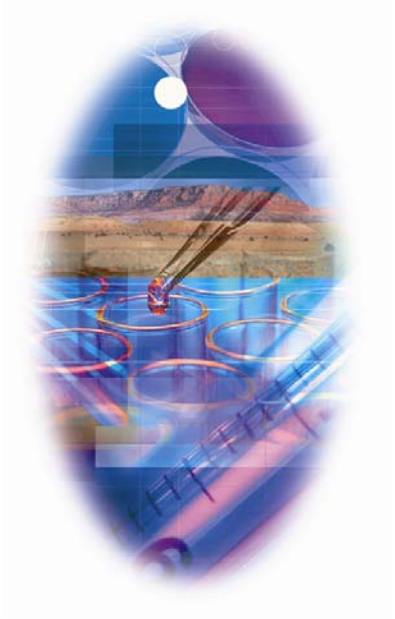
Arizona BioAgriculture Research Platform Strategic Plan

November 2007



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I. Strategic Vision and Focus for BioAgriculture Research Platform

Strategic Vision

Through rigorous R&D initiatives at Arizona's research universities, Arizona has built a strong base in plant research and is now positioned to capture a leadership position in the development of non-traditional, bioagriculture-based technologies. These technologies leverage Arizona's unique environmental and climatic conditions and show promise for the state attaining major shares of multiple high-growth market sectors, including:

- Biofuel and bioenergy production using microbial systems
- Controlled environment agriculture, biopharming, and functional foods
- Plant mining for pharmaceutical and non-pharmaceutical products
- Insect pest control for agricultural, forest, and urban environments
- Biofuel and bioenergy production using plants

By building upon clusters of proven R&D expertise and by investing in the development and commercialization of new technologies rooted in these strategic focus areas, Arizona can experience significant bioagriculture-based economic growth while building a strong presence in multi-billion dollar growth markets.

BioAgriculture in Arizona: Context and Background

Agriculture in Arizona has distinct advantages (e.g., abundant sunshine, high temperatures throughout the year, plentiful land area) and at the same time faces a set of practical parameters (e.g., limited water supply, increasing housing developments) within which to operate. Recent advances in biotechnology have given rise to new opportunities in agriculture that Arizona is uniquely positioned to lead. The BioAgriculture Research Platform in Arizona is designed to provide a framework for academia, government, and industry to assist in developing areas in BioAgriculture on which the state should capitalize.

Traditional agriculture remains an important economic driver for the state. The total market value of agricultural products sold by Arizona producers increased substantially between 1992 and 2002, growing from $1.5 billion in 1992 to $2.4 billion in 2002. Both crops and livestock revenues increased, with the largest gains coming in the crops sector (including nursery and greenhouse crops), which grew from $900 million in sales in 1992 to $1.6 billion in 2002. Additionally, confinement animal agriculture systems (dairy and feedlot) grew in size, resulting in increased opportunity to provide nutrient sources (animal waste) for energy production and water conservation. These increases are particularly striking as the amount of

farmland in Arizona has actually decreased due to housing developments and other factors.

In addition to the growth that has been occurring in Arizona agriculture, the state has numerous opportunities for further advancing its agriculture and bioagriculture-related economy along several exciting new technological pathways. Driven by intensive R&D initiatives at Arizona's research universities, new technologies are emerging that show promise for Arizona building a leadership position in multiple high-growth market sectors. These include bioenergy, controlled environment agriculture, natural products and insect control products.

Advancing Arizona's position as a bioagriculture research leader requires focusing on those activities where the state has a competitive advantage and the capabilities to leverage these advantages for economic growth. Furthermore, commercialization of new bioag technologies needs to be undertaken with sensitivity to the special pressures placed on the Arizona environment imposed by land use, climate, scarce water resources, and population expansion. A delicate balance has to be struck between growing and optimizing the economic impacts of bioag, while at the same time maintaining or improving environmental sustainability. As will be seen in this document, science and technology at Arizona's research universities show great promise for managing such balance. New bioagriculture products and growth opportunities are being generated along pathways that leverage Arizona's unique resources, while having negligible negative impacts on environmental sustainability.

IDENTIFIED FOCUS AREAS FOR BIOAGRICULTURE RESEARCH DEVELOPMENT

Both quantitative and qualitative investigations reveal that Arizona has multiple bioagriculture R&D core competencies offering potential for further development. For Arizona to position itself as a leader in bioagriculture, it must capitalize on existing and emerging strengths in specific areas and attain competitive advantage in how these areas are translated to success at the commercial level. Battelle's analysis identified multiple areas of bioagriculture R&D strengths within Arizona's research institutions. The bioagriculture platform committee helped to consolidate and/or narrow down the list to five core opportunity areas that present a convergence of clear R&D strengths with major market opportunity. This process involved measuring each R&D area against several key metrics to determine the best prospects for strategic development. Each potential area was evaluated in terms of whether or not it:

- Is a clear current R&D strength for Arizona;
- Presents an opportunity to attract major external R&D funding (such as federal research grants);
- Has existing Arizona centers and institutes around which further development may be concentrated;
- Has links to existing Arizona industry (or presents potential for the establishment of such links);
- Is likely to result in the formation of new Arizona businesses;
- Relates to issues, problems or needs facing the State of Arizona; and
- Is an area where there is currently limited competition from other regions.

Based on the above parameters, it was determined that the following five focus areas are the best fit for moving forward bioagriculture-based economic development in Arizona. Each of these areas has significant market potential, an established existing base of R&D expertise to build upon and meets the additional goal of being environmentally sustainable.

- **Microbe-based biofuels** – The primary focus is on the production of bioenergy resources (including biodiesel) from phototrophic microorganisms using sunlight. Arizona scientists have contributed to developing these processes, which perform best in the Arizona climate, and hold promise for reducing dependence on foreign energy as well as for reducing net CO_2 production. This focus on microbial biofuel systems is supported by the R&D area of converting the energy value of **animal waste and other waste-stream systems** (e.g., crop residues and human waste) to socially useful forms. Waste-stream remediation is another significant benefit within the bioenergy arena.
- **Controlled environment agriculture (CEA), biopharming, and functional foods –** CEA is an agricultural technology in which all aspects of plant growth are highly controlled. In Arizona, CEA is used most conspicuously for the production of tomatoes, but strong potential exists for its use in the production of a wide variety of high cash value foods and medically important crops. CEA initiatives are supported by the R&D focus areas merged with faculty expertise in plant physiology, horticulture, **plant genetics and genomics**, and **plant propagation and genetic transformation technologies**. Biopharming is the engineering of plants as "medicine factories." Biopharma plants are designed to produce large quantities of drugs, vaccines or other health-related compounds. Functional foods are natural or modified foods that may provide unique health or medical benefits. Plants designed for biopharming or for the harvest of functional foods can be grown under CEA conditions where modulation of the environment makes possible optimal plant growth and the production of specialized proteins or other health-related molecules or compounds. CEA conditions are conducive to Good Manufacturing Practice (GMP) and downstream processing capabilities.
- **Plant "mining" for pharmaceutical and non-pharmaceutical products –** The identification and isolation from plants of high-value products such as proteins, small molecules, or other bioactive compounds represents a valuable opportunity for Arizona. Unique plants that could be mined include plants native to the arid and semi-arid regions of the state and modified plants engineered by Arizona's research scientists.
- **Agricultural, forest and urban pest control –** Arizona's unique position of strength in basic and applied insect sciences shows promise for translational research directed at integrated approaches to insect control and insect-based pollination markets. Insect sciences in Arizona have broad R&D relevance to pest and vector control, and to plant pollination, which relates to all bioagriculture platform opportunities.
- **Plant-based biofuels** – The primary focus on plant-based biofuels is supported by the activities in **biomass production and processing improvement** and **plant genetics and genomics.** Plant-based biofuels (specifically cellulosics) are a longer-term opportunity for the state because of a lack of current R&D emphasis in this area, limited arable land and strong competition from other regions. However, Arizona has the depth in plant sciences required to move forward in this area if it chooses to do so. Activities in production and processing systems within agriculture biosystems engineering and strengths in alternative crop systems also complement this field.

- Microbe-based biofuels
- Controlled environment agriculture (CEA), biopharming, and functional foods
- Plant "mining" for pharmaceutical and non-pharmaceutical products
- Agricultural, forest and urban pest control
- Plant-based biofuels

The following sections describe Arizona's current position in each opportunity area, exploring its research assets and position, opportunity to attract major external R&D funding, industry position

for linkages and new firm formation, how it relates to Arizona needs, and competition from other states.

