animals and, with 160 livestock slaughter plants, ranks third in the nation.

The production of livestock is also distributed throughout the State of Ohio—providing benefits to most of the state's counties (Figures 5 and 6).

Figure 5: Geographic Distribution of Cattle in Ohio



Source: Ohio Department of Agriculture and the Ohio Agricultural Statistics Service.

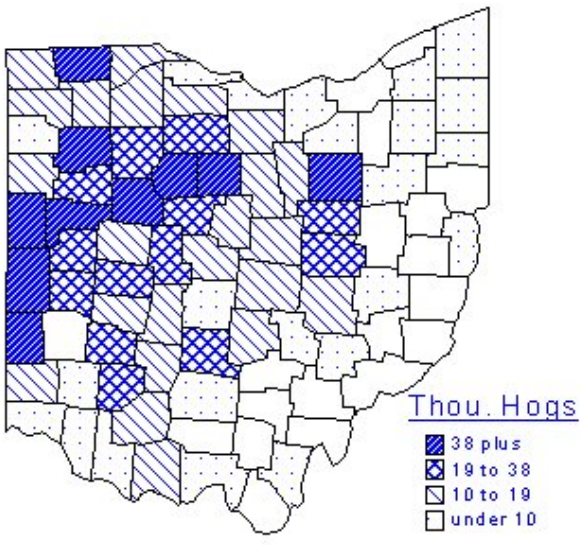


Figure 6: Geographic Distribution of Hogs in Ohio

Source: Ohio Department of Agriculture and the Ohio Agricultural Statistics Service.

The OARDC has taken a highly pragmatic approach in its animal research by focusing on the two leading categories of illness in food-producing animals—enteric and respiratory diseases. The adoption of this focused approach has allowed the OARDC to develop considerable expertise in these areas, to the extent that OARDC scientists are among the leading worldwide experts on animal enteric viruses and receive considerable external funding volumes (with a significant volume coming via the National Institutes of Health [NIH]).

The program's research focus is on diagnosis, vaccines, and treatment and control strategies. The group's work has resulted in developing diagnostic agents, reagents, and tests and monoclonal antibodies and primers for PCR testing and vaccines. Faculty within the program hold patents on several diagnostics sold in kits and a number of vaccines.

In addition to generating intellectual property and licensing revenues for OSU, the research discoveries made by OARDC scientists are having extensive impacts on Ohio livestock, poultry, and egg producers. The prevention or early treatment of a disease certainly has a large-scale impact in terms of losses prevented—the extent of which can be substantial. This may be put into perspective by referring to some of the recent outbreaks of animal infectious diseases and their estimated impacts (Table 11).

Table 11: Some Negative Impacts of Animal Infectious Diseases

Disease	Year	Location	Estimated Impact/Economic Loss
Avian Influenza	2002	Virginia, USA[16]	Over 4 million turkeys and chickens culled
Newcastle Disease	1998	Australia[17]	$9.85 million in losses (this disease has also occurred in California and Virginia)
Classical Swine Fever	1997	The Netherlands[18]	$2.3 billion in losses
Classical Swine Fever	1997-99	Dominican Republic[19]	Slaughter of 17,000 pigs
Foot & Mouth Disease	2001	United Kingdom[20]	$15 billion in losses
Foot & Mouth Disease	1997	Taiwan[21]	$8 billion in losses

Referring to Ohio production statistics can put into perspective the potential negative impacts such diseases could engender. Taking avian influenza as an example, if 4 million Ohio turkeys had to be slaughtered because of a Virginia-style outbreak, this would result in a loss of 75% of Ohio's turkeys (based on 2002 figures), which, at an average weight of

[16] Nolen, R.S. 2002. "Avian influenza strikes Virginia poultry farms." *Journal of the Am. Vet. Association,* 221:9-10.

[17] Pollard, D. 1999. "Newcastle disease outbreak in Australia." *World Poultry,* 15:36-37.

[18] Meuwissen, M.P.M., S.H. Horst, R.B.M. Huirne, A.A. Dijknuizen. 1999. "A model to estimate the financial consequences of classical swine fever outbreaks: principles and outcomes." *Prev. Vet. Med.,* 42:249-270.

[19] Dore, A. 2001. "The cost of foreign animal diseases—recent examples." *CAHNet Bulletin,* special edition, Fall 2001, pp. 4-5.

[20] Kitching, P. 2001. *Proceedings of the Second Foreign Animal Disease Course,* Madison, Wisconsin.

[21] Wilson, T.M., C. Tuszynski. 1997. "Foot-and-mouth disease in Taiwan—1997 overview." In *Proceedings of the 101st Annual Meeting of the U.S. Animal Health Association,* U.S. Animal Health Association, Richmond, Virginia, pp. 114-124.

38.4 pounds and a market price of $0.35 per pound, would equal **direct economic losses of $53.8 million.**

In 2001, Ohio livestock production totaled $1.9 billion, a significant component of the Ohio economy. Major diseases such as swine fever, foot and mouth disease, or Newcastle disease could have devastating effects on the state's agriculture and related economic infrastructure.

According to the Agricultural Research Service of the USDA, the cost of disease in livestock and poultry is routinely estimated to be 17% of production costs in the developing world.[22] The same researchers estimate that livestock diseases cost the U.S. economy $17.5 billion each year. Some extrapolations serve to illustrate the potential disease losses in Ohio. In 2001, the U.S. livestock industry generated $106.3 billion in revenues, while Ohio's livestock revenues totaled $1.9 billion (or 1.8% of all U.S. livestock revenues). **If losses occurred in Ohio at the U.S. national rate, the estimated scope of the problem in the state would amount to $315 million.**

Clearly, applied research and development activities that reduce Ohio's exposure to livestock losses have significant statewide benefit. The fact that OARDC scientists focus on the top two ranked diseases effecting livestock (enteric and respiratory diseases) means that the state has considerable expertise in the most prevalent and disruptive food animal diseases. Some specific OARDC achievements in food animal health include the following:

- OARDC rotavirus vaccines have been highly effective, most notably in swine populations where inoculations have completely protected the animal population from the intestinal diseases these viruses cause. The net result has been Ohio's hogs reaching size and quality goals on time—instead of the animals' development being retarded by the effects of rota-viruses on animal nutrition and growth. The OARDC's work on rotaviruses and caliciviruses also has extended into human medicine since the intestinal viruses can cause diarrhea diseases in human infants.
- Corona-viruses infect poultry, cattle, and swine—and with the recent severe acute respiratory syndrome (SARS) outbreak, there are increasingly urgent investigations of the human impact of these viruses (which previously had little impact on humans). OARDC scientists are among a handful of worldwide corona-virus experts; and the expertise of these Ohio animal virologists has been drawn upon by the Centers for Disease Control and Prevention (CDC), NIH, and U.S. Armed Forces in developing approaches to SARS.
- OARDC researchers have recently developed and successfully tested a vaccine for infectious bursal disease virus (IBDV)—a virus that causes immunosuppressive disease in chickens. The immunosuppression caused by IBDV is the underlying cause of many cases of respiratory and enteric diseases in chickens. OARDC scientists are continuing to work to improve poultry health though additional prevention, control, and diagnosis research on IBDV.

OARDC Impact on Ohio's Grape and Wine Industry

Ohio has a diverse agricultural base, with more than 200 different crops produced for food and fiber. One crop that has significantly increased in its importance in recent years is grapes—used in table, juice, and wine applications.

[22] http://www.ars.usda.gov/research/programs/programs.htm?np_code=103&docid=820.

Ohio has a long history of grape production and winemaking, which can be traced back to the early 1800s. By 1860, Ohio was the leading producer of wine in the United States; but, diseases such as black rot and mildew blighted Ohio grapes and caused a demise of the industry for the state. The industry grew back in the northern counties of Ohio, along Lake Erie; but, Prohibition struck and effectively ended this industry for the state.

In recent decades, the research and development work of the OARDC has helped to reestablish winemaking and grape production as a high growth industry for Ohio. The Ohio Wine Producers Association notes the following:[23]

> *The turning point for the Ohio Wine industry came in the early 1960's with the planting of French-American varieties in southern Ohio, encouraged largely by The Ohio State University's Ohio Agricultural Research and Development Center in Wooster.… Their success in the south encouraged plantings in the Lake Erie Grape Belt.*

Growth has continued to accelerate. In 1997, Ohio contained 37 wineries; but, by 2002, this number had increased to 81, with another five expected to be added during 2003. This growth is being supported by the State of Ohio through the Ohio Grape Industries Program, which funnels state funds from liquor taxes into marketing and research programs aimed at enhancing the grape and wine industry in the state.

