







EXECUTIVE SUMMARY

POSITIONING ARIZONA AND
ITS RESEARCH UNIVERSITIES:

SCIENCE AND TECHNOLOGY CORE COMPETENCIES ASSESSMENT

PREPARED FOR:
Arizona Commerce and Economic Development Commission and the Arizona Department of Commerce in association with Arizona's public research universities and the Arizona Board of Regents

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April 2003

Battelle
The Business *of* Innovation

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Executive Summary

INTRODUCTION

Research universities are emerging as a key economic asset in today's global knowledge-based economy. States across the nation are increasingly seeking to leverage the science and technology assets found at their research universities as a source of competitive advantage. Research universities are becoming anchors for an exciting array of state economic development initiatives involving commercialization activities, collaborative and multi-disciplinary research centers, and innovative new curriculum and educational programs needed for workforce training.

But each state's research base offers different areas of strength and economic opportunity. States are learning that to gain economic value from their research universities, they need to assess the specific areas of research focus and excellence found at their universities and determine how those research capacities link to market opportunities and locally-based industry specializations.

With three public research universities generating a combined $500 million annually in research funding, the opportunity for Arizona to harness the economic potential of its research universities is clear.

> "World class research is a passport to success in the global economy. Industry can no longer compete by selling standard products made with standard processes and that could be produced anywhere in the world at lower cost. Businesses must constantly innovate to raise the quality of production, introduce new product lines or services, and add greater value to their outputs. For this reason, states must create an environment that supports continuous innovation. This requires investment in cutting-edge research, facilities and equipment."
>
> National Governors Association, State Leadership in the Global Economy Task Force, 2002

Accordingly, as Arizona develops its comprehensive state economic development strategy, a critical aspect is to determine how to further build the state's growing research stature and reputation in specific university research fields that can also link to the state's efforts to build its economic future through private-public partnerships between industry, higher education, and government.

Project Approach and Methodology

The focus of this study is to identify the specific research competencies found at Arizona's research universities from both a research and broader economic development perspective, identify areas for raising Arizona's research stature and potential niches for economic development, and present opportunities for future collaborations that will fill key gaps.

This effort builds upon a recently completed assessment of the state's position in the biosciences, particularly in biomedical research efforts. This project was funded by the Flinn Foundation and conducted by the Battelle Technology Partnership Practice.

Arizona's Commerce and Economic Development Commission and the Arizona Department of Commerce, in consultation with the state's research universities, engaged Battelle to extend their core competency assessment to the non-bioscience areas found in the state.

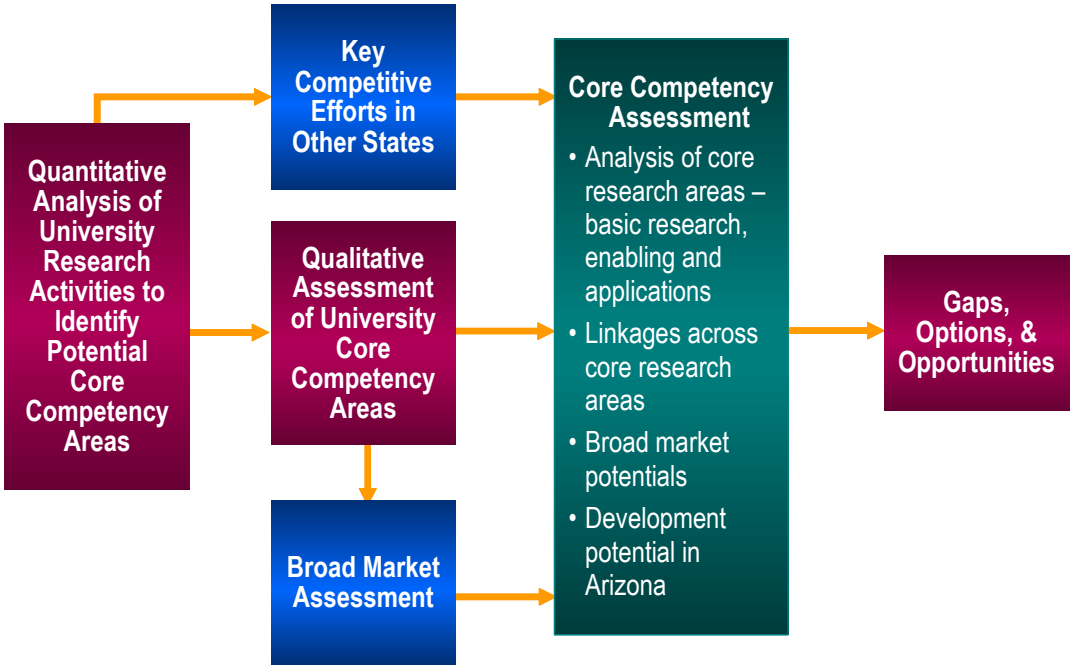
Conducting this assessment requires a variety of integrated and complementary analyses involving both quantitative analysis and qualitative intelligence gathering from interviews and market research.