		Current R&D Strength in Arizona	Opportunity to Attract Major External R&D Funding	Existing Arizona Centers and Institutions to Build Around	Current Arizona Industry Linkages or Potential Linkages	Likely to Result in Formation of Arizona Businesses	Related to Arizona Issues, Problems or Needs	Limited Amount of Major Competition from Other Regions	Overall Opportunity Rating	Development Timeframe
Microbe-based Biofuels	**P**	√ √	√ √	√ √	√ √	√ √	√	√	**Excellent**	**Mid**
Animal waste and other waste-stream systems (biogas)	S	√	√ √	√	√ √	√	√		Very Good	Mid
Controlled Environment Agriculture, Biopharming and Functional Foods	**P**	√ √	√	√	√ √	√	√	√	**Excellent**	**Near**
Plant genetics and genomics	S	√ √	√ √	√ √	√	√	√		Excellent	Near
Plant propagation and genetic transformation technologies	S	√ √	√	√ √	√	√			Very Good	Mid
Plant "Mining" for Pharmaceutical and Non-pharmaceutical Products	**P**	√ √	√ √	√	√	√	√	√	**Excellent**	**Mid**
Agricultural, Forest and Urban Pest Control	**P**	√ √	√	√		√	√	√	**Very Good**	**Far**
Infectious disease vector monitoring, analysis and control	S	√	√ √	√			√		Very Good	Far
Plant-based Biofuels	**P**		√ √		√	√			**Good**	**Far**
Biomass production and processing improvement	S		√ √		√	√	√		Good	Far
Plant genetics and genomics	S	√ √	√ √	√ √	√	√	√		Excellent	Near
		P = Primary focus area; S = Supporting R&D focus area								

II. Assessment of Opportunity Areas for Advancing the BioAgriculture Research Platform

Five unique opportunity areas where Arizona could achieve a position of excellence were identified. For each of these areas, described below are the assets already in place as well as projected investments needed to fill identified key resource gaps.

MICROBE-BASED BIOFUELS

Arizona provides unique capabilities for production of renewable biofuels using microbial-based processes due to our large amount of sunlight, water for agriculture (wastewater in particular), diversified agriculture, available land, and strong research base. Other states of the western U.S. have many of these components; however close proximity of land and water to produce fuel crops with the availability of large CAFO (confined animal feeding operations) provides a means for multi-resource production streams that greatly improve economics. This model of generating multiple, highly-diversified products from multiple feedstocks has been the foundation for the two newest energy facilities in Arizona. Pinal Energy (Maricopa, AZ) in addition to making ethanol from corn, generates distiller's grains fed to neighboring cattle. XL Dairy Group (Vicksburg, AZ) is currently building a biorefinery that features three components: dairy, waste energy and a biorefinery for ethanol and biodiesel.

Supported by Animal Waste and Other Waste-stream Systems

Microbial systems generate a range of valuable biofuels. In one attractive scenario, photosynthetic microorganisms are the main source of fuel themselves, as they convert sunlight energy and CO_2 into compounds that can be modified to useful fuel. One of the primary advantages of microbe-based biofuels over conventional biofuels, such as corn-based ethanol, is a potentially far greater net energy yield. Furthermore, the microbial systems do not compete with food production. Certain species of photosynthetic microorganisms, including cyanobacteria and algae, are ideally suited for biodiesel production because of their high lipid content and rapid growth rate. Inputs required for microbial-based bioenergy systems include sunlight, CO_2 and nutrients. Systems developed at Arizona State University (ASU) leverage CO_2 from power plant emissions and nutrients from nitrogen-rich dairy farm waste streams or contaminated groundwater as inputs to the biomass production process. At the University of Arizona (U of A), biofuel-producing algae-biomass photobioreactor systems that sequester CO_2 from electric power plants and recycles secondary treated wastewater are being designed and developed. Another suitable scenario leading to bioenergy production is microbial systems converting the energy from a range of biomass materials (e.g., animal wastes, human wastes, agricultural product, or photosynthetic microbes) to highly useful energy forms, including methane, natural gas, hydrogen, ethanol, and electricity. While renewable energy production is the principal benefit of these systems, other benefits include waste-stream treatment and the production of high-value compounds such as fertilizers, animal feed, and nutraceuticals.

Identified Assets

- **Core research strengths** – Arizona is home to experts in a number of basic research areas that are fundamental to this theme of microbe-based bioenergy. These areas include:

- **Molecular and genomic sciences** – Leading researchers at ASU are focusing on understanding the physiology of cyanobacteria and algae using genomic, proteomic and metabolomic information. At the U of A, physiological and environmental strategies are being employed to coax certain photosynthetic algae species to achieve sustained production of hydrogen gas under anaerobic conditions. The knowledge gained from these pursuits is expected to lead to an improved ability to engineer these organisms for bioenergy applications.
- **Phycology** – Leading researchers at the ASU Polytechnic Campus are experts in phycology, the study of algae. Projects directly related to microbial bioenergy systems include the study of algae as lipid and renewable energy sources and the identification and characterization of new microalgal species. At the U of A, the growth regimes of algae/cyanobacteria species/strains with high yields of hydrocarbons, lipids, starch and hydrogen gas are being designed and optimized. Projects in this area are also underway at Northern Arizona University (NAU).
- **Photobioreactor Design** – Leading researchers at the U of A's Department of Agricultural and Biosystems Engineering and at ASU Polytechnic Campus are engaged in the engineering design and scale up of algae photobioreactors for the large-scale mass production of algae for biofuel production.
- **Bioremediation, environmental engineering and water quality –** Research projects at ASU include understanding the aquatic ecology of Arizona water supplies and how a range of microbial systems can be used for water and environmental remediation. Researchers have demonstrated expertise in the design, development and optimization of outdoor experimental photobioreactor systems. The application of biofilms for environmental cleanup is a key research focus at the Center for Environmental Biotechnology at ASU's Biodesign Institute. Further remediation expertise is contained within the Department of Soil, Water and Environmental Sciences at University of Arizona, which focuses on a broad range of environmental issues, including groundwater contamination and water quality. The department is the home of the National Science Foundation Water Quality Center. Also at the U of A, the Department of Agricultural and Biosystems Engineering is conducting research investigations on the use of microbial mat consortia in remediating secondary treated wastewater as well as on the use of crop hydroponics in remediating aquaculture wastewater. At NAU, the BIORIN (Bioremediation Initiative) focuses on the development and application of molecular, chemical and isotopic technologies for use in planning and tracking bioremediation efforts
- **Animal agriculture** – Researchers in the Departments of Animal Science and Veterinary Science and Schools of Natural Resources and Nutritional Sciences at the U of A College of Agriculture and Life Sciences possess broad capabilities in livestock production and management under the semi-arid conditions of Arizona. These capabilities can be integrated with bioenergy research activities to increase the efficiency of livestock operations and associated waste management and handling, and reduce environmental impacts.

- **Center for Environmental Biotechnology, ASU Biodesign Institute** – The Center uses techniques in microbiology,

molecular biology, chemistry and engineering to develop systems for producing renewable resources and cleaning up environmental pollution.

- **Center for Bioenergy and Photosynthesis, ASU** – This consortium of approximately 20 researchers is exploring photosynthesis and is an asset for understanding the microbial processes involved in the conversion of CO_2 and nutrient-rich liquids to bioenergy.
- **BIO5 Institute, U of A** – This Institute brings together scientists from agriculture, medicine, pharmacy, basic science and engineering to treat disease, feed humanity and preserve livable environments through use of microbiology, molecular biology, computational biology, genomics, chemistry and engineering.
- **Arizona dairy farm waste streams** – There are over 200 dairy farms in Arizona producing on average at least 1000 tons of nitrogen (in dairy waste) per year. Value may be captured from this waste-stream by using it as input for microbial bioenergy systems, which require nitrogen-rich liquid as a nutrient and energy source.
- **Intellectual property** – Ten provisional and utility patents have been issued to Arizona Technology Enterprises (AZTE) to cover the use of a number of microbial species for photosynthesis-driven, bioremediation and bioenergy production applications.

Opportunity to Attract Major External R&D Funding

Strategic national security and economic security concerns as well as concerning regarding potential global climate change due to greenhouse gas accumulation are driving substantial federal commitments to alternative energy research and development. Coupled with rising concerns over biofuel impacts crop commodity prices and availability, there is likely to be considerable support made available for biofuel production that would not require the use of existing agricultural crop and range land. Anticipated funding agencies include the DOE, USDA, NSF and state energy R&D funds, as well as major petroleum companies.