The OARDC serves as the primary research and development arm for the grape and wine industry in the state. In 1984, the OARDC established a dedicated Grape Research Facility located on 30 acres in Ashtabula County. Since its establishment, the OARDC's grape research activities have made significant contributions in

- Identifying appropriate juice, table, and wine cultivars for the state—such as White Riesling, Cabernet Franc, Seyval Blanc, and Pinot Gris
- Conducting research to enhance grape quality and disease resistance through studies of rootstock-scion interactions, chemical growth regulators, plant nutrition, and general viticulture practices
- Conducting research on cold hardiness and other plant characteristics to help enhance grape production in the state.

While Ohio's grape and wine industry is far smaller than California's (ranked first), it has reestablished itself through recent growth to become the eighth ranked grape production state—producing 5,800 tons of grapes in 2002. The 2001 State of Ohio Grape Producer Summary cites a total of 1,300 bearing acres of grapes, and the industry is growing rapidly in the state with 81 wineries in operation in 2003 versus just 37 six years ago. OARDC estimates show that the wine industry in Ohio now represents $70 million in new growth value, and is enhanced by a further $10 million in the production of juice grapes[24].

Growth is predominantly occurring through the production of grapes for wines. Few Ohio grape growers make a living off of table grapes—rather, the grapes are grown for the purpose of adding value through wine production. **To this end, the OARDC has invested in a research and development infrastructure geared to providing practical assistance to the wine**

[23] http://www.ohiowines.org/info_pack.htm.
[24] Slack, Steven. "OARDC Testimony" March 19, 2003.

industry in the state. At the Center's main facilities in Wooster, the OARDC operates an experimental winemaking cellar and houses specific viticulture expertise in horticulture, plant pathology, and entomology—providing a cross disciplinary team to assist in further developing this industry in the state.

The OARDC also operates an active educational program to assist in the professional development of the industry in Ohio—with three schools held per year on winemaking techniques and practice. Results have been interesting, with the majority of wine producers in the state coming from an amateur wine enthusiast, rather than a farming, background. The role of the OARDC and the extension service is thus of critical importance—covering not only basic and advanced winemaking, but also educating and informing the practitioner in basic agriculture and viticulture techniques and practice.

Current research at the OARDC is aimed at strengthening the grape and wine industry in the state. Recent research and development activities include, for example,

- Work to increase the cold hardiness of grapes in Ohio
- Research to develop grape varieties to assist southeastern Ohio producers in developing a premium grape juice variety
- Cultivation and vineyard management techniques for reducing plant losses
- Chemicals R&D aimed at reducing total vine crop load to enhance grape quality
- New approaches to pest management, with a special emphasis on lady beetles.

OARDC Impact on Food Safety and Processing Technologies

The primary production of agricultural crops at the farm level is just one step in a vertically integrated food processing industry that is highly active in the State of Ohio. **Primary agricultural production (farming) in Ohio is important and accounts for $6.5 billion in Ohio economic output on an annual basis. Going further up the value-added chain into food processing research finds an Ohio industry that has $18.9 billion in output.**[25]

Battelle's research indicates that **the OARDC is not only an important R&D engine for primary agricultural production, but is also an important source of scientific research and technical developments for the processing sector.** The following initiatives being conducted by OARDC scientists illustrate the range of OARDC activities in the food processing sector.

Preservation Technologies for a Safer Food Supply

At the Columbus campus, OARDC researchers have placed a major research emphasis on developing new sterilization technologies to assure food safety and preservation—technologies that not only assure food safety, but also preserve the taste, texture, and other favorable characteristics of the food product. OSU scientists and engineers have made significant advancements in the application of three new technologies: (1) ohmic heating using electric current to perform rapid and evenly distributed heat; (2) pulsed electric fields of between 25,000 and 40,000 volts per centimeter applied to a product passing through a tube via 2 microsecond pulses; and (3) the application of high-pressure sterilization (at upward of 8,000 atmospheres)—a process that does

[25] Sporleder, Thomas L. 2003 "OHFOOD: An Ohio Food Industries Input-Output Model—Version 6.0." The Ohio State University Department of Agricultural, Environmental, and Development Economics, June.

not produce the food-damaging qualities of very high temperatures required in other techniques. OSU has constructed a pilot facility for the ohmic heating technology and is actively working with industry representatives in applied product testing.

The OARDC's research on applying ozone as a decontaminant for food ingredients and produce helped to win U.S. Food and Drug Administration (FDA) approval for the process. Industry throughout the United States is adopting the OARDC-researched process, which is 50% more powerful than the chlorine rinses used as the standard decontaminant. Ozone has no harmful environmental effects and dissolves to become oxygen in the food product rinsing process—so the OARDC research has helped lead to an environmentally friendly way to reduce the use of chlorine rinses and their associated disposal hazards.

Processing Technologies

The same OARDC research team looking at pulsed electric fields for sterilization also has found the technology to be suited to the processing of fruit. The short pulses of electrical energy blow holes in vegetative cells, causing the contents of the cells to leach out. This technology, a potentially effective tool in juice extraction and pasteurization, is being examined for applications in orange juice production. The ohmic technologies of OSU also are being applied in processing to greatly reduce (by an order of magnitude) the amount of lye required in the peeling process (with associated cost and pollution saving benefits).

Food Safety via Rapid Detection of Microbes

Foodborne illnesses result in considerable economic costs. According to research conducted by the FDA, only seven of the more common foodborne pathogens cause an estimated 3.3 to 12.3 million illnesses in the United States in any given year and up to 3,900 deaths. For foodborne pathogens to cause illness at a proportion equal to Ohio's percent of the total U.S. population, which is 4% (11.4 Ohioans out of 288.4 million U.S. residents), would mean between 132,000 and 492,000 foodborne illnesses in Ohio each year and circa 156 deaths. In a 1995 study, USDA researchers estimated the negative monetary losses of these seven pathogens to be between $6.5 billion and $13.3 billion nationwide, or between $260 million and $532 million in Ohio annually.[26]

The OARDC is tackling this substantial problem by developing a rapid detection system designed to detect the presence of microorganisms. Based on real-time PCR technology, the OARDC system can quickly identify DNA sequences associated with specific pathogens. The OARDC-designed system conducts the analysis on a food sample in just minutes, whereas current methods require 18+ hour bacteria growth cultures. During the long testing time of current methods, food products awaiting the test results can begin to spoil, thereby causing significant waste (estimated as $5 billion to $6 billion annually in the United States). Thus, the OARDC system holds great promise for avoiding large-scale monetary losses in meat and other food industries, in addition to assuring a safer food supply.

Protocols for two pathogens (*E. coli* 0157:H7 and *Listeria monocytogenes*) are under current development. *E. coli* alone causes between 10,000 and 20,000 serious illnesses per year and

[26] Buzby, J., and T. Roberts. 1996. "ERS Updates U.S. Foodborne Disease Costs for Seven Pathogens." *Food Review,* 20. Authors are economists with the Food and Consumer Economics Division, Economics Research Service, USDA.

between 220 and 541 deaths, with 80% of these cases tracked to foodborne infection. Based on Ohio's population, these figures suggest that *E. coli* alone causes serious illness in 400 to 800 Ohioans each year and kills 10 to 20.

OARDC Impact on Composting and Potting Soil Technologies

Compost is one of those agricultural and horticultural inputs that may be taken for granted. However, as the primary growing medium and nutrient source for a wide-variety of commercial plants, it is a major contributor to healthy plants.