The overall methodology involved a four-step process.

- **Rigorous Quantitative Analysis.** First, a variety of quantitative analyses of research activities were undertaken to identify leading areas of research focus found across the research universities in Arizona, which would underpin areas of core competency. Analyses included examination of Arizona's position in research funding across research areas, review of studies of peer recognition, analysis of publications activity, and an assessment of grant activity using cluster analysis.
- **In-Depth Qualitative Analysis.** Second, an extensive interview process with research administrators and research leaders in Arizona—with 60 interviews being conducted—was undertaken to better interpret the quantitative analyses. This also helped determine how the leading research areas link into research core competencies that are based on factors such as competitive differentiation, ability to transcend single business areas, and how difficult they are for competitors to imitate.
- **Market Assessment.** Third, an assessment involving market research was conducted to identify whether these core competency areas can be related to technology platforms that link to market opportunities and avenues for economic development in the state.
- **Gaps, Options, and Opportunities Assessment.** Fourth, the interviews and market research data, combined with analysis of programs in other states, were used to identify gaps both within and across technology platforms. These gaps identify options and opportunities to strengthen the platforms and the overall state infrastructure supporting technology-based economic development.

Our overall approach is shown in Figure ES1.

Figure ES1: Overall Core Competency Project Plan



ASSESSMENT OF ARIZONA'S POSITION IN RESEARCH INNOVATION

Core Competency Areas

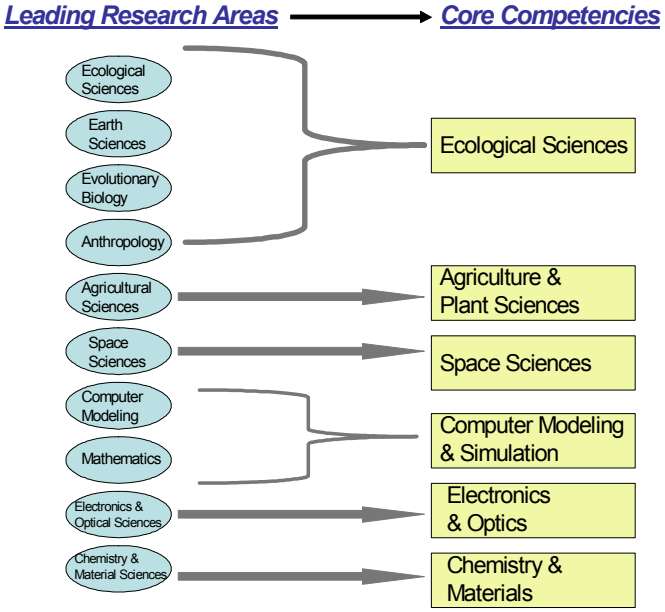
To identify leading areas of research activity, Battelle identified those research areas that had a concentration of activity and excellence as demonstrated by having:

- *A significant number of clusters of federally funded research grants awarded through rigorous peer-review processes* such as those at the National Science Foundation, the Department of Defense, the Department of Energy, the U.S. Department of Agriculture (USDA), NASA, and other federal agencies. These clusters are groups of grants that relate to one another based on the actual research activities underway in each grant. To undertake this cluster analysis, Battelle used a proprietary data-mining tool, known as Starlight, which identifies textual similarities in each of the grants' abstracts.
- *A broad base of principal investigators*, along with prominent researchers who hold multiple peer-review grants.
- *Substantial level and impact of publications* for the five-year period of 1997 to 2001, based on a compilation by ISI Thomson Scientific in its University Science Indicators database. We highlighted those research fields with at least 150 publications and a relative citation impact of 40 percent higher than the national average in that field.

The high rankings in funding or the high standing in peer recognition were based on surveys conducted by *US News and World Report*.

An initial set of ten leading research areas (outside of biomedical research) in Arizona were identified. Further analysis of these leading research areas, informed by intelligence gathered through structured interviews with research administrators and leaders, enabled Battelle to identify six areas of core competency (Figure ES2). These core competencies reflect areas of research focus in Arizona meeting the following criteria: breadth, depth, reputation and impact on their field, competitive differentiation, ability to transcend single business areas, and hard for competitors to imitate.

Figure ES2: Research Strengths to Core Competencies



A brief description of each of the core competencies is set out in Table ES1 below.