Current or Future Industry Linkages and New Firm Formation Potential

Alternative energy companies are starting to form in Arizona. Examples include GreenFuels Technologies Co., which began operations in 2006 and collaborates with Arizona Public Service, and Petroalgae, which is investing $25 million in microalgae bioenergy research at ASU-Polytechnic. In addition, Arizona-based companies such as PetroSun have significant interest in renewable, microorganism-based biofuel production. State-ordered renewable energy mandates have generated an impetus for Arizona public utilities and associated companies to invest in new renewable energy projects. The novel nature of microbial bioenergy systems will likely result in the development of new production and processing technologies, and, therefore, drive the development and growth of new commercial enterprise to develop, manufacture, distribute and service these technologies. There will also be significant commercial potential contained in the operation of microbial bioenergy production facilities, the processing of microbial bioenergy fuels and chemical by-products, and the sales and distribution of these products.

Related to Arizona Issues, Problems or Needs

Microbe-based biofuel projects are well-suited to Arizona's climate and are expected to be structured as closed-loop systems whereby water resources are recycled in the process. Arizona's arid and semi-arid climate means that the state would have a fairly difficult time competing in the production of traditional biomass crops, whereas the state's broad expanses of undeveloped and sun-baked land lend

themselves extremely well to certain alternative crops and to microbial biofuel production concepts.

Competition from Other States

There is certainly widespread and significant competition in the development of biofuels and products. However, most states are squarely focused on agricultural crop-based biofuel production (such as ethanol from corn or biodiesel from soy beans), with less attention being paid to novel approaches such as microbial biofuel production. A continuing national emphasis on deriving fuels from cellulosic plant biomass may render the playing field relatively open in the promising niche field of bioenergy production.

Controlled Environment Agriculture, Biopharming, and Functional Food Production

Supported by Plant Genetics and Genomics and by Plant Propagation and Genetic TransformationTechnologies

Controlled environment agriculture (CEA) enables "extreme plant production." Every aspect of plant growth in CEA conditions is monitored and adjusted as needed to ensure that the plants achieve maximum performance. CEA is an environmentally sound, high-technology industry applied to the production of food crops, flowers, houseplants, transplants, and bio-medicinal products. Within the sphere of CEA, biopharming, or "molecular farming," is an emerging, highly promising platform for producing proteins, drugs or "edible vaccines" from transgenic plants instead of using conventional manufacturing methods. Biopharming is predicted to reduce the costs of scale-up and capital investment in new drug production. CEA is the logical venue for biopharming production as it assures a quality-controlled and secure-production environment for these valuable plants and reduces the risks of transgene migration into the environment. Functional foods are fresh or modified foods or food components that may provide a health benefit beyond simple nutrition. CEA will provide consistency in product quality and quantity, and can maximize the production of bioactive components in foods.

Identified Assets

- **Research capacity –** The 2005 Faculty Scholarly Productivity Index, by Academic Analytics, a company owned partially by the State University of New York at Stony Brook, ranked 7,294 individual doctoral programs in 104 disciplines at 354 institutions and reported their results in the Chronicle of Higher Education. The quantitative assessment included refereed journal publications, citations, grants received, etc., all of which depend on documented peer evaluation. Their rankings for the U of A's College of Agriculture and Life Sciences are summarized in the following table:

University of Arizona College/Department	National Ranking
College of Agriculture and Life Sciences	1
Agronomy and Crop Sciences	1
Entomology	2
Nutrition	10

- **Core research strengths** – Arizona is home to experts in a number of basic research areas that are fundamental to controlled environment agriculture and biopharming (the production of medicines or vaccines using transgenic plants). These areas include:
    - **Biopharming** – Researchers at ASU are global leaders in the field of biopharming. AZTE holds a number of patents covering the use of plants as tools for synthesizing

medically useful compounds. Current plant-made pharmaceutical products at ASU include Hepatitis B and C vaccines, mucosal vaccines for STIs, Ebola vaccine, Norwalk Virus vaccine, plague vaccine, and several others. No other single state university/academic center exceeds ASU's capabilities in biopharming or its network with partners in the U.S. and Europe. The USDA Agriculture Experimental Research Stations also are actively exploring the development of edible vaccines through partnerships with industry.

  - **Arid/Semi-arid Plant Research** – The Office of Arid Land Studies at the U of A is a leader in arid land use management and water conservation and reclamation, topics that are very much tied to the practice of controlled environment agriculture. The new USDA Arid Land Agriculture Research Center in Maricopa is dedicated to studies surrounding environmentally friendly agricultural practices for arid climates.

- **Agricultural Practices and Sustainability –** The U of A's Agricultural Experimental Station's Agricultural Centers in Arizona are investigating methods for improving irrigation efficiency, disease control and disease resistance management. There are also significant strengths throughout the state in confinement animal agriculture. Researchers in the Departments of Animal Science and Veterinary Science, and Schools of Natural Resources and Nutritional Sciences at the U of A College of Agriculture and Life Sciences possess broad capabilities in livestock production and management under the semi-arid conditions of Arizona. These capabilities can be integrated with controlled environment agriculture to increase the efficiency of livestock operations and reduce environmental impacts.

- **Translational Agriculture Research Platform** – The U of A's Agricultural Experiment Station and the BIO5 Institute support "translational" research for CEA, biopharming and functional food production, which extends basic biological research findings into useful applications. Research areas include developing strategies to protect plants, grown either in the field or under CEA conditions, from biotic stresses caused by damaging arthropod pests and vectors, and new and emergent plant viruses and other plant pathogens. Plants can be "immunized" from pathogen and pest attack using pathogen-derived resistance strategies to express pathogen genes in transgenic plants, and molecular genetics and plant breeding tools, separately or "stacked," to improve plant health. In addition, the partnership between BIO5 and World Wide Wheat is developing more nutritional wheat and barley varieties that will have positive outcomes to human health.

- **Plant Genetics and Genomics** – The Plant Sciences Department at UA has internationally recognized strength in plant genetics and genomics, providing a unique academic setting for leading-edge research both in basic and applied agricultural genomics and in bioinformatics. Research programs range from the functional genomics of crop plants (rice, maize, cotton) to the biosynthesis of plant secondary metabolites, the developmental regulation of plant gene expression, the evolutionary genomics of plants and plant pathogens, response of plants to abiotic stress such as heat and drought, and the development of bioinformatics computing software for use in agricultural research and beyond.

- **Diet, Nutrition and Cancer Prevention Research** – The Department of Nutritional Sciences in the College of Agriculture and Life Sciences and the Arizona Cancer Center at the U of A support research focusing on the importance of consumption of fruits and vegetables and bioactive compounds in foods in preventing cancer and cardiovascular diseases.

- **The U of A Controlled Environment Agriculture Center** – This interdisciplinary center is a unique and valuable resource and a global leader in developing CEA as an economically, environmentally, and socially sustainable option for agricultural production. Center research focuses on a number of areas including the growth and development of sustainable greenhouse crops, innovative plant production systems, and technologies for monitoring and modulating the environment to reduce abiotic and biotic stresses, including innovative approaches to manage plant pathogens. It is also home to significant education and training facilities to meet the CEA industry needs, with an emphasis on the greenhouse hydroponics industry.
- **Arizona Greenhouse Hydroponics Industry** – Arizona has the second largest greenhouse vegetable production and the largest hydroponics area in the U.S. The state has approximately 350 acres of greenhouses, exhibiting an annual growth of 15%, most of which are located in Cochise and Graham Counties. Furthermore, the Arizona greenhouse hydroponics industries are leaders in practicing sustainable crop production techniques, such as biological pathogen and disease control and recycled water use.

Opportunity to Attract Major External R&D Funding

There is a national and international imperative for finding lower-cost solutions to the production of drugs, biologics and vaccines. The rising cost of healthcare attributed with high-cost pharmaceuticals, coupled with biosecurity associated pressures for scalable production of vaccines and other "strategic" therapeutics, suggest that funding should be available for alternative, scalable production approaches. Funding will most likely come from federal resources, and also from private industry within the biopharma sector.

Increasing emphasis on diet and healthy living and a trend towards sustainability and organic agriculture also bodes well for controlled environment agriculture approaches. Environmentally controlled production has lower requirements for pesticides, herbicides and other non-organic agricultural materials.

The United States Department of Agriculture is the primary source of funding for applied research. Research areas directly and indirectly related to CEA that are supported by the USDA include plant production, integrated pathogen and pest management, sustainable agriculture, soil and water conservation and use, foods for health, and biotechnology. Key funding sources include:

- USDA CSREES (Cooperative State Research, Education and Extension Services); USDA Hatch Funds
- Industrial and producer partners and commodity groups.

The National Science Foundation funds basic research on plant genetics and genomics, and NIH funds nutritional and human health related research.