OARDC research has been instrumental in some of the most important advances made in compost composition and composting technologies in recent decades. Prior to OARDC's research on using tree bark to produce potting mulch, the majority of potted plants were produced in a bog mulch media. The bog mulch standard had many drawbacks, not the least of which is its susceptibility to harbor and encourage the spread of plant pathogens such as *Phytophthora.* **Statistics show that, prior to the OARDC's development of bark-based mulch products, up to 75% of potted plants (such as rhododendrons and azaleas) died before they were sold, and most died post-planting. Through OARDC technologies that facilitate the nitriphying of bark, a new mulch industry was created that**

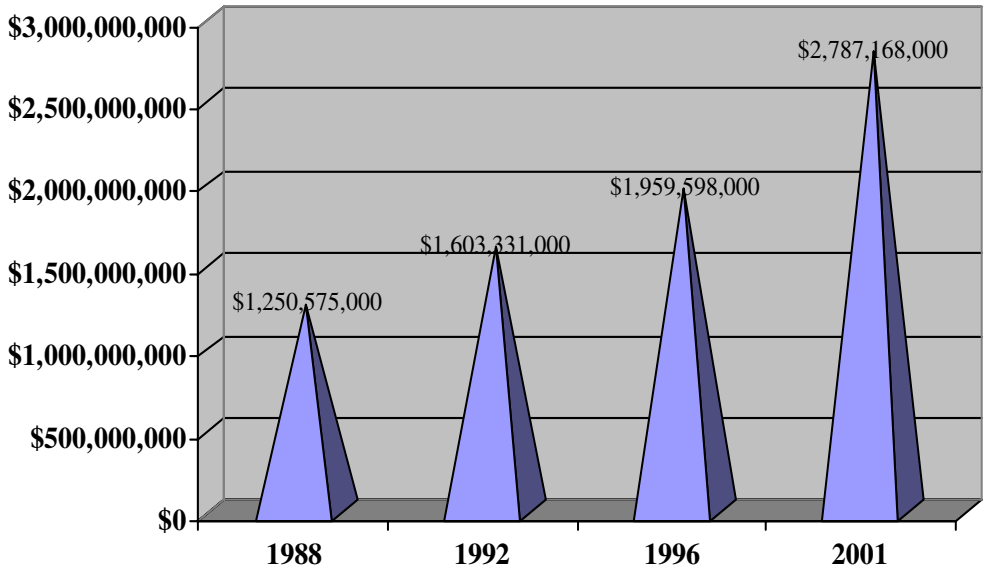
- Generates disease-resistant potting soils that have reduced in-the-pot plant disease and losses by orders of magnitude. This has changed the economics of horticulture and promoted rapid growth in the nursery industry.
- Created a resource out of tree bark, which previously was a waste product to be burned. Multiple processing plants have been developed, both domestically and internationally, based on the OARDC mulching/composting technology.

The OARDC work on disease-resistant potting soils has made the growth of the nursery industry possible in Ohio. Today, nursery and horticultural industries represent the largest component of Ohio's agricultural production sector. OARDC research conducted in 2001 indicates that overall sales by certified nursery stock dealers and producers in Ohio totaled $2.79 billion, with an annual sustained growth rate since 1996 maintained at 8.5% (Figure 7). More than 96,000 persons were found in the OSU study to work within the nursery industry in Ohio. Payroll of the sector totaled $275 million in 2001, and the nursery industry generated $275 million in tax revenues.[27]

Researchers interviewed by Battelle at the OARDC noted that the nursery industry would be only a minor player in Ohio agriculture if it were not for the disease-resistant potting soil work of the OARDC. It also was noted that previous potting mixes required four to five fungicide treatments per season, at a cost of $9 per application per cubic yard of mix. The OARDC potting mix is naturally disease resistant and requires only an occasional spot treatment, resulting in significant savings for producers.

[27] Ornamental Plants Annual Reports and Research Reviews, 2002. Special Circular 189. Key Results of the 2001 Ohio Green Industry Survey. http://ohioline.osu.edu/sc189/sc189_95.html.

Figure 7: Estimated Value of Certified Nursery Stock Dealers and Producers in Ohio, 1988–2001 Sales Growth



Source: Ohio Department of Agriculture, 2002 Annual Report and Statistics.

Current research within the OARDC on potting soils is producing major advances in the control of foliage diseases in plants through special growing media. Scientists at OSU have discovered specific organisms that, when inoculated into the soil substrate, colonize the microbial community and trigger a disease immunization effect for the plants growing in the soil. Tests have shown this approach to work with ornamental plants, tomatoes, and trees, resulting in thee times less loss to foliage diseases than on untreated test plots. The key impact of this discovery will be a substantial reduction in the use of fungicides—currently applied at a cost of approximately $15,000 to $20,000 per acre for some plants in Ohio.

OARDC research also led to the development of composting technologies for sewage sludges. OSU researchers, engineers, and scientists developed a successful pilot-scale system that ultimately resulted in a $35 million compost production plant in Akron (which is currently in production).

TECHNOLOGY TRANSFER AND COMMERCIALIZATION

As noted above, OARDC research and development has resulted in substantial economic gains for farmers, agronomists, horticulturalists, and food processors in the state. New high-yield, disease-resistant crop varieties have been introduced, livestock diseases averted, new processing technologies introduced, and rapid growth promoted in entire sectors such as the wine and nursery industries. These impacts occur through the diffusion of OARDC discoveries, knowledge, and know-how to suppliers, producers, and practitioners in the state via direct OARDC communications and the active work of OSU extension.

The OARDC does not conduct its research and development on the basis of generating patent and other intellectual property revenues—indeed, many OARDC discoveries are simply released quickly in the public domain to optimize their rapid adoption for the benefit of Ohio agriculture and agribusiness. That said, in many instances the work of the OARDC has been protected through patents and other means by the university, resulting in licensing revenue streams that help to further fund OSU research programs in Ohio.

Because the OARDC takes a pragmatic and applied approach to research, the Center and the College of Food, Agricultural, and Environmental Sciences have been particularly active generators of intellectual property. Statistics provided by the OSU Office of Technology Licensing highlights the productivity of the OARDC in generating intellectual property in 2003 (Table 12).

Table 12: The Ohio State University Agriculture and Ag-Related Intellectual Property Activity, FY 2003

	OSU Total FY 2003	OARDC/FAES Total
Invention Disclosures	130	22
Patent Applications	35	5
Patents Awarded	21	1
License/Options Executed	33	11
Start-up Companies	4	1
Total Revenue from Income Generating Licenses	$840,375	$300,000

Source: The Ohio State University Office of Technology Licensing.

Note: Until 2000, State of Ohio legislation actively prohibited the participation of university faculty in start-up companies based on their technologies. Ohio Senate Bill 286 amended this law to permit greater participation by faculty in start-up company formation and will likely result in a significant increase in OSU-generated start-ups.

These data indicate the comparatively strong commercialization activity within the OARDC/ College of Food, Agricultural, and Environmental Sciences (FAES). The OARDC/FAES complex brought in $60,756,641 in extramural research funding, which is 14.3% of all research at OSU. Invention disclosures from agriculture, however, are higher (at 16.9%) than the research funding percent suggests should be the case. Agriculture is also responsible for 33% of licenses and options executed and 35.7% of the university's total revenues generated from income-generating licenses.

In addition to licensing technology, the OARDC also has been involved in the direct generation of new business enterprises in Ohio founded on OARDC research and development discoveries. Some examples of Ohio business enterprises and business sectors formed within the past 10 years from OARDC initiatives are provided in Table 13.

It should be noted, however, that until 2000 Ohio had extremely restrictive legislation that effectively prohibited the participation of faculty in start-up companies. This law has been changed, and it is anticipated that the volume of Ohio start-up companies emanating from OSU research will increase.

Table 13: Ohio Companies Formed in Past Decade Based on OARDC Technologies

Company Name	Located in Ohio	Role of OARDC in Formation
Kurtz Brothers Composting, Columbus, Ohio	Yes	Basic science behind composting processes.
Multiple waste management agencies/corps	Yes	Basic science behind waste management processes.
Grape and wine industry in Ohio	Yes	Basic science behind grape and wine production processes.
Spray Redux	Yes	Basic science behind processes and scientist initiated the business. First OSU startup company.
ValuMark	Yes	Basic science behind processes and scientists initiated efforts to begin business.
Cargill in Sidney, Ohio	Yes	Basic science behind processes. High protein food grade soybean.