Table ES1: Description of Non-Biomedical Core Competency Areas Identified Across Arizona Research Universities

- **Electronics and Optics** – It is the combination and integration of electronics and optics that places Arizona in a class with very few other states (perhaps only New York and California). Therefore, in characterizing this competence, we emphasize where these two research areas converge, namely in optoelectronics, photonics, semiconductors, optics in computing/storage, and both wireline and wireless applications. A robust group of approximately 60 faculty works in this combined field across primarily University of Arizona and Arizona State University, and is closely linked to the high tech industry in the region and nationally.
- **Computer Modeling and Simulation** – The computer modeling and simulation core competency depends on two key attributes: the wide range of software applications, from environment and health to materials and electronics, and the strong foundation in applied mathematics. This area underpins much of the research effort at all three universities. Approximately 400 principal investigators are engaged in mathematics and computer modeling and simulation research endeavors. Computer modeling and simulation is very applications-oriented, with particular emphasis on electronics, communications, and data management. Other pockets of concentration are in materials science, energy, environment, and biology.
- **Chemistry and Materials** – This core competency ranges from geochemistry to electronic materials. It is impossible to separate out chemistry from materials inasmuch as chemistry plays a crucial role in materials synthesis, materials performance, and materials characterization. More than 100 researchers are engaged in this competence. New or improved materials are being created to advance technologies in the semiconductor, electronics, aerospace, health sciences and other industries. Chemical and materials research is found across all research universities in Arizona and is closely tied to research in other departments such as physics, electrical engineering, bioengineering, mechanical engineering, and optical science.
- **Space Sciences** – The Arizona Space Grant College Consortium ties all three Arizona research universities together. The Consortium is a NASA-sponsored program of outreach, training, and research to encourage understanding of space exploration and provide a stream of trained professionals into the industry. About 60 faculty are engaged in space sciences (astronomy and planetary sciences). Key areas of focus include basic science concerned with observations in our solar system and the emerging area of biogeochemistry to study materials on earth and other planets. However, the focus of this core competency is the engineered devices and systems that are the means to that end (i.e., powerful telescopes and satellites, measuring instruments and related materials, optics and electronics developments). The combination of astronomy and planetary sciences at UA, ASU, and NAU makes the state a national leader in space science and engineering.
- **Ecological Sciences** – Significant expertise and resources in the ecological sciences exists at all three universities, making this area by far the strongest core competence in Arizona. Over 300 faculty are engaged in research on ecology. If one counts faculty engaged in the related fields of Earth Sciences, Anthropology, and Evolutionary Biology, there are over 500 principal investigators, and with graduate students, well over 2,000 researchers are involved. Fundamental research is underway in Arizona on how all living creatures interact within our environment on Earth, embracing research on environmental effects like global climate change and adaptation, evolutionary biology of plants, mammals and insects, botany, natural resources (i.e., water, land, forests) management, earth sciences, population, communities, and landscape changes (i.e., urban ecology). Since ecology

covers such a broad area of science, engineering, and policy, the connections to other areas of research strength are numerous.

- **Plant and Agricultural Sciences** – Arizona has traditional agricultural science addressing the challenges of growing crops in arid/semi arid lands at each of its research universities, which is closely related to Ecological Sciences and Earth Sciences. Sustainable agriculture is strong at NAU. Plant science looks at genetics and other key mechanisms of plant development, such as photosynthesis, and is strong at both Arizona State and the University of Arizona. However, it is the integration of these two research areas that makes this a state core competence.

Opportunities for World Class Research "Signature" for Arizona

Battelle was also asked to identify potential world class research areas in the universities, which are worthy of nurturing as potential state "signature" research. Clearly, not all components of the core competencies meet this criterion. Below are some areas that Battelle believes are worthy of state recognition and nurturing as potential research signatures.

Arizona's strongest core competence by far is the ecological sciences. There are three areas of world-class research and scholarship in this broad and deep competence.

- Arid/semi-arid lands ecology – Battelle could not find another university system that possessed the same depth of knowledge.
- Urban ecology – The extension of the remote sensing and urban environmental systems studies to many other cities around the world substantiates Arizona's leadership here.
- Hydrology and water resources – UA is #1 nationally in hydrology; add to that distinction the four water centers, each dealing with a different problem area, and ASU's and NAU's contributions, and Arizona has what is arguably the world's biggest and best water resource portfolio. The only other collection of water resources that Battelle found is the memorandum of understanding that links the water resource centers in universities in Washington, Idaho and Oregon, with Pacific Northwest National Laboratory and Idaho National Environment and Engineering Laboratory.

After ecology, the next best core competence for Arizona is electronics and optics, which is complemented by chemistry and materials as well as computer modeling and simulation. Within this competence, Battelle sees three areas of strength (the first enhanced by the chemistry and materials competence; the last two enhanced by the computer modeling and simulation competence), but each has serious competitors in other universities in New York and California.