Current or Future Industry Linkages and New Firm Formation Potential

Arizona already has a strong and growing greenhouse production industry focused on nursery crops and fruits and vegetables. Continued R&D and associated enhancements in CEA technologies and crops will serve to reinforce this important Arizona industry. In addition, the development of biopharming applications and products, advanced functional foods and nutraceuticals produced through CEA will likely result in major opportunities for new business growth in Arizona, specifically in the fields of Good Manufacturing Practices (GMP) and downstream processing.

Related to Arizona Issues, Problems or Needs

Controlled environment agriculture actively leverages the favorable climatic characteristics of Arizona (abundance of sunlight assures high plant productivity year-round) while providing for highly efficient use of scarce water resources. CEA will offer a sustainable option and further industry growth in agriculture, biopharming and functional food production within a state that is rapidly losing farmland to housing developments, as it is the fastest growing state in the nation.

Competition from Other States

There is a recent rapid growth in controlled environment agriculture across the U.S., Canada, Mexico, Spain and other southern most regions of Europe, and China. Currently, U.S. production acreage lags considerably behind market leaders such as Canada and Mexico. Arizona, however, is at the forefront of U.S. research in plant genetics and genomics, sustainable agriculture, plant biopharming for pharmaceutical and vaccine applications and functional foods, and as such is well-positioned to take advantage of this advanced R&D by virtue of its existing expertise in controlled environment agriculture. Alignment of R&D assets, controlled environment agriculture assets, and natural products manufacturing and distribution assets will place Arizona in a strong innovator position.

PLANT "MINING" FOR PHARMACEUTICAL AND NON-PHARMACEUTICAL PRODUCTS

The identification and isolation of high-value products from plants is a growing industry. The diversity of plants native to arid and semi-arid conditions suggests a rich source of biologically active and/or commercially important compounds. Tapping into this source has already yielded some valuable finds. Modification of existing plant varieties is another potentially rich source of high-value pharmaceutical or non-pharmaceutical compounds. However, increased capabilities in the physiologic, genetic and molecular characterization of these plants and any symbiotically associated partners (such as bacteria and fungi) are needed, together with further screening for desirable compounds or products.

Identified Assets

- **Core research strengths** – Arizona is home to experts in a number of basic research areas that are fundamental to this theme of plant "mining" for natural products. These areas include:
    - **Arid/Semi-arid plant research** – The Office of Arid Land Studies at the U of A is a leader in natural products chemistry, economic botany and new crop development. Studies on the cultivation of alternative crops in arid/semi-arid conditions are a focal area of the USDA-ARS Arid Land Agriculture Research Center in Maricopa.
    - **"Mining" for natural products**– Groups at NAU are focused on the identification of high-value products from forest materials and from halophiles, organisms that grow in highly saline conditions.
    - **Pharmacy –** The College of Pharmacy at the U of A is consistently ranked one of the best in the nation by U.S. News and World Report. In the 2007 rankings, it is number seven. In terms of NIH funding, the U of A College of Pharmacy ranked sixth nationwide in 2004, bringing in $9.6M in research awards.
    - **Pharmacology** – The College of Medicine Department of Pharmacology at the U of A ranks high (31st in 2005) for NIH funding amongst its peers nationwide.

- **Southwest Center for Natural Products Research & Commercialization, Office of Arid Land Studies at the U of A** – This center is internationally renowned for its work in the identification of high-value compounds from plants, plant-associated (endophytic and rhizosphere), and lichen-associated microorganisms. The center focuses on screening for compounds that possess anti-cancer activity by inhibition of cancer cell proliferation, metastatic cancer cell migration and heat shock induction, and anti-HIV activity by inhibiting viral replication. This Center also focuses on the characterization of botanically derived medicines with anticancer and anti-inflammatory properties, plant anti-stress agents for use in arid land agriculture, and improved production of plant natural products by soil-less hydroponic and aeroponic techniques.
- **Southwest College of Naturopathic Medicine** – Researchers at the college are engaged in a number of naturopathic projects, including the identification of human health benefits from plants indigenous to Arizona. One example is the stabilization of blood sugar following the consumption of prickly pear, a benefit that is meaningful to individuals with diabetes. The college has a record of working with both ASU and U of A for characterization of medically valuable herbs and plants, and in conducting tests to examine the toxicology, pharmacology, and effects on the immune system of specific natural products.
- **Critical Path Institute (C-Path)** – C-Path is an independent, publicly funded, non-profit organization dedicated to accelerating the process of medical product and drug development. The institute brings together FDA scientists, researchers, members of the pharmacy and pharmaceutical industries, medical product developers and technology commercialization organizations for the purpose of building collaborations that could lead to improvements in the medical product and drug development process.
- **Industry presence** – Arizona is an existing hub for companies in the nutraceuticals/natural products industry. Although most of these companies tend to offer products claiming to improve general quality of life, there is opportunity to expand into products with specific disease prevention chemistries. New entrants would not only be able to tap into the market but also utilize resources (e.g., contract manufacturers, distribution systems) within the existing Arizona infrastructure.
- **U of A Agricultural Experiment Stations in Arizona** – Activities at the outlying Agricultural Centers include the identification of commercially valuable products from native plants, such as a latex alternative (from guayule), a fiber used in specialty paper (from hesperaloe) and castor oil for use as an industrial lubricant (from lesquerella). Yulex Corporation is an Arizona company and the world's leading provider of medical products made from the natural rubber latex of guayule.

Opportunity to Attract Major External R&D Funding

As a sector comprising opportunities in drugs, nutraceuticals, functional foods and other natural products there is considerable opportunity to attract R&D funding from a broad range of sources. At a federal level, funding may come via multiple agencies, including the NIH, FDA and USDA. Major funding opportunities also exist through commodity trade groups, private industry and the foundation community.

Current or Future Industry Linkages and New Firm Formation Potential

According to BCC Research, the global market for plant-derived drugs was worth an estimated $18 billion in 2005. BCC expects this

figure to grow to nearly $19 billion in 2006 and more than $26 billion by 2011, at an AAGR of 6.6 percent between 2006 and 2011[1]. As an R&D-driven industry, it is clear that there must be substantial R&D funding flowing into the sector to generate such growth. Drugs, of course, cover just one part of a multi-faceted natural products market which also encompasses health supplements, nutrition enhancement, functional food and other associated products with multi-billion dollar markets. The current global functional foods market is estimated to be anywhere between $7 billion and $63 billion in U.S. dollars, depending on sources and definitions. The global functional foods market is expected to grow to $167 billion by 2010. The global growth rate for functional foods will likely achieve an average of up to 14 percent annually through 2010. After 2010, the functional foods market size is expected to comprise approximately five percent of total food expenditures in the developed world[2]. Against such a background of projected market growth, it is likely that Arizona could build significantly upon its existing base of natural products companies.

Related to Arizona Issues, Problems or Needs

A key advantage of work in this area is that it takes advantage of plants already present and adapted to growth in Arizona's environmental and climatic conditions. The plants to be "mined" are adapted to the efficient use of scarce resources.

Competition from Other States

Other states are focused on work in nutraceuticals and functional foods. However, only Southwestern states, with arid and semi-arid conditions can work in this specific niche. Mexico is also an active competitor in plant mining for biopharmaceutical and other applications.

AGRICULTURAL, FOREST AND URBAN PEST CONTROL

Supported by Infectious Disease Vector Monitoring, Analysis and Control

The Arizona Center for Insect Science, comprised of over 130 faculty across the three ABOR universities, is perhaps the leading concentration of scientists worldwide working in basic insect science and insects as model organisms. Combined with deep expertise in more traditional aspects of entomology in Arizona, this breadth of insect expertise brings with it specific opportunities for not only major-league basic science discoveries but also commercializable insect R&D. Broad and deep expertise in insect developmental biology, neurobiology, anatomy and physiology from a basic science perspective holds promise for important discoveries in insect control. By combining basic science expertise with strengths in insect control in agriculture, forest and urban applications, Arizona is uniquely positioned to bring advancements to the $6.5 billion[3] U.S. pest control market and many times larger global market. In combination with Arizona's strengths in plant sciences (discussed further herein), and position as a world leader in climate change science, the state's R&D institutions are well-positioned to investigate integrated insect management strategies and technologies that are relevant for our economies futures. Opportunities exist for a range of potential commercializable technologies in areas such as chemical, natural and transgenic insecticides, plant inoculants, transgenic plants, pests or predators, development and sustainable management of insect-

[1] BCC Research. "Plant-Derived Drugs: Products, Technology, Applications." June, 2006.
[2] Just-Food "Global Market review of Functional Foods: Forecasts to 2010." December, 2004.