Spray Redux Case Study

Spray Redux, based in Cleveland, manufactures an OARDC-developed, OSU-patented double nozzle spraying system that increases herbicide and insecticide efficacy and reduces application rates (thereby providing both cost savings and environmental benefits). The Double Nozzle Sprayer delivers a fine spray of active ingredient in a coarse spray of water to place efficient small droplets of pesticide on the target crop or weed. The coarse spray contains no active ingredient in its large droplets, but draws the active ingredient in the fine spray into the canopy. Spray Redux's Double Nozzle Sprayer reduces farm expenditures by using less herbicide and/or insecticide without compromising crop protection. Cost saving is the obvious direct benefit, but there are other indirect benefits of reducing pesticide use. By reducing the application rate, soil tilth is improved by reducing the amount of pesticide entering the soil. This can contribute to better plant growth and increased yields.

Several new company formations are likely to occur based on current OARDC research and development activity. Notable among these are the following examples.

Beef Marbling, Tenderness, and Diagnostics Company

The research work of OARDC scientists in molecular markers and animal genetics has resulted in significant new technologies to be developed into a new business enterprise in Wooster. Using the OARDC cattle herd, and controlling for exogenous variables, the OARDC research team identified multiple cross-population genetic markers, one of which is statistically associated with an animal's propensity to produce highly desirable marbled meat. The discovery of these markers has presented the opportunity to form a new animal diagnostics and testing company that will be of significant value to livestock producers. Marbled beef commands a significant price premium under USDA grading standards; but, no way has existed for producers to accurately tell whether an animal is likely to produce such marbled meat. As a result, producers are "working in the dark"—feeding animals with expensive, high-quality feed in hopes that marbling will result, even though the genetics of the animal make such marbling statistically unlikely. The OARDC-developed technology will allow a calf's DNA to be tested at birth to see

whether it has the propensity to marble based on its genetic markers. More economical livestock feeding will result, with the best feed reserved for animals likely to produce the high-value marbled beef. Benefits to livestock producers will come from both the revenue and cost reduction sides of the equation—with a $10 test helping to realize an additional $100 in revenue from a marbled beef carcass, plus cost reduction occurring through feeding lower-quality, lower-cost feed to nonmarbling cattle and moving these lower-quality beef cattle to market sooner.

The technology shows promise for applications in detecting and predicting beef tenderness in addition to marbling. It also has significant potential for identifying disease susceptibility markers in livestock—helping to optimize and rationalize vaccination regimens and save on vaccine costs. The technology also shows promise for application in additional livestock, such as hogs and lambs. Disease marker technology would also be relevant to the large poultry industry in Ohio.

Seed Vigor Analysis System Company

Collaborative research between OARDC/FAES researchers and computer scientists at OSU has resulted in a novel computerized pattern recognition system for use in seed vigor[28] analysis. The system has been developed to working stage, with prototypes installed in the field. An OSU start-up company would appear to be the logical result of this research and development program.

The seed vigor analysis system provides a unique approach to standardizing the assessment of seed at export and import sites. The seed market is global with large-scale cross-border shipments occurring. The seed has to be tested at both departure and arrival; but, the current subjective methods of vigor analysis create nonstandard metrics throughout the world—particularly in developing countries where analytical expertise is harder to acquire. The OSU-developed system uses scanners and interpretation software to rapidly measure seed vigor from a sample of seed and is currently being applied to major crops such as soybeans and corn. OSU has patented the approach and is preparing to either license the technology or generate a start-up business enterprise.

Additional Activities

Entrepreneurship momentum appears to be building now that Ohio's legislation has changed to be more favorable to faculty engagement in start-up companies based on their research. During the time period in which Battelle conducted its impact analysis and wrote this report, an additional two Ohio companies were founded based on OARDC research. These companies include Bavoy, Inc., which is applying new technology for processing soy for use in baked goods, and TurfTech Now, leveraging OARDC's expertise in turf grass development, systems, and management.

[28] Seed vigor is a measure of how fast and uniformly seed will germinate and grow.

Additional Impacts of the OARDC

As the Center's name implies, the primary role of the OARDC is research and development related to agriculture and agribusiness. That said, the work of the OARDC extends into education, workforce development, and social and community services through the integration of the Center's research into the activities of OSU Extension, ATI, and the degree programs of the OSU College of FAES. The OARDC also maintains active community service and outreach missions.

EDUCATION AND WORKFORCE DEVELOPMENT

Education is an important component of the work of the OARDC and many of its faculty. The OARDC serves as a critical knowledge generator and disseminator within an integrated OSU system providing research, dissemination of research, undergraduate education, graduate education, and professional development.

The OSU Extension is the primary outreach arm of Ohio State, established with the mission "to help people improve their lives through an educational process using scientific knowledge focused on identified issues and needs."[29] At its core, the OSU Extension is an applied educational network—working to strengthen communities and agriculture in Ohio. Multiple OARDC faculty also hold appointments in Extension—carrying their up-to-date research expertise into the field for direct Ohio application.

Extension groups its educational programs into four major areas:

- *Agriculture and Natural Resources*: commercial agriculture/horticulture/forestry management, recreational and urban gardening, environmental resource management and protection, risk management/marketing, and farm income enhancement
- *Community Development*: attracting new businesses, keeping and expanding existing businesses, recycling and composting, job training, leadership development, community visioning/goal development, public policy, and land use
- *Family and Consumer Sciences*: family life, nutrition, home-based businesses, budgeting, health and wellness, and managing multiple roles
- *4-H Youth Development*: career exploration, leadership and self-esteem development, and programs for youth-at-risk.

Sharing land directly adjacent to the OARDC in Wooster is the OSU ATI, providing two-year agriculture- and horticulture-related programs with transferability into four-year programs in Columbus. Being co-located with the ATI, the OARDC provides internships and employment opportunities for the Institute's agriculture and horticulture students.

The majority of the OARDC faculty hold teaching appointments within the OSU College of FAES. Using both distance education technology and frequent interchange of personnel between Wooster and Columbus, OARDC faculty are integral elements of the undergraduate and graduate

[29] http://www.ag.ohio-state.edu/.

teaching staff for the university. The OARDC is a particularly important provider of advanced education and training for masters and doctoral students—providing a choice of environments, including the studies and research at the Columbus campus and the deep research and applied learning resources of the large Wooster campus.

The OARDC also extends its outreach and education program reach through a wide variety of publications, newsletters, research bulletins, and the OARDC Website. These resources are widely available to Ohio's agricultural and agribusiness practitioners, bringing their level of knowledge up-to-speed on the latest agricultural research, techniques, and technology.

Social and Community Impacts

In addition to the OARDC's applied scientific research and development for agriculture and horticulture, the OARDC also has departments actively engaged in rural development, sociological research, and family studies. Studies relating to social and community issues in Ohio are conducted within two primary OARDC departments—Human and Community Resource Development and the College of Human Ecology. The following examples of the current research initiatives of these departments/colleges illustrate the range of current issues they are addressing in Ohio.

Within Human and Community Resource Development

- Community Development: Rural Ohio Workforce Preparation
- Decentralization, Capital Mobility, and Local Well-Being: Rural Counties in a New Policy Era
- Rural Restructuring: Causes and Consequences of Globalized Agricultural and Natural Resource Systems
- Community and Agricultural Change at the Rural-Urban Interface: A Sociological Perspective
- Rural Labor Markets: Workers, Firms, and Communities in Transition
- Systems Analysis of the Relationships of Agriculture and Food Systems to Community Health
- Attitudes of Ohio Residents Toward Production and Consumption of Genetically Modified Organisms

Within College of Human Ecology

- Rural Low-Income Families: Tracking Their Well-Being and Functioning in the Context of Welfare Reform
- Family Business Viability in Economically Vulnerable Communities
- Bequest Intentions and Retirement Adequacy of Families Who Own Farms or Businesses
- Economic and Social-Psychological Influences on Financial Decisions: Socially Responsible Investing

- The Impact of Marital Status on Women's Retirement Satisfaction
- Family Predictors of Child Behavior Problems: Parental Depression and Marital Problems
- Factors Related to Coparental Conflict After Divorce
- Understanding the Parenting Behaviors of Adolescent and Young Adult Males Who Have Fathered a Child With an Adolescent Mother
- Intervention Strategies for Divorcing Families: An Analysis of Providers, Programs, and Effectiveness
- Impact of Technology on Rural Consumer Access to Food
- Design and Evaluation of Food Safety Education for High Risk Groups
- Developing Evaluation Instruments for Consumer Food Safety Education
- Correction of Moderate Zinc Deficiency in the Elderly

Other Community Service

The OARDC and its faculty and staff are also actively engaged in community service and social outreach activities. Examples include

- The Campus Tour Program and the Open House Program
- K-12 liaison, education, and programming efforts.