- Materials that are being produced at the electronics/optics interface – photonic, optoelectronic, and nanoelectronic materials are specialties.
- Integration of these materials into complex circuitry – strength in embedded systems is pervasive.
- Wireless – wireline infrastructure unification is a key competence.

In the bioengineering area, discussed in the Flinn Foundation study, the clear strength that Arizona has is the linkage of neuroscience with the materials, software, and electronics capabilities to provide a neural engineering platform. Neural engineering advances in Arizona include using

thoughts to instruct robots for an advanced neural prosthetic interface, and spinal cord stimulation to restore gait. This could definitely be developed into a world-class bioengineering specialty with enormous impact in the health field. Competitors do exist, however. Oregon boasts a world class neuroscience core competence at Oregon Health and Science University and University of Oregon, and a growing neuro-products (imaging) industry cluster.

Space Sciences has two areas of world class research. For example:

- Advanced land-based and space telescope design and mirror construction at UA; and
- Design of remotely operated instruments for measurements in space.

Competitors include the University of Colorado, Cornell, and the University of Chicago, but Battelle could not find any state university system that possessed the combined strengths of astronomy and planetary sciences that Arizona has, hence the interest in the integration of these research capabilities.

Plant sciences also has two strong areas, which could be very powerful if integrated:

- The Plant Genomics Institute at UA, led by Rod Wing, sequences plant genomes, which can be used in crop enhancement and as models for human disease; and
- The Arizona Biodesign Institute at ASU, where Charles Arntzen's group is a world leader in development and manufacture of edible vaccines.

Competitors in plant sciences include St. Louis, with Washington University, Danforth Plant Sciences Center, Monsanto and others; the Research Triangle; Cornell University; and Saskatoon, Canada. Nevertheless, it is the breadth of plant science capability at UA and ASU, including crop genetics, the use of plants as models for human disease, and edible vaccines that makes this area an attractive signature research candidate.

Developing and Forming Technology Platforms

Technology platforms serve as a bridge between the research core competencies and their use in commercial applications and products. They share the following characteristics:

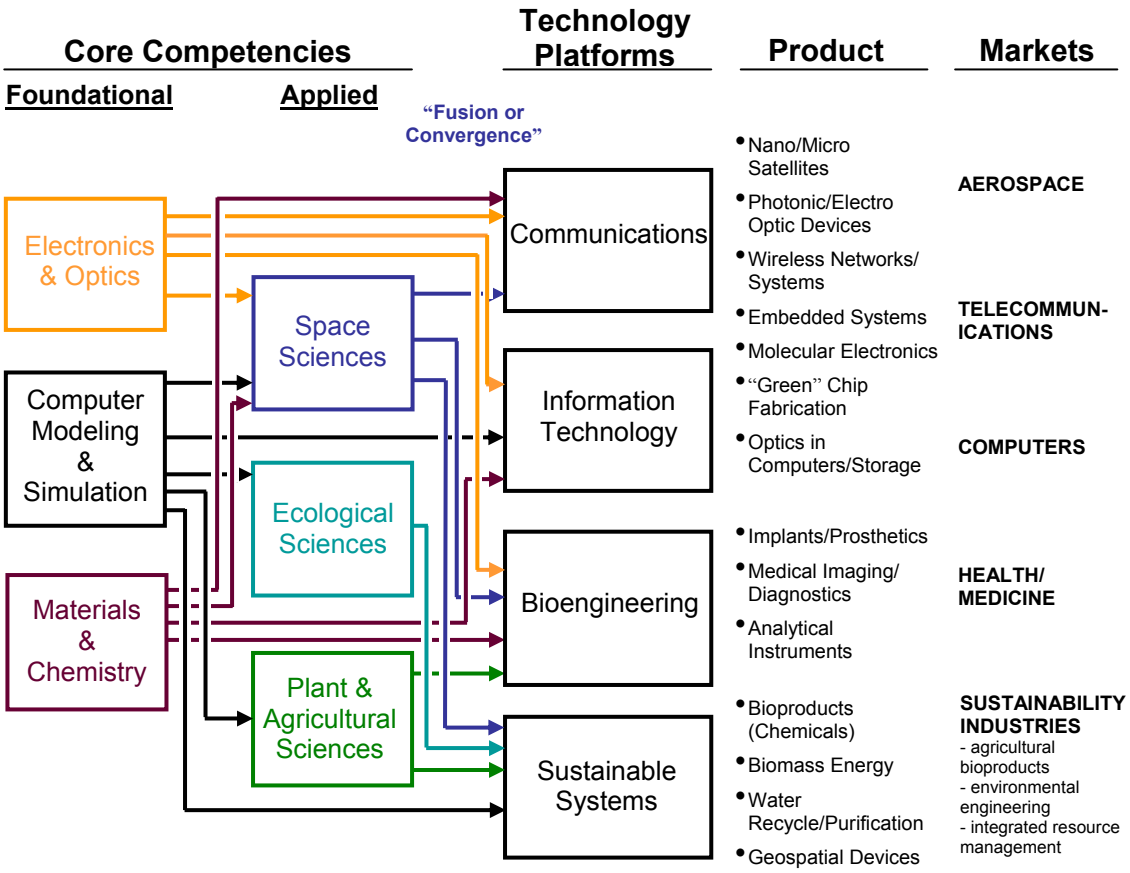
- Applications orientation, merging early-stage laboratory-scale science and technology into systems and devices;
- Robust and "evergreen" to address current as well as emerging market opportunities;
- Produce a regular stream of innovative, perhaps disruptive, products (i.e., a product pipeline);
- Require cross department and cross-university collaborations – brand new teams as well as enhanced existing teams; and
- Require partnership with industry to provide customer perspective and productization skills.