[3] U.S. National Pest Management Association – reported at http://www.pestcontrolportal.com/industry/news/showNewsArticle.asp?id=87

resistant crops and trees, and informational products to assist stakeholders in decision-making. Applications for such technologies exist in agricultural, horticultural, forestry and urban markets, and have major implications not only in the prevention of product and property damage, but also in the protection of human and livestock health in the case of insect vector-borne diseases.

With the rapid growth of the world's population, the need for increased food productivity is urgent. Insects are a major source of lost production in both the field and in storage, and the diseases they carry are a primary source of lost human capital productivity. While some insect-borne diseases such as malaria are devastatingly endemic in the developing world, others such as West Nile Virus increasingly threaten human health in the U.S. Overlaid on this are the uncertainties associated with contemporary and anticipated climate change. There is thus an urgent and growing need for cost-effective, adaptable insect management technologies. The absolute magnitude of insect control required for resilient agricultural production will rise with global warming, which is expected to expand significantly the geographic range of multiple insect pests[4] and their associated ecosystem, agriculture and health impacts. Interactions among the components of global change (temperature, precipitation, land use) are expected to produce "climate surprises," where decision-support technologies will need to be in place to match appropriate pest control technologies with local climatological and ecological conditions.

[4] Janine Bloomfield. "The Potential Impacts of Global Warming on America's Forests: Critical Findings for Forest Lands from the First National Assessment of the Potential Consequences of Climate Variability and Change" http://www.climatehotmap.org/impacts/forests.html

Identified Assets

- **Core research strengths** – Research strengths directly related to agricultural, forest and urban pest control and/or infectious disease vector monitoring, analysis and control include:
    - **Entomology** – The University of Arizona Department of Entomology is an internationally recognized program. Home to 26 faculty, the Department has deep research strengths in integrated pest management; insect biology, ecology, evolution, taxonomy, biodiversity, genetics, physiology, and neurobiology; and insect/plant and insect/host interactions. The Department's synergistic links between basic and applied science are exemplified by its program for managing pest resistance to insecticides and transgenic crops, which is considered the strongest program of its kind in the world.
    - **Infectious Disease Studies** – Expertise in the detection of infectious disease in animals via rapid diagnostics is being leveraged at the Arizona Veterinary Diagnostic Labs, Tucson and in the UA-Plant Disease Network Labs. The Biofilm Infectious Disease Laboratory at NAU is engaged in investigating novel diagnostics and treatments for infectious diseases communicated by biofilms. Knowledge gained from these areas could be applied toward understanding and improving the detection of pest-borne infectious disease.
    - **Climate and Environmental Change Studies** – All three regent universities have strengths in R&D related to climate change and environmental changes. The University of Arizona is a world leader in detecting, understanding and predicting patterns of climate change throughout the history of Earth. Programs of excellence,

such as the Institute for the Study of Planet Earth, the Department of Ecology and Evolutionary Biology, and Hydrology and Water Resources are world leaders in understanding the societal and environmental consequences of climate change. Research programs such as the Environmental Research Laboratory have focused on understanding the importance of climate change for agriculturally important crop species in semi-arid and arid regions of the globe. New programs, such as The University of Arizona Biosphere 2, B2 Earthscience and the Institute of Atmospheric Physics are focused on understanding how climate variability and change affects ecosystem processes, ecosystems services and the human endeavor. In addition, NAU is the regional coordinator for the DOE's National Institute for Climatic Change Research Program.

- **Center for Insect Science** – CIS is a multidisciplinary group that emphasizes insects as model systems/exemplars for wide-ranging research in the neurological, microengineering, and computational and biological sciences. The center is headquartered at the University of Arizona with participation of faculty from ASU and NAU as well, and is home to a community of ecologists, molecular biologists, vector biologists, people working in biomedicine, and evolutionary/genetic biologists. With over 130 faculty members, CIS has deep expertise to draw upon in aspects of insect science and biology directly relevant to insect control such as insect neuroscience, molecular biology and insects as disease vectors.
- **Center for Infectious Diseases and Vaccinology, ASU Biodesign Institute** – Research at the center focuses on infectious disease processes and therapeutic strategies for combating them. Mechanisms of host-pathogen interactions and immune responses are at the core of these studies. Although the focus of the Institute is placed on diseases that affect humans, knowledge gained in these fields could be applied toward understanding any infectious disease transmitted by pests.
- **The USDA Carl Hayden Bee Research Center** – This center, located in Tucson, has research programs directed at enhancing pollination of crops by improving bee nutrition, controlling pests such as Varroa mites and red fire ants, and managing honeybee operations in areas with Africanized bees.
- **Social Insect Study Group, ASU School of Life Sciences –** Examples of insect social behaviors include foraging, division of labor, cooperative care of young, and collective decision-making. The focus of research in the Social Insect Study Group is on understanding the genetic, neurobiological, and physiological basis of such behavior. The group also investigates the role of evolution in social insect behavior using molecular phylogenic analyses and modeling tools.

As described, insects form the central focus of R&D for the majority of groups listed. However, research is also being conducted on the control of other pests, and could be integrated into a larger-scope pest control platform. For example, a research group at NAU has achieved considerable success in developing chemistries that prevent reproduction in targeted mammal species—a technology that is being brought to market as a solution for control of feral cats and dogs. Such technology could have broad implications for the control of invasive exotic species.

Opportunity to Attract Major External R&D Funding

Federal research funding in insect pest control can come though multiple agencies depending on the R&D focus of the work. NIH funding through the NIAID is available in infectious disease vectors and associated diseases. USDA and industry funds are available in areas related to insect pest control. NSF funds basic insect science

research, and the U.S. EPA funds research on the insect/environment interface.

Current or Future Industry Linkages and New Firm Formation Potential

Pesticides constitute a worldwide $32.7 billion market, of which 27.5 percent ($9 billion) is insecticides[5]. Recently the sector has experienced 4.6 percent growth after remaining fairly static for several years. Key to growth has been increases in the South American market, especially Brazil and Argentina. A large portion of the market (77 percent) is controlled by six large global companies, so barriers to entry can be significant for new companies. Arizona is not a major player in the agrochemicals industry, but there is potential to establish a niche position in insect pest control products—especially if insect science expertise is used to develop "green agrochemical" solutions and pesticides with significantly enhanced performance. The fastest growing segment of the insect control market is transgenic crops, which began in 1996, reached $6.1 billion in 2006, and is projected to grow 10% in 2007[6]. In partnership with the deep expertise in plant sciences, insect scientists in Arizona are strongly positioned to compete in this market. Increasing concern over exotic insect-borne diseases entering the U.S., in combination with insect vector dislocations related to global climate change, might well open many new avenues for market entrants in insect control for healthcare applications.

[5] Allan Woodburn Associates 'Agrochemicals – Executive Review', reported in 'First growth in global agrochemical market for a decade', Agrow No 466, 18 February 2005

[6] Clive James. ISAAA Brief 35-2006. Global status of commercialized biotech/GM crops: 2006. International Service for the Acquisition of Agri-Biotech Applications.

Related to Arizona Issues, Problems or Needs

Arizona's multi-billion dollar agricultural industry relies on the control of arthropod pests and vectors, weeds, and plant pathogens to sustain its profitability. Urban pests are a substantial challenge in the Arizona climate, with representatives of the Center for Insect Science noting that urban losses to insect damage are greater than they are for agricultural damage. The AZ-Plant Disease Network in the College of Agriculture partners with state and federal agencies to track and report new and emergent pests and pathogens. A similar alliance is in place for livestock and other animal pathogens and pests through the Vet Science Diagnostics Labs. Plant and animal diagnostics capabilities are being enhanced to achieve state-of-the-art and high-throughput capacities for the most important pathogens and pests. Telediagnostics communications are being developed to enhance and expedite communications between university diagnostics laboratories and rural and urban communities. Tools to improve epidemiological surveillance, including molecular databases for pathogen and pests, and development of an Arizona baseline pathogen database are proposed to increase awareness, communications, and responsiveness. Other programs are underway to safeguard the health of Arizona's communities, which are threatened by the recent spread of insect-borne diseases, with a particular emphasis on pathogens transmitted by mosquitoes, such as the West Nile and dengue viruses.

Competition from Other States

Because of the niche nature of potential markets available to new market entrants, and the complexity of developing effective new approaches to insect control, this is not likely to be a highly competitive field for interstate competition. While entomology as a discipline is present across land-grant institutions throughout the United States, no location can currently compete with Arizona in terms of the critical mass of expertise contained within the Center for

Insect Science and associated entomology programs, especially as they are integrated with a climate change framework.