In terms of volunteerism and community service, members of the faculty and administration of the OARDC have adopted important leadership roles in Wooster, Wayne County, and further afield in Ohio. Examples include

- The Wooster Board of Education (Casey Hoy serving as President in 2003)
- Wayne Economic Development Council (Bill Ravlin, Chair, 2002, Executive Board)
- Wooster Area Chamber of Commerce (Steve Slack, Director of the OARDC serving)
- Rotary, Lions, and Kiwanis service organizations (multiple faculty and staff)
- Active support and participation in the Wayne County Fair.

Future Initiatives—Emerging Opportunities for Expanding the Impacts and Benefits of the OARDC in Ohio

Throughout its 121-year history, the OARDC has constantly adjusted its areas of program focus to match the current and emerging needs and opportunities of horticulture, agriculture, and agribusiness in Ohio. As a research and development institution, the OARDC has to maintain its position at the forefront of science in agriculture—regularly adjusting and building upon its areas of research emphasis and expertise.

The 21st century has opened with dramatic advances in the biosciences. Advancements in genomics and post-genomic sciences (such as proteomics) have opened new avenues of study and paved the way for rapid progress in multiple areas of biology and the plant and life sciences. In response to the opportunities presented in what has been termed the "Biotech Century," the OARDC has multiple new and emerging initiatives aimed at leveraging life science advances and biotechnology for the benefit of Ohio and Ohioans. Chief among the new and emerging scientific initiatives of the OARDC are

- The Ohio Plant Biotechnology Consortium
- Ornamental Plant Germplasm Center
- Emerging infectious diseases research program and the Plant and Animal Agrosecurity Research facility
- Bio-based energy program.

In addition to the above OARDC initiatives, the Center is also engaged in multiple projects specifically geared to economic development and the leveraging of new scientific discoveries into commercial opportunities in the state. At the forefront of the OARDC's work in this area are

- ATECH (funded in part by FY 2004–2005 Ohio State Budget)
- BioHio research park and business incubator.

The OARDC is also funding several new interdisciplinary programs, including

- The Agroecosystems Management Program
- The Ohio Composting and Manure Management Program
- Organic Food and Farming Education and Research Program.

And, the Center is taking the leadership role in multiple externally funded research and development initiatives, including

- The Ohio Aquaculture program, which is federally funded
- The Center for Advanced Processing and Packaging Studies, funded by the NSF
- The Center for Innovative Food Technology, funded by the USDA.

Each of these new initiatives and programs has the potential to generate significant economic impact benefits for the state. An in-depth analysis of economic and community development potentials stemming from current and emerging OARDC initiatives is the subject of the later Phase II research to be performed by Battelle (see "Study Goals"). In the Phase I economic impact research reported herein, Battelle considers some of the basic impact parameters and potentials that may present themselves through the OARDC's new programs and emerging initiatives.

OARDC Initiatives

Ohio Plant Biotechnology Consortium

Headquartered at, and administered by, the OARDC in Wooster, the Ohio Plant Biotechnology Consortium has been established to facilitate collaborative work in Ohio biotechnology between 11 Ohio-based institutions.[30] The primary mission of the consortium is the pooling of scientific resources and talent to accelerate Ohio's plant biotechnology research and efficiently develop new plant and plant-based technologies. Benefits to Ohio are anticipated to come via

- The attraction of increased levels of external research funding into Ohio, especially given the preference of federal agencies such as the NIH and NSF to fund multi-institutional collaborative research
- The advancement of life sciences and plant biotechnology research in the state
- Improved commercial development of technologies and the applied development of new bio and bio-based products for Ohio's agriculture, food processing, biomedical, and other related sectors
- The leveraging of talent and resources from across the state, creating a whole that is greater than the sum of its parts.

Initial projects of the consortium have focused on developing mechanisms in soybeans to control insects and disease without applying chemicals, developing cold-hardy palms, and establishing genomic libraries for crop plants. Areas of continued exploration and research focus for the consortium are most likely to include recombinant DNA technology, pest resistance, bioremediation via plants, plant nutrition, new uses for traditional crops, nutraceuticals, and novel plant products.

Economic Impact Potential—*The Ohio Plant Biotechnology Consortium may result in multiple positive impacts for Ohio, including federal government and private industry research funding, new licensable and commercializable discoveries, and an enhanced position for Ohio in what is anticipated to be the 21st century's leading growth sector.*

[30] Membership of the consortium includes The Ohio State University (with consortium administration operated by the OARDC), Bowling Green State University, Cleveland State University, Kent State University, Medical College of Ohio, Miami University, Ohio University, University of Cincinnati, University of Toledo, Wright State University, and Youngstown State University.

Ornamental Plant Germplasm Center

The OPGC has been established at the Columbus campus as a joint project between OSU and the USDA. The primary mission of the center is to "conserve and nurture the world wealth of herbaceous ornamental plant diversity."[31] The center is one of 24 germplasm repositories in the National Plant Germplasm System. OSU established the OPGC with the goal "to build the OPGC into the world's leading herbaceous ornamental plant genebank."[32] As an extension of this goal, the center will work not only on genebanking, but also on research and development, education, and training.

The possession and presence of a germplasm repository presents Ohio with an important resource for future research and development initiatives. Through biotechnology techniques, the genes and genetic traits of one species can now cross species boundaries to impart beneficial characteristics in completely unrelated species. For example, a cold hardiness gene may be found in a particular ornamental herbaceous plant that may subsequently be transferred into other plants such as soybeans, tomatoes, or wheat. The possession of germplasm thus forms a basic building block upon which scientific progress and discoveries may be made.

The OPGC has been established not only to conserve and preserve germplasm, but also to serve as a part of a system designed to promote industry-oriented collaboration and enhance the commercial application of germplasm resources and knowledge. To this end, one of the goals of the OPGC is to build a network of partners and collaborators from academe, the horticultural industry, biotechnology industry, botanical gardens and arboreta, and the USDA.

Through the preservation of germplasm and the controlled dissemination of valuable germplasm for research and development purposes, the OPGC may be a resource to assist academic and industrial scientists develop future crops that are resistant to pests and disease; more efficient in their use of nutrients and environmental resources; and more appealing to the marketplace because of improved color, texture, taste, smell, or nutrition characteristics. The germplasm may also be valuable in applications outside of agriculture and horticulture—presenting opportunities in the discovery of medicines, chemical products, and other commercializable resources.

In working to achieve these goals and potentials, the OPGC will initially concentrate on the following activities:

- Collecting, documenting, and conserving genetic variation present in ornamentals and related plants in the wild
- Exchanging germplasm domestically and internationally to broaden the genetic base
- Identifying and evaluating useful genetic traits desired by the industry and consumers
- Providing germplasm to researchers in industry, universities, and other institutions for developing improved ornamentals
- Developing genetic maps of desirable traits for transfer into ornamental plants
- Identifying methods for successful long-term storage of ornamental germplasm as seed, tissue culture, and bulbs.

[31] http://opgc.osu.edu/main.asp?ID=2.
[32] http://opgc.osu.edu/main.asp?ID=2.

As noted previously in this report, after a period of dramatic growth in the 1970s, 1980s, and 1990s, the nursery and horticultural industries today represent the largest component of Ohio's agricultural production sector. OARDC research conducted in 2001 indicates that overall sales by certified nursery stock dealers and producers in Ohio totaled $2.79 billion with more than 96,000 persons working in the industry. Having a resource such as the OPGC dedicated to preserving and enhancing the ornamental plant germplasm resources in the state may result in new plant varieties, strains, and characteristics that will impart a competitive advantage for the sector in Ohio.

Economic Impact Potential—*Enhanced research funding, new licensable and commercializable discoveries, the enhancement and improvement of crops and other agricultural products via gene transfer technologies, and enhanced varieties of ornamental plants for Ohio nurseries.*

Emerging Infectious Diseases Research Program and the Plant and Animal Agrosecurity Research Facility

The widespread movement of people, goods, and commodities via rapid intercontinental transit and the increased globalization of trade have brought tremendous economic advantages to the United States' free trade, capitalist economy. While globalization has brought with it sustained economic advantages for the nation, it also comes with risks—risks imposed by the potential movement of diseases into the United States via accidental or deliberate (i.e., terrorist) means.