Based on Battelle's assessment, the six science and technology core competencies can be ordered into ***four technology platforms*** that could be a source of innovative technologies and/or products for Arizona's economy. These are:

- Communications
- Information technology
- Bioengineering
- Sustainable Systems

The overall scheme is shown in Figure ES3.

Figure ES3: Framework for Arizona Public University Technology/Product Pipeline to Industry



There are several key niches identified for Arizona in each of these technology platforms. The analysis provided in the full report describes in more detail the key components of each technology platform, and some near and longer-term product opportunities, based on the market analysis. At this stage, it will not be a complete "pipeline," but rather, examples with obvious market potential, which should be of interest to industry.

Communications

This platform addresses the telecommunications challenge. It is closely tied to the second platform on Information Technology; in fact some include telecom in the IT classification. However, we have chosen to keep the two separate in order to bring focus to a real strength of Arizona, namely the existence of four core competencies that can be integrated into next generation telecom systems—electronics and optics, computer modeling and simulation, chemistry and materials, and space sciences. All four of the core competencies, if carefully integrated and nurtured, could give Arizona a world leadership position in telecommunications.

In this market space, Arizona universities' core competencies are being used to produce innovative technologies and/or products in three niche areas, all of which play into the telecom system of the future:

- High bandwidth, high-speed wireline technologies (0-5 years);
- Unification of wireless and wireline systems (0-5 years); and
- Micro/nano satellites (approximately 10 years).

Information Technology

Like the preceding technology platform, the IT platform addresses the "anywhere, anytime" promise of the Internet, but from the perspectives of computers and peripherals, semiconductors and software. Because of the hardware and software dimensions, this platform embraces the electronics and optics, chemistry and materials, and computer modeling and simulation core competencies.

In the IT market space, key commercialization opportunities for Arizona's technologies are:

- Ubiquitous computing environments (0-5years);
- Software systems (0-5 years);
- Semiconductor materials/manufacturing (0-5 years);
- Optics in computing/storage (5-10 years); and
- Nano (molecular) electronics (>10 years).

Bioengineering

Inasmuch as bioengineering is an interdisciplinary area, it uses almost all the identified core competencies, plus connections to other university units, such as Mechanical Engineering, the Manufacturing Institute (design and manufacturing), Industrial Engineering (e.g., human factors, ergonomics), Systems Science and Engineering Research Center (for neuroengineering), and Exercise Science and Physical Education (for motor control and biomechanics).

This area was identified in the Flinn Foundation-supported Arizona Biosciences Roadmap and a Phase II effort is underway to further investigate these bioengineering niches to insure that Arizona can increase its research and technology competence in this area. Some near-term opportunities (0-5 years) and some longer-term areas (approximately 10 years) that will be under consideration for Arizona leadership in this rapidly growing and crowded field include:

- Neural engineering (0-5 years);
- Application of optics for medical diagnosis and treatment (0-5 years); and
- Implantable biocompatible devices (more than 10 years).

Sustainable Systems

This platform is based on the thesis that if we want economic progress to continue, we must systematically restructure the global economy to make it environmentally sustainable. An economy is sustainable only if it respects the principles of ecology. An eco-economy would be one that satisfies current needs without jeopardizing the prospects of future generations to meet their needs.

The ecological sciences are Arizona's top core competence and the plant and agricultural sciences competence is also strong. Therefore, this is an area where Arizona has an opportunity to be both a market creator and leader. There are several areas of sustainability that Arizona could take the

lead in. In developing this platform, it is important to look beyond the traditional measures of commercialization. The knowledge gained from environmental research will play a critical role in land use planning, siting of industrial and residential developments, agricultural policies, and so on, which will have a different but no less important impact on economic development. Arizona could well become the lead state for the best model of sustainable growth.