PLANT-BASED BIOFUELS

Supported by Plant Genetics and Genomics and by Biomass Production and Processing Improvement

A major goal for reducing national dependence on foreign oil is the development of domestic energy systems that are commercially feasible and environmentally sustainable. The production of biofuels from plant matter is an important field that is already being heavily researched by numerous organizations throughout the country. Breakthrough areas that will benefit this field include identification of optimal sources of biomass, engineering to improve growth with limited or poor-quality water, engineering to improve conversion to ethanol, and technological advances in digestion and processing. Of these, the area in which Arizona is positioned to play a leading role is in conversion of plant matter to biomass, particularly using microbial-based methods.

Identified Assets

- **Related research strengths** – The development of transgenic plants and other plant improvement technologies for biofuels and other renewable biomass applications is not a primary R&D focus of Arizona's universities. However, the state appears to be extremely well positioned with respect to having the advanced research assets required to rapidly build capabilities and applications in this important field.
    - **Plant genetics and genomics** – The University of Arizona and the Department of Plant Sciences is an acknowledged center of excellence, world-renowned for its work in plant biology, genetics and genomics and home to 24 faculty with focused R&D in these areas. Their work may be instrumental in uncovering new technologies that allow the utilization of novel crops for production of biofuels. While much of the U.S. production of renewable biofuels focuses on conversion of corn to ethanol and oil crops (soybean and others) to biodiesel, these crops are not efficiently and economically grown in Arizona. However, researchers at the U of A are investigating new feedstocks, including sweet sorghum and switchgrass, for production of ethanol and for use of cellulosics to feed cattle, amongst other applications. Since these crops are not part of the human food chain, their utilization would have minimal impact on food costs and growth using reclaimed or partially-treated wastewater has potential and is being investigated. Also at the U of A, fungal species are being isolated and identified for the efficient breakdown of cellulosic biomass.
    - **Forestry** – Northern Arizona University is conducting early-stage research in forest biomass and applications for bioenergy production. Currently, the emphasis is on the opportunities presented for biomass use stemming from the thinning of forests and the heavy load of underbrush that has built up in western and mountain state forests.
- **Translational Agriculture Initiative** – This program, contained within the University of Arizona BIO5 Institute, is dedicated to applying the U of A's expertise in plant molecular and cellular biology, genetics and genomics towards the development of crop plant improvements. The multidisciplinary resources of the Initiative could be applied to biomass/bioenergy plant improvement as well as to more traditional plant improvement

activities such as yield enhancement and stress resistance as well as improved nutrition.

- **BioDesign Institute** – ASU's Biodesign Institute has distinctive programs in plant transformation (currently focused on biopharming) that might also be directed towards plant transformation for bioenergy applications. Combined with ASU's emphasis on environmental bioenergy (currently focused on microbial conversion), ASU can bring some distinctive assets to bear on this opportunity area.

Opportunity to Attract Major External R&D Funding

As discussed under the microbial bioenergy heading, there is a major federal and private industry sponsored funding impetus on R&D related to alternative energy sources. Major funding, in particular, is being directed towards the development of crops and processes for producing fuels from lignocellulosic biomass.

Current or Potential Industry Linkages and New Firm Formation Potential

Arizona's first bioethanol plant began operations in May 2007. The Pinal Energy plant, which is expected to produce 50 million gallons of ethanol yearly, uses corn grown locally and imported from Midwestern states as feedstock. But because Arizona is not a major producer of the "traditional" crops used in biofuel production (i.e., corn and soybeans), the state may be more optimally positioned to take advantage of the concerted national push on developing biofuels from cellulosic materials. Cellulosics include woody materials, switchgrass, agricultural waste, and forestry waste. The development of cellulosic feedstock ideally suited to the Arizona environment, and/or cultivation of existing cellulosic materials such as from state forests, represent significant opportunities within the plant-based biofuel industry. To this end, NAU is working on potential application for forest biomass in the northeast region of the state where there is considerable potential for growth of alternative crops such as sweet sorghum, millet and grasses suited to Arizona's comparatively dry climate.

The biofuel industry is highly distributed due in large part to the high costs of transporting plant biomass to biofuel plants. Therefore, production plants tend to be relatively small and located close to biomass sources. To the extent that these sources are developed in Arizona, it is anticipated that production plants will be co-located near these sources, creating significant and positive economic development implications for the surrounding area. Development may be enhanced further by the state-mandated imperative for Arizona public utilities to invest in renewable power sources.

Related to Arizona Issues, Problems or Needs

Arizona has experienced rapid population growth and perhaps more than most states needs to be concerned with meeting its power needs in an environmentally sustainable manner. The development of new plant crops, suited to growth in Arizona environmental conditions, could open significant market development opportunities throughout major areas of rural Arizona.

Competition from Other States

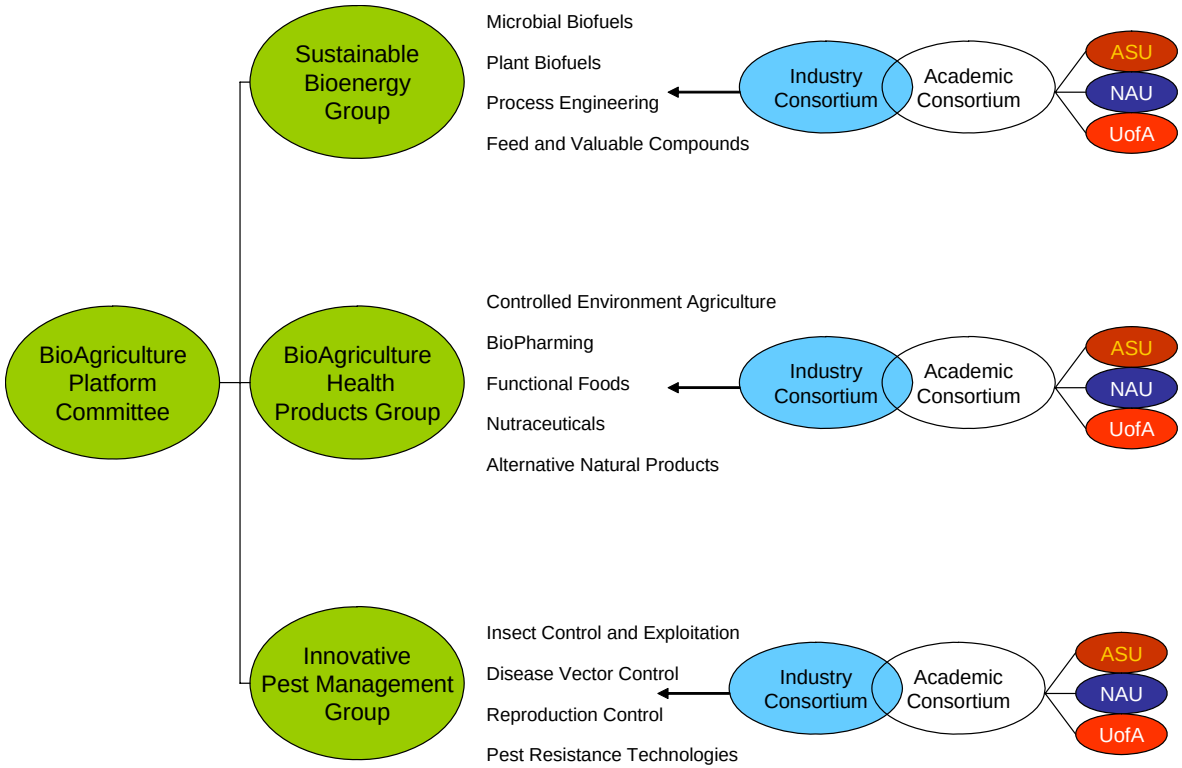
Major land grant and private research universities, in combination with multiple federal research labs, are focused on biofuel development and approaches to the use of cellulosic biomass. Competition for funding is becoming increasingly stiff.