Today's U.S. agriculture is highly efficient, productive, and healthful based in large measure on the concerted science work of agricultural R&D centers such as the OARDC and the application of new technologies, techniques, varieties, and know-how by America's farmers and livestock producers. The stability and economic viability of this finely honed system of livestock production depend, however, on the maintenance of healthy animals. Indeed, the economic health of crop farmers in Ohio also depends on livestock health and demands because fully 80% of Ohio's crops are sold as livestock feed in a value-added process of producing high-quality, high-value meat and poultry. Emerging infectious diseases therefore represent a tremendous potential threat to agriculture in Ohio and the United States as a whole.

As noted earlier in this report, infectious disease outbreaks in livestock can have a devastating effect on an economy rooted in agriculture. The foot and mouth disease outbreak alone in the United Kingdom resulted in estimated economic losses totaling $15 billion. Massive levels of economic disruption could be caused in the United States by the spread of such a disease either by accidental transmission or by a deliberate bio-attack by terrorists or other enemies of the United States.

The OARDC maintains deep levels of expertise in infectious animal diseases and is home to the Food Animal Health Research Program—a program that contains some of the worlds leading experts in highly contagious respiratory, enteric, and other animal diseases. When the coronavirus SARS emerged as a pathogen with worldwide threat status, OARDC animal virologists were brought in by the CDC, NIH, and the U.S. Department of Defense to consult on the threat and approaches to be taken. The establishment of a formal animal agrosecurity initiative at OSU and the OARDC is a natural extension of the existing base of expertise and offers substantial economic development potential for the state in developing

- Rapid detection diagnostics tools, systems, and processes—tools likely to be in high demand both domestically and internationally

- Vaccines and other preventive tools
- Drugs, biologics, and treatment regimens to suppress outbreaks
- Quarantine, culling, and other systems and protocols to contain outbreaks and reduce the threat of diffusion.

The work in animal agrosecurity will be significantly enhanced at the OARDC by the recently funded BL-3 facility—providing a resource for the containment and study of highly infectious disease organisms and pathogens. Designed as a one-of-a-kind facility, the planned OARDC BL-3 installation will combine resources for isolating and studying both plant and animal organisms (thereby making optimal use of scientific and infrastructural resources). The OARDC anticipates that the BL-3 installation will facilitate three primary research areas:

- Emerging Animal Infectious Diseases—especially the investigation of zoonotic diseases (diseases that can transfer from animals into the human population).
- Insect/Vector-Borne Diseases—with the initial thrust being on vector-borne diseases of plants. The OARDC expects that one area of focus will be biocontrol, whereby insects (including exotic insects) may be used as predators to control pests (such as soybean aphids).
- Plant Diseases—with a focus on diseases that have not yet entered the Ohio environment but pose a risk of doing so. By working on these diseases (e.g., soybean rust) in a controlled environment, the OARDC can perform research to assure that the state is ready to deal with plant infectious disease outbreaks that may occur in the future. It is also expected that the BL-3 facility will be used for the safe conduct of transgenic experiments.

Economic Impact Potential—*The preservation of agricultural business volume and associated agribusinesses via the detection, prevention, or treatment of emerging animal diseases. New licensable and commercializable diagnostics, vaccines, and treatments and enhanced levels of federal and commercial research funding.*

Bio-Based Energy Program

Bio-based energy initiatives hold promise for creating benefits for farmers, industry, consumers, and the environment. Bioenergy comes from natural sources such as agricultural, forest, and aquatic resources and has the potential to produce a wide variety of commercial products including fuels, electricity, chemicals, adhesives, lubricants, and building materials.

Fuels from biomass have taken root in the United States. Ethanol produced from corn is one of the most visible of the existing products, but other applications of bioproducts are also in the marketplace. The U.S. Department of Energy and other policy makers have placed a priority on developing alternatives to fossil-based fuels and chemical products because these nonrenewable sources are being depleted and because biofuels would help the U.S. economy become less dependent on foreign fossil-fuel sources. With an emerging bio-based industry, agricultural research and development is moving beyond the traditional areas of food, feed, and fiber and is showing promise for a bio-based economy that will

- Be rooted in life sciences coupled with bioengineering processes
- Reduce the U.S. vulnerability in terms of access to and supply of petroleum for energy and industrial products

- Increase the sustainability of U.S. industry via the use of a domestically produced and indefinitely renewable base of plant resources
- Use R&D to become increasingly cost effective against depleting fossil-fuel resources
- Create new commodity outlets for farmers, increasing the economic viability of the farm and helping to create both rural and urban employment opportunities in new bio-based industries
- Produce value-added bio-based products (fuels, chemicals, and materials) for domestic use and for earning export dollars
- Provide demand for plant-based biomass that may be grown throughout the United States, rather than reliance on fossil-based resources that are present only in limited localities
- Improve the environment through lowered emission levels of pollutants, reduced acid rain, and reduced greenhouse gases.

Significant potential exists within the OARDC/OSU research establishment for the institution to adopt a leadership position in certain aspects of bioenergy and biofuels. One of the OARDC's current programs is focused on energy production from waste streams, and the team has taken the unique approach of examining the potential in higher-order waste streams generated within the food processing industry—an important industry in Ohio. By leveraging expertise in anaerobic digestion, microbiology, biochemistry, and engineering, it is anticipated that OSU may produce new processing technologies that provide two central economic benefits: (1) generating gases for the production of energy commodities and (2) substantially reducing waste streams that currently have significant disposal costs associated with them. OSU researchers are also working on biodiesel fuel, with the initiative focused on producing fuels from soybeans. Industry in Ohio is starting to take note of the progress being made on bioenergy and biofuels at the OARDC and OSU, and the potential exists to expand the research initiatives significantly into a formal research center. Further funding for infrastructure, such as a pilot plant digester, is required to move the research and application of research findings to the next level on the path to commercialization.

Economic Impact Potential—*Enhanced levels of federal government and private industry research funding, new licensable and commercializable discoveries, production of energy commodities from renewable bio sources, a significant reduction in waste disposal and remediation costs in Ohio, and an enhanced position for Ohio in what is anticipated to be one of the 21st century's leading growth sectors.*

ATECH Program

This initiative, titled the Food and Agricultural Technology Commercialization and Economic Development Program (ATECH), aims to foster and accelerate development as a result of university research and Extension programs with a primary focus on food, agricultural, environmental and life science technologies.

ATECH is designed to maximize the commercialization potential of OARDC research and will be formally staffed with personnel dedicated to realizing this potential. The staff will work to assist faculty staff and students in identifying and protecting intellectual property (IP)—it will then facilitate the commercialization or technology transfer of the technologies or knowledge into the private sector via new business enterprise formation or the licensing of technology to

new or existing commercial entities. It is also anticipated that ATECH will provide technical evaluation and market analysis services to both newly establishing and established companies.

At the current time, food, agricultural, and environmental sciences at OSU are a leading generator of IP, royalties, and licensing revenues for the university. The ATECH program is being developed to build on this existing track record through a formalized, professionally staffed service. With initial funding of more than $580,000, the ATECH program will recruit two senior staff into "Development and Marketing" and "Technology Commercialization" leadership positions, supported by two associates providing administrative and IP support. These positions are designed to dovetail with the BioHio Research Park development, helping to provide an integrated turnkey service for promoting ag-related economic development including applied research; commercializable IP protection; commercialization planning and development; industry partnerships; and co-location of new, established, and emerging agbioscience businesses on an OARDC research park.

Economic Impact Potential—*Enhanced levels of OARDC/OSU new business formations based on OARDC-developed research and technologies. Increased licensing, royalty, and technology commercialization revenue streams to seed further OSU initiatives in Ohio. Enhanced collaborative research and development partnerships between academe and food processing, agribusiness, environmental, and life science companies locating facilities on the BioHio research park. Enhanced economic output and employment base for Wooster, Wayne County, and the State of Ohio.*

BioHio Research Park

While the OARDC has been a generator of applied scientific research for the benefit of Ohio agriculture, legislative restrictions (which changed in 2000) on faculty engagement in commercial spin-offs limited its forming of new business enterprises. In addition, a lack of commercially oriented facilities, labs, and offices adjacent to the OARDC research complex placed limitations on creating local economic development benefits from OARDC/industry collaborations.