- **Sustainable manufacturing –** (0-5 years) For environmentally compatible products and manufacturing processes that fit into current fabrication plant designs; (5-10 years) designing the next generation fabrication plant to take advantage of miniaturization that micro/nano systems provide, which will radically reduce the plant footprint; and (more than 10 years) the emerging areas of bio-nanomaterials and molecular electronics.
- **High value bioproducts –** (0-5 years) "Green factory" producing edible vaccines; and (5-10 years) new, environmentally friendly industrial products such as chemicals for plastics, solvents, and fibers.
- **Water resources –** (0-5 years) The concentration of hydrology and water expertise in the state makes this a potentially very rich area to mine for technology that will help solve world water problems and also create economic benefit.
- **Remote sensing –** (0-5 years) The strong remote sensing and data analysis capabilities of the Arizona universities would be an asset to the state's environmental engineering/consulting cluster, providing new capabilities to assess water resources, land use, forest health, etc. In the longer term (5-10 years), these capabilities could be linked to the micro/nanosatellite competence to produce a new business of remote monitoring and control.
- **New construction materials –** (5-10 years) The investments being made in new materials technology that fuses chemistry, biology, and physics can produce new bio-inspired construction materials, which will not require the high energy input to fabricate, yet will have the strength of traditional steels or concrete. They can also be designed to be biodegradable after their useful operating lifetime.
- **Sustainable agriculture –** (0-5 years) NAU and UA are already engaged in sustainable agriculture, which can be further enhanced through integration with the plant genomics advances.
- **Sustainable forests –** (0-5 years) NAU and UA are studying a broad range of forest issues, including fire management, tree growth, and use of low-grade wood from clear-cutting.
- **Renewable energy –** (more than 10 years) The state has abundant wind and solar energy and a small group of companies in Flagstaff (wind) and Phoenix (solar). NAU has an active wind energy research program that could be leveraged to grow this industry.
- **Infectious disease treatments –** (more than 10 years) Concerns over environmental variability and change and its impact on human health are steadily growing around the world. Many of the possible threats are becoming more widespread in arid and semi-arid regions around the world, and this provides a unique opportunity for Arizona.

Gaps, Options, and Opportunities

For three platforms—Communications, Information Technology, and Sustainable Systems—Battelle identified the gaps within these platforms and the options to be addressed to build and strengthen each platform. The report also identifies opportunities that cut across these three platforms to position Arizona's public research universities and the state for the future. These represent preliminary analysis of gaps, options, and opportunities and a full roadmap for each platform would enable the setting of priorities and implementation plans for each platform, an activity outside the scope of the current project.

Communications

Key gaps in communications to build a more robust platform includes:

Gaps:

- Limited coordination
- Limited collaboration at system scale
- Quality and depth of graduate student pool
- Facilities for interdisciplinary showcases
- Faculty gaps in specialty areas
- University-industry differences in interest/time frames
- System capabilities to draw industry
- Deficiencies in technology transfer/ commercialization process
- Limited strategic alliances and partnerships with other research centers

Key options to consider in addressing these gaps in the communications platform include:

Options:

- Statewide umbrella communications entity
- Showcase facilities for interdisciplinary, systems labs to engage industry
- Recruit world-class faculty from higher education and industry
- Establish statewide program of graduate student excellence in communications
- Improve communications between researchers and technology transfer function

Information Technology

Gaps for information technology included several that overlapped communications, but there were also distinct issues.

Gaps:

- Address talent base at K-12
- Not nationally competitive in major federal research awards
- Limited hardware/software system infrastructure across universities to interest industry
- No software focus to build critical mass within state
- Aging non-competitive IT labs and materials
- Chip development fragmentation of focus/interests

To position Arizona in this highly competitive information technology platform, the following options might be considered:

Options:

- Enhance faculty gaps
- Improve technology transfer/ commercialization processes
- Compare and follow Sematech Roadmap to Chart Arizona's IT Future
- Focus IT efforts around translational research/product development key areas
- Increase IT collaboration across research universities
- Attract industry IT research operations to Arizona

Sustainable Systems

There were some similarities in Battelle's findings as to gaps, options, and opportunities regarding the communications and information technology platforms. However, in the case of sustainability, this platform is at a more formative or developmental stage, necessitating a different set of needs and requirements.

Gaps:

- Limited markets for sustainability
- Applications at local/regional levels missing
- No single national center of leadership and responsibility
- Building research quality through faculty/student excellence needed
- Technology commercialization support critical to "building your own"
- Green manufacturing niche area for Arizona through research collaboration

Additional gaps include:

- Need for central users facility;
- No federal research anchor for sustainability in Arizona now;
- Losing star researchers outside the state; and
- No industry association linking users and products of sustainability.