III. Priority Actions to Advance the Bioagriculture Platform in Arizona

ORGANIZATION

Currently the BioAgriculture Platform is operating under the guidance of a steering committee. The committee has been advising and commenting on the work of Battelle in regards to platform development and it is envisioned that the committee will maintain oversight of platform development as actions and initiatives are implemented. Examination of the five recommended development opportunity areas, highlighted in the previous chapter, indicates that the committee could move platform progress forward by establishing three subject area working groups that will be responsible for specific initiatives and actions for key opportunity areas. The figure below illustrates the recommended structure moving forward:

Figure 1: Structure for Moving Forward



The three opportunity area groups include:

- **Sustainable Bioenergy Group** – Focused on driving forward initiatives geared toward large-scale microbial and plant bioenergy production using solar energy and CO_2. Additional outcomes will be generation of value-added products and development of other sustainable bioenergy technologies. This effort will require innovations in large-scale microbial production and in harvesting, lysis, and extraction; innovations in plant biomass processing technologies will also be needed, as well as new crops for biofuel production suited for arid lands.
- **BioAgriculture Health Products Group** – Focused on realizing development potential from controlled environment agriculture and non-transgenic field production as they pertain to health-related products such as drugs, vaccines and other products produced via biopharming, natural products extracted from native Arizona plants, nutraceutical products, and functional foods produced via controlled environment agriculture methods.
- **Innovative Pest Management Group** – Leveraging Arizona's deep expertise in insect sciences to provide solutions to insect management and control and disease vector control issues. Also integrating other elements of R&D in Arizona relevant to pest control, such as NAU's focused expertise in chemical control of animal reproduction systems.

Each opportunity area group should comprise representatives from both industry and academic consortia. In each of the groups all three of the Arizona regent universities have an important contributory and leadership roles to play. Industry/university collaboration is absolutely key to fostering joint approaches in opportunity areas and issues and also to developing a critical mass of support to stimulate action. The overall BioAgriculture platform committee will be able to speak for the sector development with one voice, channeling the decisions, needs and initiatives of each of the three opportunity area groups.

By structuring in this fashion, Arizona BioAgriculture will have a single, unified entity providing a shared voice for the enhancement of the overall bioagriculture science and business environment in the state. The state will also have a structure that allows for the specialized and unique needs of each bioagriculture opportunity area to be addressed, and for guiding joint industry/university R&D projects of importance to each area and its members. The academic consortia provide opportunities for researchers, scientists and faculty from across various constituencies on each university campus to work together on opportunity area-oriented initiatives, research projects and commercialization opportunities. Working in collaboration with industry-consortia representatives in each opportunity area, this approach will allow the development of shared vision and activities in some or all of these areas:

- Identifying, soliciting and prioritizing specific R&D projects for each focus area
- Identifying and assembling teams of faculty, scientists and industry representatives with the required skills for working on prioritized cross-disciplinary projects and initiatives
- Providing input to the infrastructure and technology investments, staff enhancement and other key investments required to strengthen performance in each key opportunity area
- Prioritizing projects for presentation to the overall bioagriculture platform committee for funding initiatives and other special requests

- Coordinating the development of requests for federal and other major external support funding for the development of the bioagriculture platform and its key opportunity elements
- Coordinating special events, conferences and symposia related to each opportunity area
- Participating in communications, public relations, awareness building and outreach activities important to the progress of each opportunity area.

ACTIONS

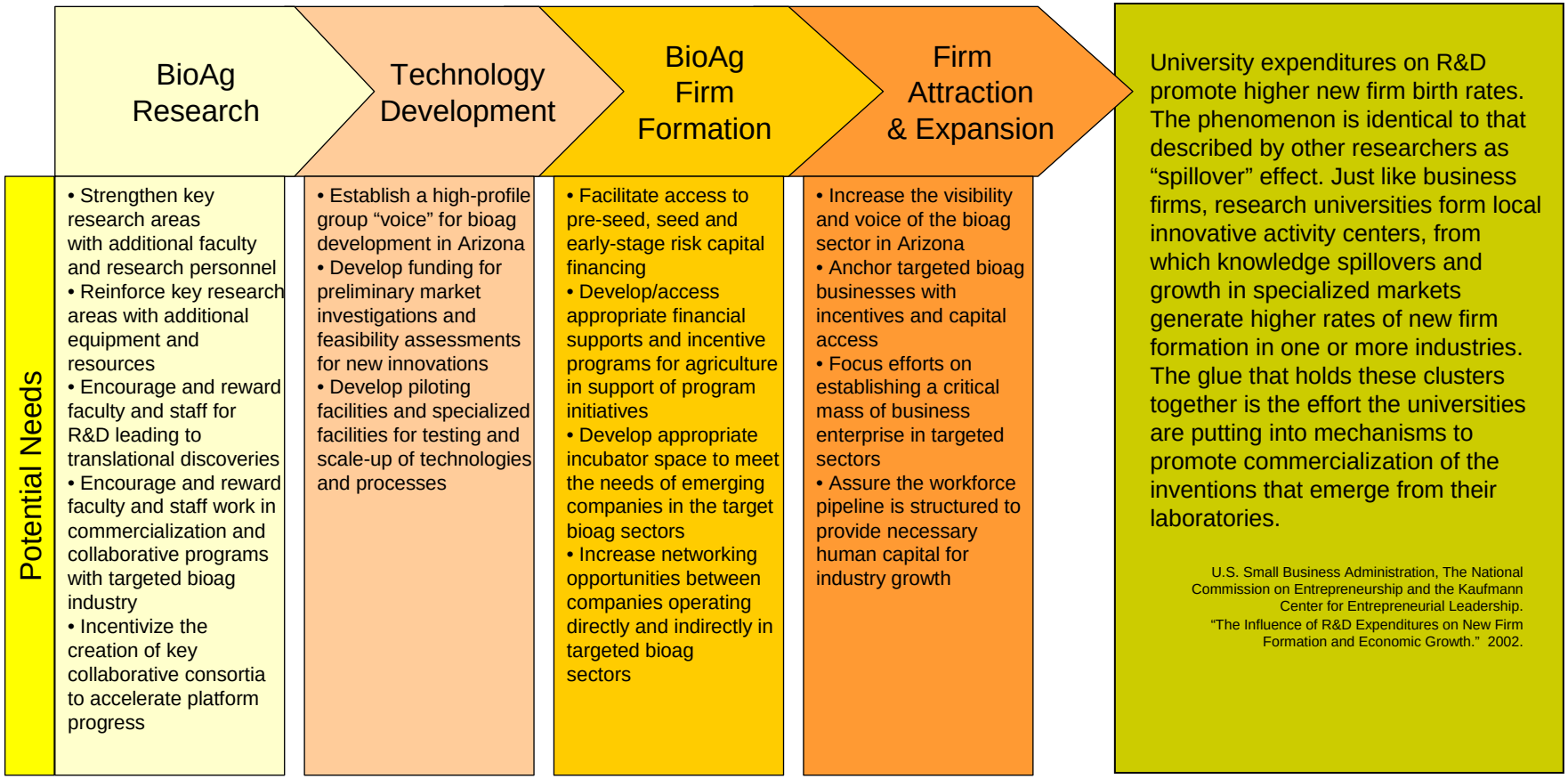
It should be the role of each of the three opportunity area groups to develop a prioritized listing of specific actions required to fulfill group goals and strategic targets. There are, however, several macro areas of action that were identified by Battelle during the course of this project that should be taken into consideration by the BioAgriculture Platform Committee and each of the three opportunity area groups (these are profiled below).

It is evident that the BioAgriculture platform contains multiple areas of development opportunity for Arizona. Realizing the significant economic development potential contained within these areas of opportunity will require coordination of a set of specific actions. Some action items are shared across each of the opportunity areas while others will be specific to the needs of individual R&D fields. Figure 2 illustrates many of the key needs identified:

Action items exist across four principle categories:

- Strengthening bioagriculture R&D in target opportunity areas
- Translating and piloting promising bioagriculture technologies towards commercialization
- Building new bioagriculture business enterprise
- Attracting, expanding and retaining bioagricultural business enterprises in the state.

Figure 2: BioAgriculture Platform Development Needs



Key actions suggested under each action category are as follows:

Strengthen Research

Action	Description
Strengthen key research areas with additional faculty and research personnel	While each of the opportunity areas already contains a significant base of faculty and research scientists engaged in relevant R&D, there is still a need to reinforce and strengthen R&D teams. World-class science and innovation requires world-class faculty and top-quality graduate students—and each opportunity area group will need to identify and prioritize specific key posts to recruit for and fill.
Reinforce key research areas with additional equipment and resources	World-class science also requires world-class infrastructure. Arizona has shown itself able to make key investments in major infrastructure projects (such as the BioDesign Institute and BIO5), and it is likely that further investment will be required in specific infrastructure areas in the targeted opportunity groups.
Encourage and reward faculty and staff for R&D leading to translational discoveries	While Arizona's regent universities have made significant strides forward in fostering entrepreneurial environments on their campuses, there is still room for improvement. Once key collaborative R&D teams are identified, it is imperative that each university work with department heads and other senior personnel to assure that policies and procedures are in place to reward faculty and staff support of these initiatives.
Encourage and reward faculty and staff work in commercialization and collaborative programs with targeted bioag industry	Commercialization of technology is a complex process requiring the dedication of much time and effort. For faculty and staff to be actively engaged in the translation of discoveries towards commercialization, they need to be assured that this activity will be appreciated, recognized, and rewarded. Any key barriers to faculty participation in this process must be removed.
Incentivize the creation of key collaborative consortia to accelerate platform progress	Moving initiatives forward from each of the opportunity groups would be greatly facilitated if state funds or other funding sources can be made available to incentivize collaborations. Use of a matching funds program has proven to be a significant driver of applied collaborative R&D projects at institutions across the U.S.