To foster technology-based agbioscience development, the OARDC and community stakeholders in Wayne County have worked with the Battelle Technology Partnership Practice to assess the feasibility of establishing an agriculture-oriented research and commercialization park on the OARDC campus site.

Battelle's research concluded that it is possible to develop a viable agbioscience research park in Wayne County. However, in order to do so, the region's efforts must focus on the key ingredients that will help spur economic growth, including developing research anchors, focusing on commercializing research into the marketplace through emerging firms, and nurturing those firms in the region through services and programs such as incubators and accelerators. Focusing resources, mobilizing private and public partnerships, and having patience and a long-term commitment are critical to developing the park.

An agbioscience research park in Wayne County can add real value to the region. The Greater Wayne County's industrial base, research assets, and global trends in agricultural markets would suggest that it would be in the best interest of the county to take advantage of test fields, an arboretum, and existing land by carefully planning and implementing a nontraditional research park.

But, to create a research park providing value-added, high-quality research and development jobs rather than another office park, it will be absolutely critical for the region to recognize that this is a long-term proposition that will require a sustained commitment. It should be anticipated that the research park will grow exponentially over an 8- to 10-year period or longer.

It also should be realized that the agbioscience research park is a unique design. It will seek to attract tenants based on their desire to be in close proximity to OARDC and the other proposed research anchors and to benefit from the services provided to park tenants. To build such a park requires that the project's sponsors be willing to secure public and private investments in the research and development anchors that will be needed to create a research park.

Economic Impact Potential—*Enhanced levels of OARDC/OSU new business formations based on OARDC-developed research and technologies. Enhanced collaborative research and development partnerships between academe and food processing, agribusiness and life science companies locating facilities at the research park. Enhanced economic output and employment base for Wooster, Wayne County, and the State of Ohio.*

ADDITIONAL OPPORTUNITIES

As noted previously, the OARDC is also funding the following new interdisciplinary programs.

The Agroecosystems Management Program

AMP has several key goals, most notably to

- Provide opportunities for those involved in research, teaching, and outreach from different disciplines and different institutions to interact, discuss, and develop whole systems approaches to the challenges affecting the food system.
- Foster an ecological approach to agriculture.
- Link together social, biological, and engineering sciences to provide a foundation for innovative processes and projects.[33]

AMP is designed to bring together stakeholders (including farmers, veterinarians, academic researchers, teachers, etc.) from different disciplines, backgrounds, and institutions to discuss and develop whole systems approach to the challenges affecting agriculture and rural communities. Its activities include public seminars on systems research, sustainable agriculture, and agroecosystems; sponsorship of stakeholder-initiated workshops on sustainable management practices; and support of local learning communities. AMP also has produced a practical management guide that relates basic principles of ecosystems-based management to specifics of crop and livestock production.. The program has developed a number of research proposals and projects on agroecosystems assessment, sustainable management practices, and preservation of rural communities. An undergraduate course has been added to the OSU curriculum, and educational materials have been developed for grades K-12.

[33] http://www.oardc.ohio-state.edu/amp/default.htm.

The AMP initiatives are aimed at supporting research, education, and outreach through an integrated program with activities that

- Emphasize on-farm participatory research.
- Make sustainable agricultural and ecological management an integral part of the college curriculum, and increase involvement of the farming community in student instruction and independent study.
- Facilitate the development of farmer-based cooperatives and value-added enterprises.
- Increase emphasis on extension activities in sustainable agriculture on a county-by-county basis, in particular building learning councils as continuing education activities.
- Find innovative ways of disseminating existing information about sustainable farming concepts and practices to the farming community.
- Sponsor exchange programs between Ohio and other states to build farmer leadership in sustainable agriculture.
- Host workshop/conference series on sustainable agricultural issues.
- Sponsor outreach activities specifically targeted at linking the interests of rural and urban communities.[34]

The Ohio Composting and Manure Management Program

Similar to AMP in its aim of encouraging sustainable agricultural practices, OCAMM's goal is to "research, develop and communicate sustainable strategies for the management of animal manure and nutrient inputs on Ohio farms."[35]

OCAMM is working on strategies such as composting, land application, facility design, and feed management—assessing these technologies and processes for their ability to recycle nutrients, reduce the need for chemical fertilizer and pesticide inputs, improve soil fertility, reduce odor emissions, and improve environmental stewardship. OCAMM program participants include livestock producers, livestock system consultants, equipment manufacturers, trade associations, compost users, and public agencies as well as faculty and staff at OSU. The overall goals of OCAMM are

- To develop, demonstrate, and teach the most economically, ecologically, and environmentally appropriate approaches to animal manure management for both large and small Ohio producers.
- To help Ohio livestock and composting businesses achieve consistent production of high-quality, diverse, stable, accurately labeled, and safe bioproducts that include various levels of animal manure.
- To maintain and build on OSU's regionally, nationally, and internationally recognized capabilities through exemplary teaching, research, demonstration, and outreach activities in composting and livestock manure management.[36]

[34] http://www.oardc.ohio-state.edu/amp/objectives.htm.
[35] http://www.oardc.ohio-state.edu/ocamm/.
[36] Ibid.

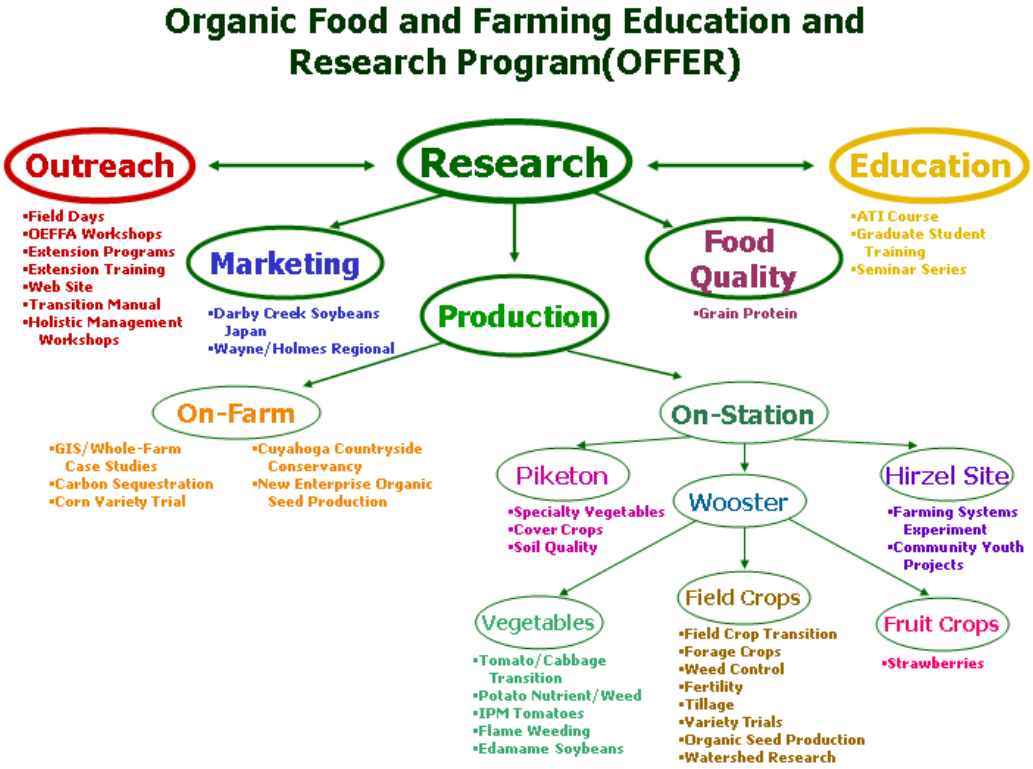
The OCAMM Program builds upon the existing expertise of OARDC scientists in composting and waste management technologies and practices (see "OARDC Impact on Composting and Potting Soil Technologies").

Organic Food and Farming Education and Research Program

OFFER comprises an interdisciplinary team working "to develop research initiatives to better characterize how organic agriculture works, particularly in terms of underlying crop-soil relationships, pest control, economics, and system management."[37]

The OARDC has allocated funds to support research conducted at either the OARDC main campus in Wooster, branch experiment stations around Ohio, or on private organic and transitional farms. The breadth of the interdisciplinary work of OFFER and its links to research stations and private farms throughout Ohio are illustrated in Figure 8.