Among the options that might go into an investment plan or strategy for what is at the earliest stages of what could become a full technology platform are the following:

Options:

- Establish statewide sustainability organization linking state government and universities
- Establish or reposition a state industry association
- Attract major federal sustainability center/institute to Arizona
- Establish pilot regional projects in Arizona

Cross Cutting Opportunities

Although we have proposed specific platform options to address gaps for each platform, there are options and opportunities that are generic to all platforms. We call these "cross cutting opportunities" that address all three technology platforms just discussed. This does not negate the options and opportunities specific to each platform but represent macro-level solutions across all three areas. What is very encouraging is that many of the solutions have already been initiated in part by at least one university, so there is momentum and a base to build on.

These crosscutting opportunities are presented in five categories:

- Creating a collaborative environment;
- Attracting the best and brightest;
- Application centers;
- Business development and marketing; and
- Technology transfer and commercialization.

Creating a Collaborative Environment

Of all the gaps identified in interviews, the challenge of starting and maintaining collaborations across the universities in the state was mentioned most frequently.

Cross-Institutional Collaborations

Options to address enhanced cross-institutional collaborations are suggested for each of the technology platforms, because these are the engines for economic growth. Fortunately for Arizona, in most cases a collaborative effort exists on which to build.

Collaboration options for each platform include:

Telecommunications. It may be possible to form a university-industry collaboration around the technologies needed for the telecom system of the future—the unification of wireless systems with the conventional wireline infrastructure. This collaboration could be built on the foundations provided by Connection 1, an NSF industry/university cooperative research center, and the Consortium for Embedded and Internetworking Technology (CEINT) at ASU, and the proposed Center for Intelligent Optical Networks at UA.

Information Technology. A possible base for research university collaboration and a university-industry collaboration is to capitalize on the convergence of electronics and optics, which will yield new optoelectronic materials, semiconductors, lasers, molecular/nanoelectronics, and optical computing and storage systems, revolutionizing information technology infrastructure. A new initiative is needed to embrace all the research at ASU, NAU and UA that can contribute to this convergence. A start is being made at UA with the proposed Photonic Technology Center that will serve to integrate the university's enabling capabilities.

Sustainability. This broad area is the wave of the future, and so now is the time to bring the contributing components together into a systems approach that can address community and industry needs and provide answers that are backed by good science. The foundation for a statewide collaboration could be the Institute for the Study of Planet Earth (ISPE), formed at UA.

Making ISPE the Arizona Institute for Planet Earth is the logical next step, with coordinating offices at ASU and NAU.

Improving Connectivity

With the major research and development resources in Arizona being geographically dispersed, one option is creating a "Collaboratory" for each platform, in which the state's researchers can work cooperatively to further research and develop applications for technology without regard to geographical location. Hardware and software is now available that can enable researchers to interact with their colleagues, access instrumentation, share data and computation resources, and access information in digital libraries. By providing access to instruments, data, and computer display sharing, the Collaboratory would enable researchers in different geographical locations to interact as if they were located more closely.

Another option for improving connectivity is for Arizona to organize and provide support for formal technical networks that will foster the collaboration needed between research and industry to achieve the state's technical and economic goals. The value to participants includes the expansion of their knowledge base, access to resources not available in their home institutions, and increased opportunities for collaborative R&D funding.

Technical network activities could include developing and maintaining an inventory of network capabilities, conducting topical workshops or seminars sponsored by the partners, and developing joint research opportunities and contributions to new intellectual property and capabilities. The Collaboratory environment discussed above would be very useful in enabling the networks. The state could assist in organizing the networks and make funding available to support network activities such as Web sites, workshops, and other gatherings.

Attracting the Best and Brightest

Recruiting Incentives

There are still major opportunities to enhance the depth of research, management, and entrepreneurial capacity in Arizona. Specific actions might include:

- Develop the Arizona Executive Corps, to bring serial entrepreneurial managers to the state both to temporarily manage prototype development and seed and pre-seed funds, and offer business counseling and mentoring. Eventually, these managers can serve as CEOs and CFOs of spin-offs and startups coming from these technology platforms.
- Expand the entrepreneurial assistance role through university-industry partnerships to offer in-depth training and networking programs to develop qualified CEOs and help train firms in various aspects of business and technology management and other skills, including taking greater advantage of the universities' business schools, faculty, and student body.

Growing Your Own

For long-term sustainability, a state must have a system that continuously yields first-class students, researchers, entrepreneurs and business leaders. New programs that encourage innovation and commercial deployment are needed. A few that are compatible with Arizona's capabilities and culture include:

- Advanced interdisciplinary science courses for high schools that are developed in the universities and taught in their laboratories with university/private sector mentors;
- Increase the number of local state science fairs that would produce high school teams for international competitions like Intel's Science Fair;
- Expand on the Flinn Scholars program to further increase the scholarships and/or internships available to the best students in advanced communications, information technology, biosciences and ecological sciences;
- Address the need for additional resources for pre-prototype development and technology commercialization support such as capital gaps, by forming private equity funds focused on seed and early stage investing in each platform area; and
- Establish stronger industry relationships and partnerships in each platform through an applied matching grant program, leveraging industry funds and forming collaboration between research faculty in each platform and small and large firms in and outside the state.