Strengthen Technology Development and Commercialization

Action	Description
Establish a high-profile group "voice" for bioag development in Arizona	Build upon the existing BioAgriculture Platform Committee to establish a credible and high-impact committee comprising leaders in agriculture, agribusiness, industry, academic R&D, and relevant associations to speak with a shared voice on platform development needs and requests.
Develop funding for preliminary market investigations and feasibility assessments for new innovations	Assure that funds are available to facilitate early-stage investigations of the technological and market feasibility of key innovations coming out of bioag R&D areas. A competitive grant program should be developed, with submissions made to each of the three bioag opportunity groups who will then forward their recommendations for project funding to the bioag platform committee. Initial grants for commercialization investigations should be in the $50,000-$100,000 range per project.
Develop piloting facilities and specialized facilities for testing and scale-up of technologies and processes	Many of the technological focus areas in Arizona bioag will require investment in pilot facilities and scale-up operations to provide proof of concept and market viability. Areas of investment will likely include pilot and scale-up facilities for microbial biomass production, transgenic plant development, biomass processing, Good Manufacturing Practice (GMP)-level plant production and processing for biopharming operations, nutrient extraction, etc.

BioAgriculture New Firm Formation

The generation of new business enterprise first and foremost requires the basic business climate to be appropriately structured. Without a positive in-state business climate, commercializable technology that is developed runs the risk of migrating out of state. Key basics that must be in place include:

- Business-friendly tax policies
- Incentives designed to support the needs and opportunities of bioagriculture companies
- A quality of life conducive to attraction of top-quality scientific and business talent
- Competitive costs of doing business
- A supportive cluster of businesses achieving agglomeration economies and benefiting from specialized support services to meet their needs
- A network of sector companies and related interests working to drive policies and support programs to enhance the climate for their type of business.

Most of the above have been addressed in previous bioscience strategy development reports from Battelle, but the specific actions outlined below are recommended for consideration by the bioagriculture platform committee:

Action	Description
Facilitate access to pre-seed, seed and early-stage risk capital financing	Access to capital or lack thereof, tends to be the most significant barrier faced by fledgling technology enterprise. It can be a particular challenge for companies outside of mainstream technology sectors—and bioagriculture projects certainly would be considered outside of the mainstream. It will be imperative, therefore, that the platform committee work to identify early stage capital sources with interest, and preferably experience, in bioag sector investments. Having early phase commercialization investigation seed funds available will further help assure that only those technologies already shown to have good feasibility prospects will be presented to external funders. This will help raise credibility.
Develop/access appropriate financial supports and incentive programs for agriculture in support of program initiatives	Much of America's agriculture is sustained through subsidies and other support mechanisms. Furthermore, development of specific sectors of the U.S. economy is encouraged via specialized funding programs, incentives, and tax concessions. Once specific initiatives are identified for commercialization, the platform committee should work to identify existing programs to support platform development, and/or work to establish new incentive programs to facilitate platform development. For example, income tax credits and excise tax rate reductions for microbe-based biodiesel fuel mixtures could encourage the production of biodiesel from microbes.
Develop appropriate incubator space to meet the needs of emerging companies in the target bioag sectors	It is likely that many of the companies seeking to grow in the new bioag technology fields outlined herein will need access to specialized piloting and scale-up facilities as discussed herein. As such, business incubation facilities will likely need to be co-located with, or located in close proximity to, these piloting and scale up facilities. Specialized containment facilities, biosecurity facilities and other unique elements may need to be incorporated into such incubator facilities.
Increase networking opportunities between companies operating directly and indirectly in targeted bioag sectors	As targeted bioag technology sectors develop, it will be important to establish industry and support-organization networks to facilitate free-exchange of ideas, encourage partnering and provide a forum for shared expression of industry goals and needs.

Attract, Expand and Retain Bioagriculture Industry

Action	Description
Increase the visibility and voice of the bioag sector in Arizona	Unlike Midwestern states, Arizona does not have an immediate "brand presence" when it comes to traditional agriculture. In a way this may be an advantage, since Arizona does not have to overcome a "sticky" image that might be inaccurate. However, the state does have numerous and significant strengths in both agricultural and biosciences research and thus has a major opportunity to forge a brand image for itself around key bioagriculture opportunity areas.
Anchor targeted bioag businesses with incentives and capital access	Once specific target sectors are agreed upon, existing businesses operating in Arizona in these sectors must be considered "strategic" in nature. As such, work should be performed to assure that these strategic sector companies have access to expansion capital or other resources required for growth and that any barriers to growth that may be mitigated are addressed.
Focus efforts on establishing a critical mass of business enterprise in targeted sectors	Many aspects of doing business are helped when a cluster of like businesses forms within a state. Service and component providers to the cluster provide specialized services and understand specific business needs; workforce and education providers are able to tailor programs to the cluster; personnel are easier to recruit as they enter an environment with a deep pool of employers. Promoting cluster development is thus a key tool of modern economic development.
Assure the workforce pipeline is structured to provide necessary human capital for industry growth	The bioag sectors identified for growth in this report are innovation-, knowledge-, and technology-driven. As such, they require skilled human capital not only in the knowledge development (R&D) phase, but also in the specialized production tasks that come once innovations are commercialized. Workforce skills thus become important across a range of position from elite scientific R&D workers through to skilled production, management, sales and distribution personnel. Aligning education and training programs, together with articulation agreements between education and training providers, is an important activity in technology-based economic development.

CRITICAL FIRST STEPS

The most difficult steps to take on the pathway to success are usually the first ones. These first steps set the stage for what is to come, even if they seem small in retrospect. The successful realization of the potential contained in Arizona for bioagriculture based economic development will likely depend on success being achieved with these first elements:

- The BioAgriculture Platform Committee becomes a long-term organizing entity to shape and define the vision of Arizona BioAgriculture; under this committee three opportunity area groups are formed each with representatives of industry and academia.
- Funds are provided to seed an initial round of collaborative commercialization-feasibility studies with the most promising technologies identified by each opportunity area group.
- A prioritized action list for personnel and infrastructure enhancement is produced that specifies the precise need and benefits of each and how they will progress the overall goals for the bioagriculture sector in Arizona.
- Funds are provided to make the required investments in targeted personnel, infrastructure, pilot facilities, and other key investments.

Appendix A: Other Potential Opportunity Areas for Arizona BioAgriculture

A number of other areas were considered, but analyses and discussions suggested that these areas did not offer opportunities as significant as those discussed above. The principal shortcomings of these opportunity areas included lack of sufficient R&D strength, few or no linkages to industry, relatively small potential for the formation of new businesses, little relation to Arizona issues, problems or needs, and strong competition from other areas. Therefore, these potential bioagriculture opportunity areas were omitted from further analysis.

	Current R&D Strength in Arizona	Opportunity to Attract Major External R&D Funding	Likely Support Based on Emerging Policies and Trends	Existing Arizona Centers and Institutions to Build Around	Current Arizona Industry Linkages or Potential Linkages	Likely to Result in Formation of Arizona Businesses	Related to Arizona Issues, Problems or Needs	Limited Amount of Major Competition from Other Regions	Overall Opportunity Rating	Development Timeframe
Use of bioenergy for enhancing rural and farm economies		√ √	√		√		√		Good	Far
Root systems, growing media and inoculants	√	√	√		√	√		√	Good	Near
Environmental toxicology (impacts, monitoring, remediation)	√ √	√	√				√		Good	Near
Environmental monitoring, sensing and diagnostic systems	√	√	√			√	√		Good	Near
Climate change impacts	√ √	√	√				√		Good	Mid
Insect-inspired engineered products and materials	√	√		√		√		√ √	Good	Mid
Environmental and ecological insect impacts	√ √	√		√				√ √	Good	Mid
Gene-to-ecosystems effects and impacts	√ √	√						√	Fair	Mid
Environmental restoration	√	√	√				√		Fair	Far
Processing and separation chemistry		√	√			√			Fair	Far
Bioenergy environmental impact monitoring and assessment		√	√						Poor	Mid
Ecosystem engineering via plants		√							Poor	Far
Environmental and ecological systems modeling and simulation	√	√							Poor	Far