Figure 8: OARDC's OFFER Program



As with AMP and OCAMM, the OFFER Program is focused on both research and educational activities. Key research focus areas are in field crops, vegetables, fruit crops, food quality, and whole farm management. Educational activities include the development of manuals and educational materials for farmers, the conduct of management workshops and training programs, and outreach activities aimed at enhancing understanding of the benefits and economics of a holistic and organic approach to farming.

[37] http://www.oardc.ohio-state.edu/offer.

The emerging emphasis of the OARDC on organic and sustainable agricultural practices serves to demonstrate the broad scope of the agricultural research complex at OSU. The organic work runs in parallel to that of state-of-the-art breeding, genomics, and proteomics research initiatives that also characterize many of the OARDC research projects.

The OARDC is also taking a leadership role in the following federally funded research and development initiatives.

The Ohio Aquaculture Program

Operated from the OARDC Piketon branch station, the Ohio Aquaculture Program is helping to lead diversification of income streams for Ohio farmers through the application of the aquaculture of fish and freshwater shrimp. The OAP works to provide practitioners and potential aquaculturists in Ohio with information on fish culture methods, nutritional requirements, aquacultural system design and management, species selection, and water quality management.[38]

The Piketon center is fielding an increasing volume of inquiries and requests for information in relation to aquaculture. Currently this is, however, still a fledgling industry in Ohio, with its growth being supported by the OARDC through

- Research on appropriate fish species, shrimp species, spawning, aquaculture methods and management
- Educational programs, materials, and seminars aimed at enhancing the efficiency of current aquaculturists in Ohio and providing potential producers with the in-depth knowledge required to make informed production decisions.

The Center for Advanced Processing and Packaging Studies

CAPPS is a major federal initiative funded by the NSF. The goal of the initiative is "to conduct industrially relevant research directed at developing methods and technologies for the production of safe, marketable, high-quality shelf-stable aseptic and refrigerated extended shelf-life products."[39]

The initiative brings together OSU scientists in agriculture, food science, engineering, and a broad variety of additional disciplines to work on projects that

- Enhance the safety and quality of aseptic and extended shelf-life products
- Characterize emerging, aseptic and extended shelf-life processes
- Assure the integrity and functionality of aseptic and extended shelf-life packaging.[40]

CAPPS is a pragmatic, applied initiative that links university scientists and scientific resources with key industrial players in the food packaging, aseptic processing, and related technology manufacturers. This emerging initiative has already attracted the involvement and formal membership of some of the major corporations active within the industry, including Coca-Cola, ConAgra Foods, Gerber, Kraft Foods, Procter & Gamble, Abbott Labs, and Tetra Pak.

[38] http://southcenters.osu.edu/aqua/.
[39] http://www-fst.ag.ohio-state.edu/CAPPS/mission.html.
[40] http://www-fst.ag.ohio-state.edu/CAPPS/objectives.html.

Some of the research approaches being taken under the CAPPS initiative include those in sterilization and pasteurization using pulsed electric fields, ohmic heating and high pressure methodologies (see "OARDC Impact on Food Safety and Processing Technologies").

The Center for Innovative Food Technology

CIFT is an initiative funded by the USDA. Like CAPPS, CIFT is an interdisciplinary program aimed at providing formal links between scientists and academic researchers in the university community and industry practitioners—and through these links it aims to provide applied solutions to problems and challenges in topics ranging from food safety and quality to functional foods and "foods of the future."

As a core goal, CIFT is working to provide U.S. and Ohio food processors with technical solutions that will give them a competitive edge in one of the largest industry sectors. It also provides training and education services and information services targeted at small business development within the sector.

Conclusion

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 more than 1,600 jobs. These expenditure impacts are, however, eclipsed in their importance by the benefits accruing to the state through the intensive R&D activities housed within the OARDC's campuses. The OARDC is a scientific institution with a uniquely practical mission—enhance agricultural and agribusiness productivity and sustainability through intensive programs of applied research. In terms of OARDC's work only in developing 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 preventing and responding to infectious food diseases saves Ohio's agriculture from the potential of large-scale economic losses, through disease outbreaks, that 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 sustaining and enhancing 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 preeminent biosciences and agbiotech R&D center as the U.S. economy moves into what has been termed the "Biotech 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 agbiosciences bodes well for Ohio to achieve a prominent, if not leading, position in the most promising area of the knowledge economy.

Appendix A: Input/Output Analysis—Impact of OARDC Expenditures on Sectors of the Ohio Economy

Data presented on the appendix table show the indirect employment impact of the OARDC expenditures in the State of Ohio. It is important to note that these are only indirect jobs created by OARDC budgetary spending; they do *not* include jobs generated through OARDC R&D activities, which would be considerably in excess of these figures within the agriculture, horticulture, and food processing sectors of the Ohio economy.

	IMPLAN Sectors with >0.5 jobs created	Ohio Employment Impact
23	Greenhouse and Nursery Products	1
27	Landscape and Horticultural Services	3
38	Natural Gas and Crude Petroleum	3
55	Maintenance and Repair—Residential	2
56	Maintenance and Repair Other Facilities	16
59	Sausages and Other Prepared Meats	1
79	Bread—Cake—and Related Products	1
148	Wood Household Furniture	1
164	Paperboard Containers and Boxes	1
174	Newspapers	2
179	Commercial Printing	2
386	Motor Vehicle Parts and Accessories	1
434	Local—Interurban Passenger Transit	2
435	Motor Freight Transport and Warehousing	10
437	Air Transportation	1
440	Transportation Services	1
441	Communications—Except Radio and TV	5
442	Radio and TV Broadcasting	1
443	Electric Services	2
446	Sanitary Services and Steam Supply	1
447	Wholesale Trade	3
448	Building Materials and Gardening	9
449	General Merchandise Stores	25
450	Food Stores	33
451	Automotive Dealers and Service Stations	23
452	Apparel and Accessory Stores	9
453	Furniture and Home Furnishings Stores	10
454	Eating and Drinking	65
455	Miscellaneous Retail	44
456	Banking	10

457	Credit Agencies	13
458	Security and Commodity Brokers	3
459	Insurance Carriers	8
460	Insurance Agents and Brokers	4
462	Real Estate	22
463	Hotels and Lodging Places	6
464	Laundry- Cleaning and Shoe Repair	7
465	Portrait and Photographic Studios	1
466	Beauty and Barber Shops	8
467	Funeral Service and Crematories	2
468	Miscellaneous Personal Services	3
469	Advertising	1
470	Other Business Services	7
471	Photofinishing—Commercial Photography	1
472	Services to Buildings	5
473	Equipment Rental and Leasing	1
474	Personnel Supply Services	24
475	Computer and Data Processing Services	10
476	Detective and Protective Services	3
477	Automobile Rental and Leasing	2
478	Automobile Parking and Car Wash	2
479	Automobile Repair and Services	7
480	Electrical Repair Service	1
481	Watch—Clock—Jewelry and Furniture Repair	0
482	Miscellaneous Repair Shops	2
483	Motion Pictures	2
484	Theatrical Producers—Bands Etc.	1
485	Bowling Alleys and Pool Halls	1
486	Commercial Sports Except Racing	1
487	Racing and Track Operation	1
488	Amusement and Recreation Services—N.E.C.	11
489	Membership Sports and Recreation Clubs	4
490	Doctors and Dentists	29
491	Nursing and Protective Care	16
492	Hospitals	37
493	Other Medical and Health Services	11
494	Legal Services	9
495	Elementary and Secondary Schools	6
496	Colleges—Universities—Schools	8
497	Other Educational Services	3
498	Job Trainings and Related Services	1
499	Child Day Care Services	5
500	Social Services—N.E.C.	8

501	Residential Care	7
502	Other Nonprofit Organizations	4
503	Business Associations	3
504	Labor and Civic Organizations	12
505	Religious Organizations	2
506	Engineering—Architectural Services	9
507	Accounting—Auditing and Bookkeeping	11
508	Management and Consulting Services	8
509	Research—Development and Testing Services	3
512	Other State and Local Govt Enterprises	4
513	U.S. Postal Service	4
522	State and Local Government—Education	62
525	Domestic Services	6
		752