Application Centers

Infrastructure is either missing or deficient for all the platforms. This gap was the second most frequently mentioned in interviews. Therefore, to help forge and sustain the collaborative environment, Battelle suggests that Arizona help create and fund the initial operation of Application Centers around each platform, which will provide access to facilities, equipment and experts to enable industry, working in partnership with academic researchers, to adapt, develop, and utilize discoveries from the state's research institutions.

The Application Center will:

- Include one-of-a-kind equipment or facilities (e.g., wet labs, clean rooms) that enhance the current or planned capabilities of Arizona's research institutions and industry;
- Operate as user facilities, shared by both research institutes and private industry;
- Focus on translational research, i.e., activities undertaken to increase the commercial value of Arizona's innovations;
- Provide a training ground for undergraduates and graduates;
- Emphasize the development of products that will support the growth of emerging markets and the creation of brand new markets;
- Seek to leverage and influence federal investments in research and development; and
- Be networked to institutions conducting basic science research and the companies that are the end users of the technology being developed.

The Centers would provide demonstration and test-bed facilities as well as testing and evaluation services. Examples of the type of services that could be provided by the Centers include capabilities to allow for the manufacture of limited quantities of prototypes for testing, and further development or access to a computer-aided design facility to provide software development and simulation. An additional attractive feature would be availability of space to incubate entrepreneurial startup companies. Such an infrastructure would help Arizona surpass its competitors in these areas by reducing commercialization time.

Business Development and Marketing

Growing the R&D Business

To move to the next level, Arizona's public research universities might push the envelope in addressing how to secure additional federal research dollars. More market intelligence is needed to create awareness of large opportunities before they become wired to other institutions. Centralizing this function at the university, or having a single office for the Arizona university system, would be advantageous. University assignments to key federal agencies would help build "mind share" within those agencies. Also, a continuous Washington presence is required to work with Arizona's delegation. Strategic hiring of key government officials after they have retired is one way to initiate this. Finally, each platform should have at least one business development professional to work with faculty on large procurement opportunities. While competitive intelligence is very important, the key to success is building the team that can deliver the winning proposals. Strategic hires of professional project managers, who can pull together university-industry partnerships, would be a great investment.

Technology Transfer and Commercialization

This area is the Achilles heel of most universities and research institutes and Arizona is no exception. While this is a subject of much interest to faculty, there appears to be a general lack of knowledge of the universities' current programs, policies, and changes in personnel and practice in recent years. UA, ASU, and NAU (through its agreement whereby ASU manages its intellectual property) have made critical new hires and changed policies and procedures to reduce the barriers to successful commercial development of inventions. Universities' will need to continue to address this general communication problem between faculty and the Technology Transfer Offices, and gaps in the overall system, such as ASU's recent technology ventures initiative.

SUMMARY AND CONCLUSIONS

Arizona has a considerable research base in its three public research universities on which to build a strong technology-based economic development effort. Combining this analysis with the earlier Arizona biosciences roadmap suggests six technology platforms on which Arizona's public research universities can focus:

- Communications;
- Information technology;
- Sustainable systems;
- Bioengineering;
- Neurological sciences; and
- Cancer-therapeutics.

These six platforms represent:

- Competitive research areas nationally for the state's three public research universities as measured by the "market place" of academic research, e.g., citation analysis and federal funding concentrations (e.g., multiple PI awards), and augmented by Battelle's "Starlight" cluster analysis of linkages within and across these areas.
- Interdisciplinary areas that, for the most part, take advantage of a wide range of disciplines and whose enhancement is more likely through higher education collaboration across Arizona's public research universities.
- The basis for sustained and growing industry, government, and academic partnerships in both research and knowledge and technology commercialization.

The six core competencies identified in this study were blended into four technology platforms that have the potential of catching the next major technological waves: advanced communications, gene-based medicine, and sustainable systems. Gaps and options for enhancement of three of the platforms—communications, information technology, and sustainability—were identified through interviews and analysis of similar programs elsewhere. The fourth platform, bioengineering, is currently the subject of a platform development strategy, supported by the Flinn Foundation and involving the three research universities, other research organizations, and Battelle.

Finally, Battelle identified five crosscutting opportunities and actions that might be considered and needed to address all technology platforms. Because a core competency analysis led to the identification of these platforms, this study can only address gaps, options and opportunities in a preliminary fashion. To further build Arizona's future in these platforms, each will need to be further developed as comprehensive roadmaps.